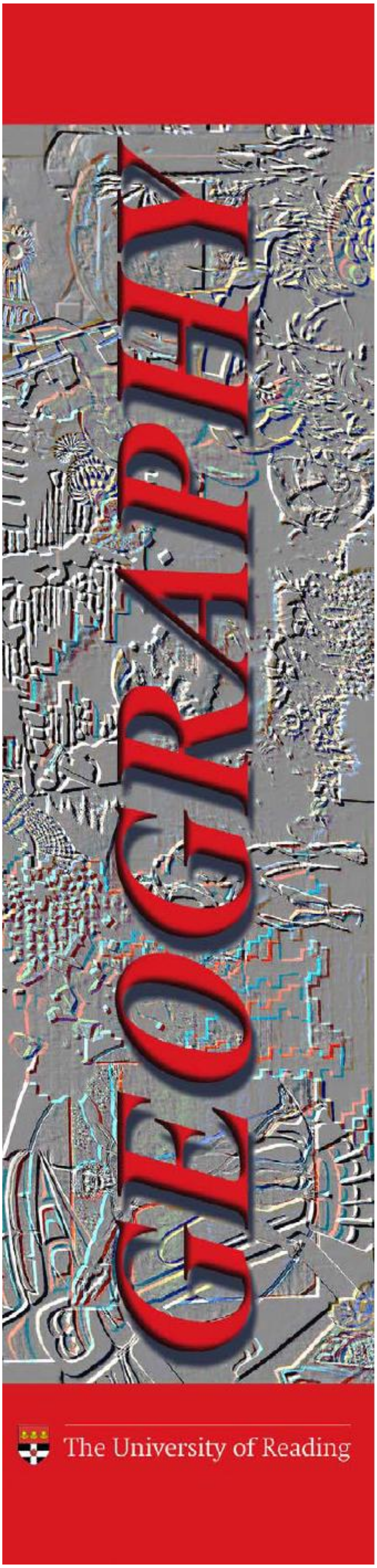

Genetically Modified Cotton and Sustainability

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Geographical Paper No. 184

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2008

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INTRODUCTION

The genetic modification of organisms and the concept of sustainability have attracted much interest by the popular and academic media and in the political arena in the last 30 years. The capacity to modify the basic constituents of life, i.e. the deoxyribonucleic acid (DNA) sequences of the genes, is a powerful tool and, in common with all technologies, it has potential disadvantages as well as advantages. In agriculture, genetic modification (GM) can address crop protection issues, e.g. weed, virus and insect problems, as well as environmental constraints to productivity such as soil salinity, waterlogging and drought. This ability to modify the genetic base of plants so that beneficial characteristics are passed on by the plants' inherent reproductive processes would appear to coincide with the concept of sustainability. After all, a new gene that confers a 'natural' resistance to damaging pests or disease would reduce the need for potentially environmentally damaging, expensive and energy-intensive pesticides and increase productivity. Surely this would be better for the farmer, the environment and society? Despite this, GM has generated polarized views as to its value. One major concern is the power of the seed-producing multi-national companies who produce GM organisms and whose monopoly via patents etc is thus an element of globalization. Further concerns embrace the role of the state in the regulation of GM crops and the control of GM seed, plus the issue of technology transfer between developed and developing nations and how such exchange should be financed. Would GM exacerbate the gap between those who have and those who have not? Notwithstanding controversy, GM crops, including cotton and specifically insect-resistant cotton, have been cultivated for a decade and new developments are taking place at a rapid rate which suggests that GM is now an established and permanent weapon in the armoury of modern agriculture. GM offers a real possibility of increased production on land already under agriculture and thus reduces the need for further land with its natural vegetation cover to be converted to agriculture with implications for carbon storage and global warming.

In contrast, sustainability, or sustainable development, is a universally accepted and welcomed concept given its fundamental principle of "*Development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" as defined by the United Nations (Brundtland) Commission in 1987 (Brundtland, 1987). Current 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. Stated in these terms it is difficult to imagine dissention; who would want to damage the inheritance of future generations? Indeed if there is a controversial aspect of sustainability it relates to the mechanisms of achievement and 'trade offs' which can occur. It may be argued that the environment cannot be compromised or 'traded' in any way, while less stringent approaches accept that a certain degree of environmental degradation is inevitable and a small price to pay for economic growth. However, all parties argue that the underpinning goal is to keep the impact of humans to a minimum. In this context agricultural sustainability is of primary importance to developed and developing nations alike given that agriculture supports all other human endeavour but has a substantial environmental impact given its requirement of land and resources. Some form of trade off is characteristic of all technologies which, in turn, are a major aspect of people-environment relationships.

The pro-GM lobby considers GM crops to be an important contribution to sustainable agriculture because they enhance productivity per unit area through reduced risks; conversely the anti-GM lobby considers such crops to be problematic on several counts including:

- The encouragement of agriculture to spread into areas presently unsuitable for it and thus to increase the threat to natural ecosystems. A classic example is the degradation of tropical forest for cultivation of crops such as soybean.

- Potential for contaminating the wider environment through deliberate and inadvertent release of GM organisms. For example, genes may escape from a crop into wild relatives and thus create 'super weeds'.

- Potential contamination of the food chain which might cause human health problems.

One of the problems in the GM debate is the diversity of characteristics which can be engineered in plants. Some of these, such as traits for enhancing colour, flavour and shelf-life, may be more obviously geared towards agri-business in the developed world. Also included here may be traits that allow for easier factory farming of animals or use of machinery in fields. While no doubt contributing to the success and profitability of agricultural business, supermarkets and/or consumers it is more difficult to pinpoint the benefits for resource-poor subsistence farmers in the global South. Indeed given that the GM companies are primarily in business for profit, not altruism, the richer markets of the world are clearly their main focus. However, several traits which can be genetically modified are, at least in theory, of benefit to subsistence farmers. This is a grey area of the GM debate. This paper will address this question by exploring a specific GM technology, i.e. insect resistance in cotton, and its impact on resource-poor farmers in the Republic of South Africa. Cotton is a crop which is limited by a range of factors, including the ubiquitous constraints of water supply and soil fertility, but is especially vulnerable to insect pest attack.
Even if water supply and nutrients are adequate, yields (amount of product harvested per area of land) can be severely reduced by insects which attack the developing cotton bolls. From their perspective farmers have no choice but to limit this damage by the use of insecticides, and for such farmers in the tropics this typically means the use of knapsack sprayers and no protective clothing. Thus not only do farmers have to cope with the economic costs of spraying they also have to live with the damage that such chemicals can cause to their own health and that of their families. Surely anything which reduces such a need for pesticide has to be welcome?

Following the presentation of background information to inform the debate re GM crops and sustainability and the specific case of GM cotton, this paper reviews the evidence for its socio-economic impact based on published work for Bt cotton in South Africa; the first country on the continent of Africa to allow the commercial release of GM crops. Although this case study involved only one form of GM trait and one country, it nevertheless provides valuable insights into the impact of a GM crop for resource-limited farmers. Given the paucity of such examples, this practical experience also makes a significant contribution to the GM debate, and provides insights concerning the sustainability of the technology.

BACKGROUND

The following sections provide definitions and a basic introduction to biotechnology, genetic modification and sustainability. Other sources include Charles (2001), Chrispeels (2003), Curtis (2004), Mannion (2007), Pringle (2003), Pua and Davey (2007), Sanderson (2007), Slater *et al* (2007) and Thomson (2006).

Genetic modification

Genetic modification, also known as genetic engineering, is one of many aspects of biotechnology which is the manipulation of living organisms for specific tasks. There are many applications of biotechnology including, human health, the remediation of damaged land and mineral resource recovery but it is in agriculture that most advances have been made. The history of biotechnology is as old as the first ancestors of modern humans who developed the ability to manipulate organisms through selection and the use of fire. One of the major developments in people-environment relationships some 10,000 to 12,000 years ago was the domestication of specific plants and animals and the initiation of permanent agriculture. Agriculture is itself a technology and it is a means whereby humans influence the carbon cycle (Mannion, 2006). Today, agriculture sustains a global human population of 6,602,000,000 and it remains a major cause of environmental change given the destruction of ecosystems it replaces and inputs of fertilisers and agrichemicals. Through the millennia, plant and animal selection and breeding have been undertaken to improve crops and farm animals. This involves a form of genetic selection but it takes place at the level of the whole organism i.e. the macro-biological level. As a result the genetic make-up of staple crops such as maize and wheat are far removed from their ancestors.

In the last 30 years such selection has become increasingly precise due to the work of Watson and Crick in the early 1950s on the structure of DNA, the so-called secret of life (Watson and Crick, 1953; see also Watson, 2003). DNA is a long and complex molecule: a polymer which comprises nucleotides within a framework of sugars and phosphates which are linked by esters. Each sugar has attached to it a base, of which there are four, namely cytosine, guanine, adenine and thymine. The bases are known by the shorthand terms A, T, C and G. This four letter alphabet works in groups of three, AAA, ATC, TCG, GGG and so on. The sequence of these bases encodes information which determines the sequence of amino acids within proteins and thus provides the control for all life on the planet; from bacteria and viruses to human beings. Lengths of these 3 bases sequences make up a gene, and it is genes that code for characteristics. As DNA is a molecule, albeit a complex one with a double helix, it can be prised apart and the sequences of bases determined. In effect, the genetic code can be unravelled opening the way for an understanding of the way life works at its most basic level (see Jones and Walker, 2003, for an introduction). In practical terms such capacity will enhance the understanding of diseases such as cancer. For example, it is becoming possible to pinpoint the sequences of bases which confer a heightened

susceptibility, and it is also becoming possible to 'cut and paste' parts of the DNA molecule (a single gene or a number of genes) from one strand of DNA into another, and in so doing transfer the ability to express physical characteristics.
Research has also focussed on the identification of genes and gene components which control certain crop/animal characteristics e.g. drought tolerance, flavour, colour, resistance to pests etc (see further details in Slater *et al*, 2007). Such capacity can enable selection at the molecular level. The identification of 'useful' genes in non-agricultural organisms has also proceeded, including the isolation of fish and bacterial genes which confer specific advantages. Thus existing qualities or traits may be reduced or intensified through genetic manipulation, or foreign genes or their components may be introduced into crop plants from related species or from entirely different species. It is also possible to combine these approaches for crop improvement and it is possible to produce crop plants with more than one GM characteristic. Such crops are described as having stacked genes. Examples include maize, cotton and soybean which are all now available with both engineered herbicide and insect resistance. Crops with three and four stacked genes are also starting to become available as reflected in the following statement by Syngenta (2007a):

"*Syngenta is on track to deliver a full suite of stacked traits in corn, glyphosate tolerance and resistance to both leaf and soil insects, building on the quality and breadth of its germplasm from the combination of GARST®, GOLDEN HARVEST® and NK®. These stacks will be introduced over the next three years*".

Examples of crops now available with introduced characteristics include GM maize, soybean, rapeseed (canola) and cotton. In these cases herbicide resistance has been engineered by introducing genes from other organisms 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 and thereby killing them. If a crop plant has a form of the enzyme which is insensitive to the herbicide then it will be unaffected while all the weeds will die. The tolerance of the latter group is due to introduced genetic material from another bacterial group, the *Streptomyces* (Block *et al,* 1987 and Thompson *et al,* 1987). The advantage of herbicide resistance is that crops can be sprayed to eliminate weeds without impairment of the crop itself. Thus the competition for light, water and nutrients is considerably reduced. A further example of introduced characteristics is that of the insertion of genes from the bacterium *Bacillus thuringiensis* (Bt) into maize, potato and cotton to enable the production of a crystal protein which has insecticidal properties. The crop plants become resistant to certain insects through the action of a toxin produced by the crystal protein on insect larvae. Not only is productivity increased, which increases the overall efficiency of the agricultural system through improved resource use, but fewer conventional chemical pesticides or biological controls are required. To date GM crops with resistance to European corn borer, south-western corn borer, tobacco budworm, cotton bollworm, pink bollworm and the Colorado potato beetle are available commercially.

An example of a dual approach is that of the development of Golden Rice, a bio-fortified rice engineered to produce a high level of vitamin A. Without sufficient vitamin A blindness (*vitamin veronicas deficiency*) may occur and many millions of people, especially children, in parts of Africa and Asia are vulnerable to this disease. Golden Rice has been hailed as one solution to this problem, especially where rice is the major dietary component. Its production 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 (endosperm) i.e. the part of the plant consumed by humans. It also involves the addition of gene components from other species including the daffodil and the soil bacterium *Erwinia uredovora* to further enhance beta-carotene production (see Golden Rice Project, 2007, Potrykus, 2001, and Sakakibara and Saito, 2006, for further details). This is an example of how genetic modification can be used to improve nutrition on a large scale. In the context of nutrition improvement, rice is a particularly good example insofar as it is the staple diet of at least 1.6 billion people. 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 is the subject of many GM programmes focussed on a variety of crop attributes which range from productivity improvement to vitamin and micro-nutrient availability (see Sauter *et al.*, 2006).

There are six stages in the process of producing a GM crop plant. As shown below:

1. Gene mapping is used to find and isolate the gene with the required characteristics.

2. Several copies of the isolated gene are made using a process called polymerase reaction (PCR)

3. The genetic material is transferred from the isolated material to the crop plant genes. This transformation can be achieved in three ways: using a soil bacterium into which the required genetic material has been inserted and which 'infects' the host plant, a protoplast (a cell from which the cell wall has been removed) or via a 'gene gun' (a means of injecting the genetic material into the host).

4. The transformed genetic material is allowed to grow into a plant under laboratory conditions.

5. The plant is checked experimentally to determine if it demonstrates the desired characteristics.

6. Tissue culture, the growth of plant tissue rather than the whole organism, and cloning can be employed to generate hundreds of seedlings with the desired characteristics. Alternatively, seed from the transformed plants can be produced, though for some species the seeds are sterile.

For additional detail see Heaf (2005), Singh and Jauhar (2006), Monsanto (2007) and Syngenta (2007b).

The case of Bt crops

The use of the bacterium**,** *Bacillus thuringiensis* (Bt) in agriculture has been reviewed by Metz (2003). The bacterium, a rod-shaped aerobic bacterium, was first discovered by Shigetane Ishiwatari, a Japanese biologist, in 1901 when he was investigating the causes of death in silkworms. However, Ernst Berliner, a German scientist who was engaged in isolating the cause of death in a species of flour moth, rediscovered it in 1911 and gave it the name *Bacillus thuringiensis* (after the town of Thuringia) which replaced its earlier name of *Bacillus sotto.* This same scientist also found that Bt contained a crystal protein though it was to be another 50 years before the significance of the crystal protein was discovered (see Knowles, 1984 for mode of action). The ability 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. By 1958 it was available in the USA. Two years earlier the active component of Bt was determined to be the crystal protein and this prompted intensive research on Bt ecology and biochemistry. Originally considered to be toxic only to lepidopteran pests, in the 1970s it was discovered 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 a number of beetle species. Other subspecies, i.e. kurstaki, entomocidus, galleriae and aizawai are effective against lepidopteran larvae. By the 1980s Bt sprays had become an important tool in crop protection, especially where insects were becoming increasingly resistant to chemical pesticides and because Bt sprays do not cause environmental contamination or residue accumulation.

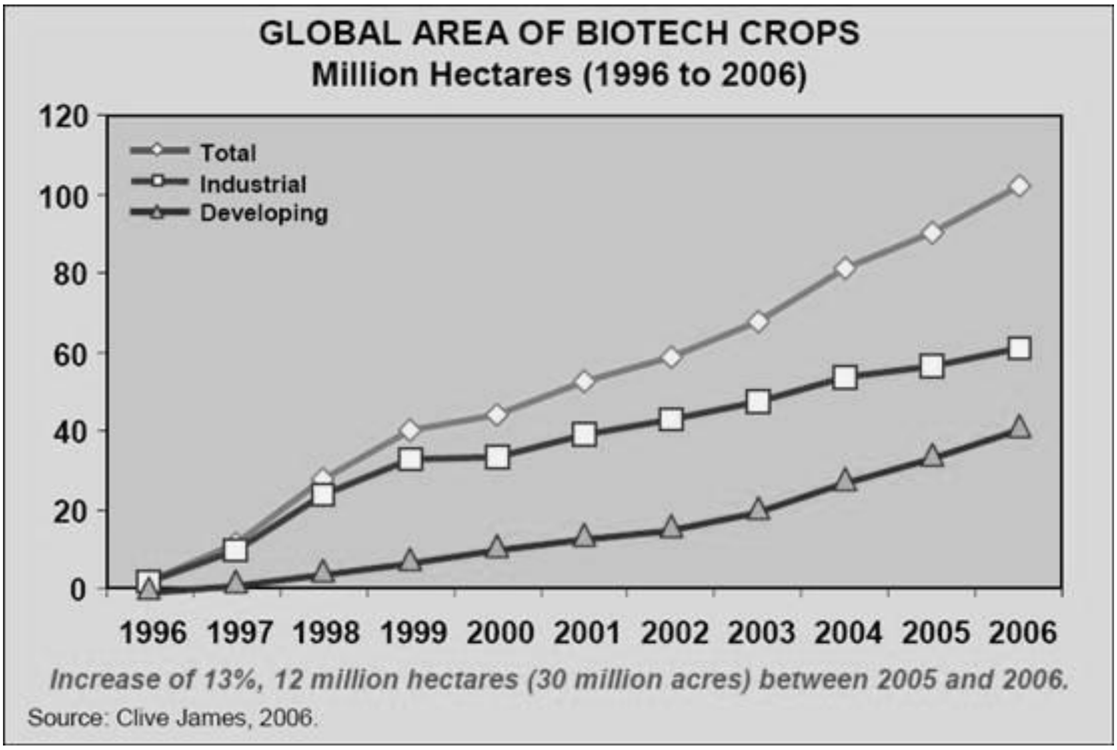
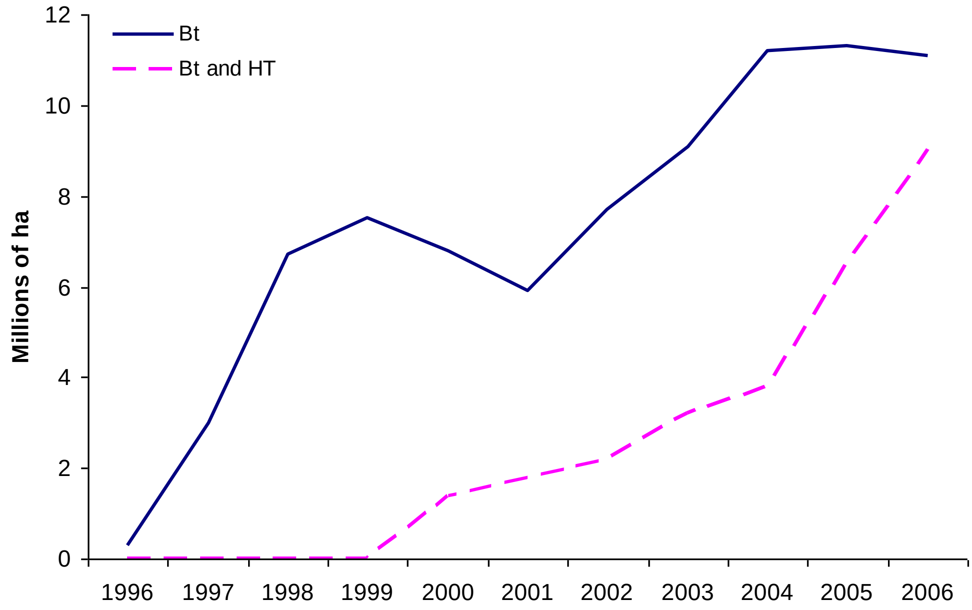


Figure 1. Global area of biotech crops (from James, 2006)

By this time genetic engineering was beginning to emerge and attention shifted to the possibility of isolating the Bt gene for the endotoxin production and inserting it into crop plants. The gene was isolated in 1981 and the first Bt crops were field tested in the USA in the early 1990s. The first genetically engineered crop plant, maize, was registered with the Environmental Protection Agency (EPA) of the USA in 1995. One year later Bt cotton was registered. From 1986 onward, the area planted with transgenic crops in general (Figure 1) and Bt crops in particular (Figure 2) has gradually increased. Today Bt maize and cotton are widely grown; Bt canola, soybean and potato are also available and in some cases second generation products are now being marketed despite fears that such crops would have short commercial lives due to the rapid spread of insect resistance (Ferry *et al*, 2006). Data for maize are given in Figure 2 and data for cotton are given in Figure 3 in the following section. Both figures also give data on the extent of cotton with stacked genes for Bt and herbicide tolerance (HT). The tables show that GM maize and cotton have been adopted relatively rapidly since they first entered the market a decade ago. The major producing nations are the USA, Brazil, Canada, China and India. Overall, in 2006 some 22 countries grew biotech crops, comprising 11 developing countries and 11 industrial countries. Of particular note is the relative lack of adoption in Europe. In 2007 trials began in South Africa of a drought-tolerant maize produced by Monsanto, the company at the forefront of research on and the marketing of genetically modified crops.

Figure 2. Global adoption of Bt maize (Bt and Bt/Herbicide Tolerance) 1996 to 2006 (millions of Hectares). Source: James (ISAAA), 2006



The specific case of Bt cotton

Bt cotton, with engineered protection against tobacco budworm, bollworm and pink bollworm, was produced in the late 1980s by Monsanto, one of the world's major agrochemical companies. The engineered protection comprised the insertion of a gene from Bt which controls the production of an endotoxin which is effective against certain insects by binding to the appropriate receptor on the surface of epithelial cells in the gut. It is expressed in all cells within the cotton plant, though it is particularly important in the leaves because these provide food for the bollworms etc. This Bt cotton underwent field trials in the USA in the early 1990s and following approval from the EPA 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 in 2002 it was adopted, after regulatory studies which began in 1995, in India. These are the major transgenic cotton-producing countries today.

Further commercial products have been developed e.g. RoundupReady® cotton (i.e. with herbicide resistance), which has been commercially available since 1997 and which is grown only in the USA. 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 develped. These comprise varieties with Bollgard® plus RoundupReady and Bollgard II® plus RoundupReady® Flex cotton (the latter has improved herbicide resistance) with both insect and herbicide resistance.

Figure 3. Global adoption of Bt cotton (Bt and Bt/Herbicide Tolerance) 1996 to 2006 (Millions of Hectares). Source: James (ISAAA), 2006.

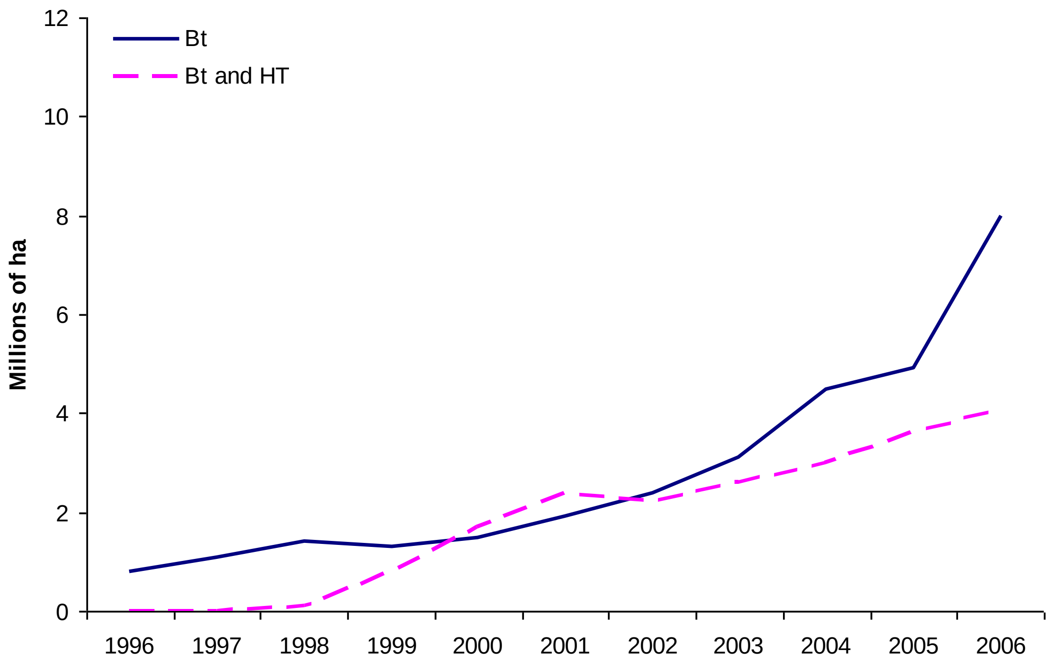


Figure 3 shows that by 2006 some 12 million ha worldwide were planted with transgenic cotton (combined single gene and stacked gene). Apart from China, which has produced its own transgenic seeds and where 70% of the cotton crop is Bt GM (Kong-Ming, 2007), Monsanto controls the worldwide seed market for transgenic cotton. In terms of global area planted with GM crops, cotton occupies third position after soybean and maize. Data from James (2006) show that in 2006 it 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). Further data on the geographic distribution of GM cotton are given in Table 1.

Table 1. Global Area of Biotech Crops in 2006: by Country. Source: James, 2006.

Rank	Country	Area (million hectares)	Biotech Crops
1*	USA	54.6	Soybean, maize, cotton, canola, squash, papaya, alfalfa
2*	Argentina	18.0	Soybean, maize, cotton
3*	Brazil	11.5	Soybean, cotton
4*	Canada	6.1	Canola, maize, soybean
5*	India	3.8	Cotton
6*	China	3.5	Cotton
7*	Paraguay	2.0	Soybean
8*	South Africa	1.4	Maize, soybean, cotton
9*	Uruguay	0.4	Soybean, maize
10*	Philippines	0.2	Maize
11*	Australia	0.2	Cotton
12*	Romania	0.1	Soybean
13*	Mexico	0.1	Cotton, soybean
14*	Spain	0.1	Maize
15	Colombia	<0.1	Cotton
* *14 biotech mega-countries growing 50,000 hectares, or more, of biotech crops*			

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%.

Sustainability/sustainable development

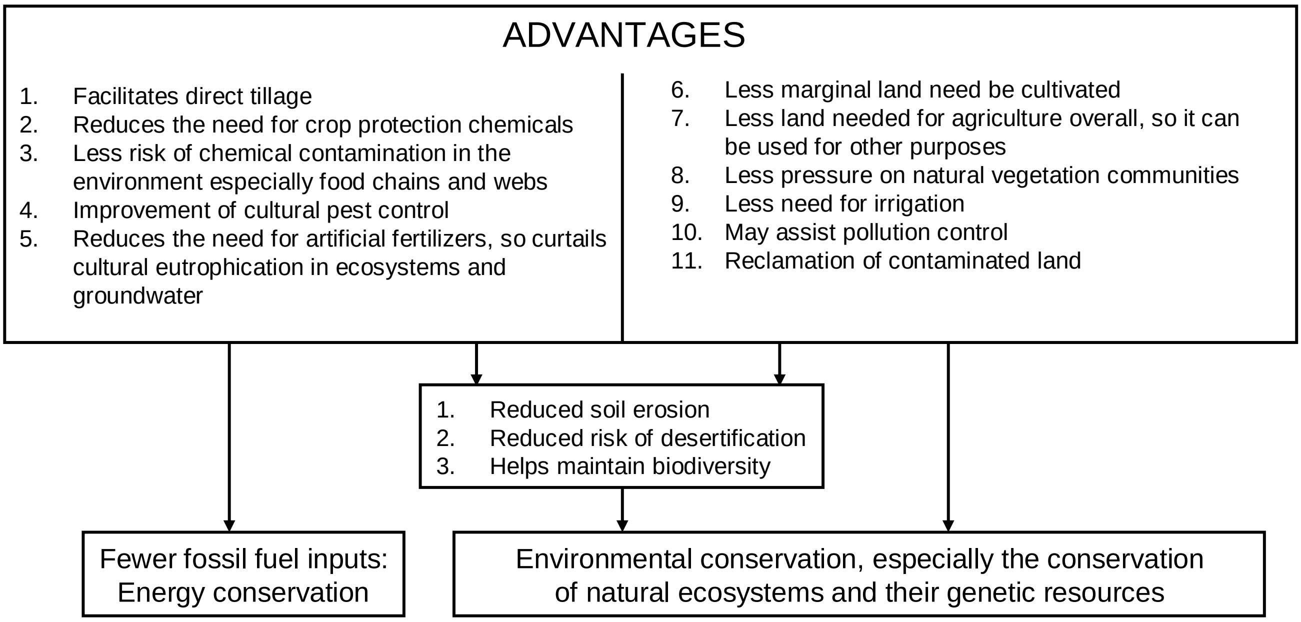
While the cultivation of GM crops is increasing, what has been the experience so far in terms of the contribution they can make to sustainable development? This is not an easy question to answer for a number of reasons, not least being the somewhat vague definition of sustainability which is often employed. The concept of sustainable development was introduced by the UN in 1987 via the Brundtland Report (see introduction). It invokes the planned minimum use of resources to achieve development within a system which can support future generations. Agriculture has played and continues to play a vital role in development, not only in developing countries but also in developed nations. This is because developed nations greatly influence the economies of the developing countries through trade and through home-based agricultural subsidies. Moreover, world population is increasing by some 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 United Nations, 2007). This increase plus enhanced demands for meat and meat products will place considerable pressure on existing agricultural systems and further impetus to create agricultural land from remaining natural ecosystems, especially in the tropics and sub-tropics. Neither prospect is welcome and adequate food production in the next few decades will be a challenge; sustainable food production will be an even greater challenge. A particularly significant part of 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 any further destruction because of their vital role in biogeochemical cycling and carbon storage (see Mannion, 2002 and 2007 for further discussion).

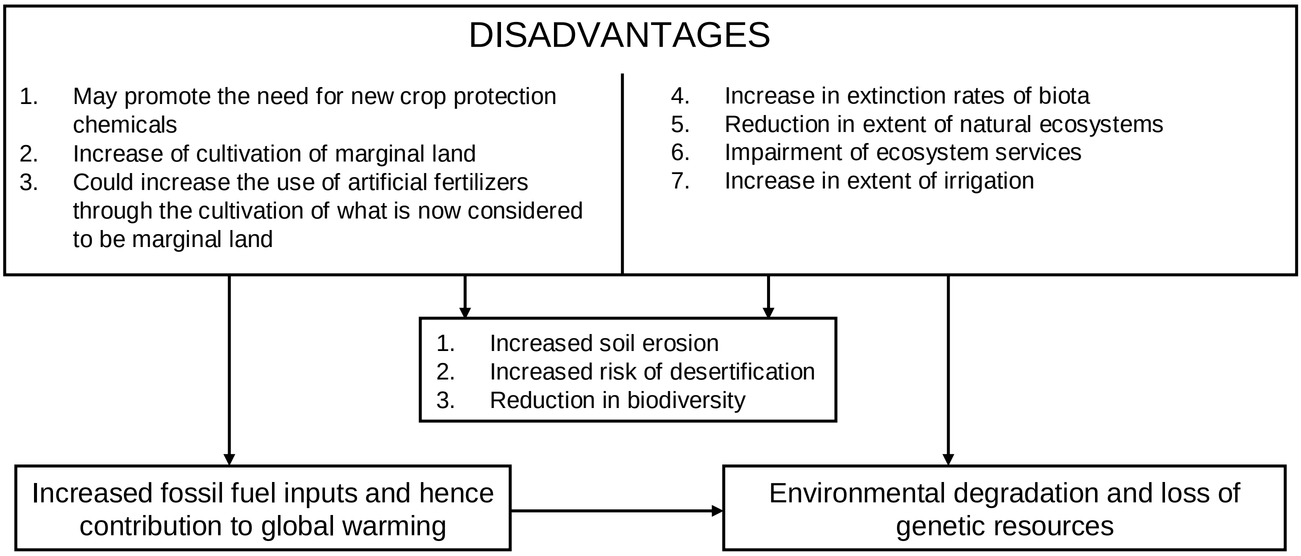
GM crops are a significant tool in modern agriculture but they have the potential to cause further loss of natural ecosystems just as much as they may help conserve them (see Mannion, 1998 and 2006 for a discussion). The need for conservation has been set out in detail elsewhere (e.g Wilson, 2002 and 2006) and involves species conservation as well as the important role played by ecosytems in biogeochemical cycling and the regulation of atmospheric composition. Avery (2000) is a staunch advocate of the intensification of existing agricultural systems for a variety of socio-economic and environmental reasons. Figure 4 summarises the main advantages and disadvantages of GM crops. In brief, GM can contribute to intensification by improved use of soil, nutrients, and light and by increasing yields but it may have repercussions in relation to land-cover/land-use.

In addition, insect resistant GM crops result in a decline in chemical pesticide use and thus reduced contamination of soils and water. These are amongst the positive aspects of GM crops. In relation to negative aspects, the use of GM to create drought, salt, frost tolerant crops could encourage their spread into areas currently unsuitable for agriculture and so compromise the integrity of natural ecosystems. This illustrates the fact that GM technology has potential disadvantages which may become real disadvantages through injudicious application.

Thus there are positives and negatives to be considered, and the GM-crop era is less than 20 years old, so extrapolation into the future is problematic due to unforeseeable factors. As so often occurs when applying the sustainable development concept it becomes necessary to negotiate and compromise on values, and these differ markedly between stakeholders. Thus some stakeholders are more willing to accept the potential risks of Bt cotton, especially if they are not likely to suffer the consequences directly when compared to others. However, what is the evidence to date from growing Bt cotton in developing countries such as South Africa? There has been much work in this area and the following sections will explore some of the results and conclusions.

Figure 4. A summary of the advantages and disadvantages of crop biotechnology (from Mannion, 2006).





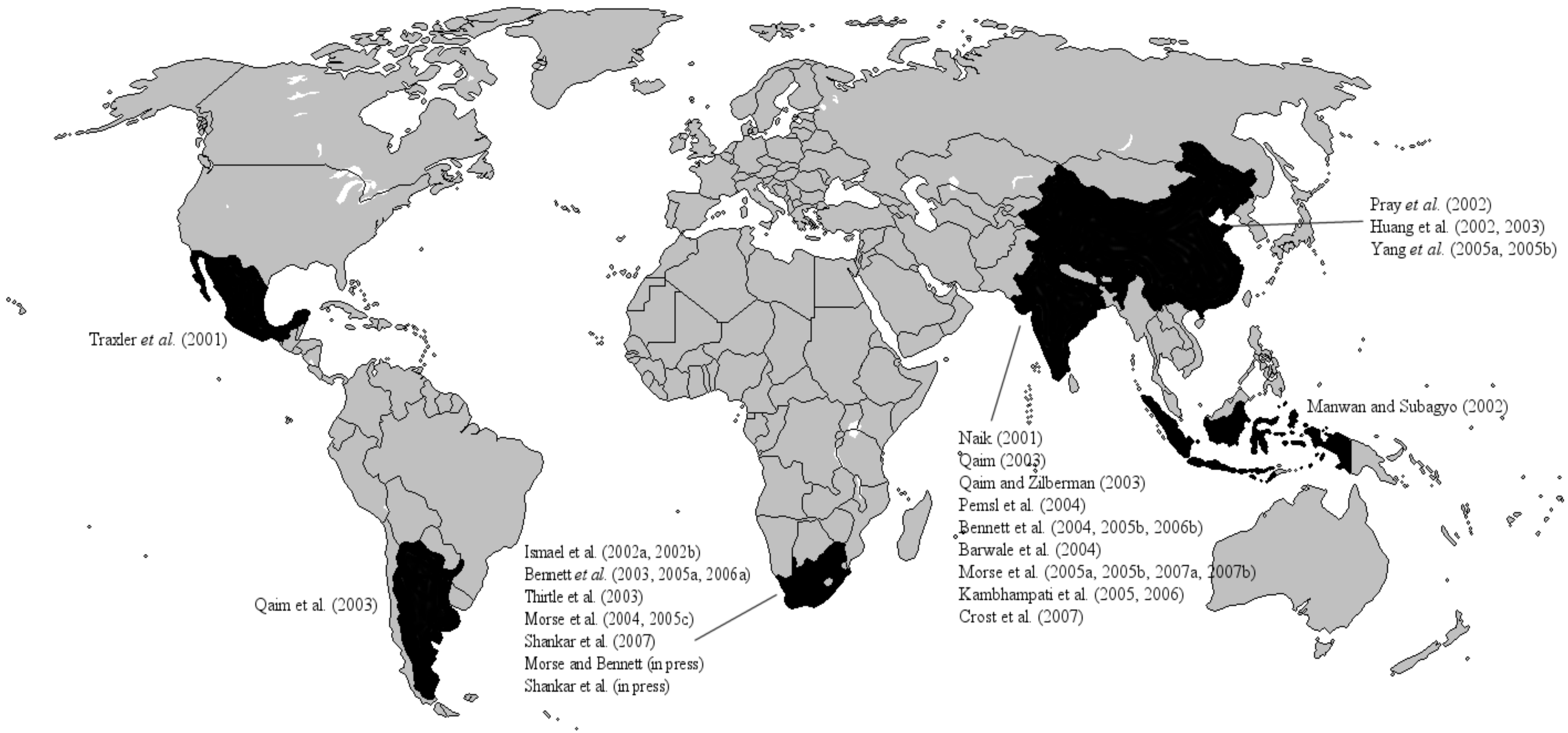
SOCIO-ECONOMIC IMPACTS OF BT COTTON

The majority of evidence to date suggests that Bt cotton has generally had a positive economic impact for small-scale farmers in developing countries. A recent paper by Smale *et al* (2006) provides a review of methods and findings of 47 peer-reviewed 'Bt cotton' papers published since 1996; they conclude that and the economic benefits are promising even if evidence for a sustained impact is not yet readily apparent. Figure 5 lists some of the key papers on Bt cotton in the developing world from 2002 to 2007. The geographical spread of the work is patchy, with a focus more on India, South Africa and China, but India and China are amongst the largest producers of cotton so it is not surprising that these countries should receive a great deal of attention. The studies broadly indicate an increase in yield, reduced insecticide use (insecticide product per hectare) and reduced expenditure (as less pesticide is used) and an overall increase in the gross margin for Bt varieties compared to non-Bt varieties. Gross margin is given by:

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

Gross margin can be negative (farmer makes a loss) or positive (farmer makes a profit). Pesticide costs are a part of 'all costs'; also included are the costs of labour, fertilizer, planting material, running costs of machinery and so on. While revenue is relatively straightforward to find provided the yield and the price achieved by the farmer (price can be obtained from either the farmer or the market) are known, the problem is in calculating the cost of production. There are the obvious costs of inputs applied during the growth of the crop such as seeds, fertilizer, pesticides, water and so on, but labour is also important. These are usually referred to as variable costs as they will vary depending upon what the farmer wants to do, and he/she can choose, if they wish, to make some of them zero. The farmer does not have to spend money on pesticide or fertilizer, but the yield may suffer as a result. Thus yield tends to increase as variable costs increase; but the relationship is complex due to the law of diminishing returns. The complication with respect to a comparison is that the studies in Figure 5 employ varying measures of 'costs'. Some include labour, for example, while others do not, and while labour may be included for some activities it may be left out for others. Also, while hired labour can be readily costed if the rate charged per hour, how many people were hired, and the length of time worked are known, it becomes more complicated with household labour. Some discount household labour is effectively free, but this is not strictly correct as it does not take into account the opportunity cost. If household members were not working in the cotton fields then could they not be working in some other areas of income generation? As well as complications over what to include in 'costs' such studies often differ in the mode of data collection. Some of the early studies relied heavily on data derived from plots which researchers established and managed on farmers land. Thus they were not 'farmer managed' and were not necessarily reflective of what farmers did in practice. Critics of GM were quick to criticise such work as being unrepresentative and potentially biased. Other studies have avoided this problem by focussing instead on plots owned and managed by farmers. Nonetheless, all of these issues make comparison between studies difficult, even if the work has been carried out in the same country.

Figure 5. 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)

The analysis of data from such studies has typically employed multiple regression, with yield as the dependent variable and the various inputs as independent variables. Thus each of the independent variables will have its own regression coefficient, standard error and significance, and the researcher can see which of them makes significant contributions to yield.In some cases interaction terms are included.

However, even if data are readily available the studies are typically focussed on gross margin assessed over a short period of time (a single or only a few growing seasons). They provide snapshots rather than a longer-term picture, and fail to answer the key question about the sustainability of an increase in gross margin. Will the gross margin benefits over non-Bt varieties continue into the future, and if not then why? Also, such studies to date have not tended to ask how any extra income has been used by farming households. What has been achieved with the additional resource? This is not simply a matter of what the extra income has been used for but also the use put to saved labour because Bt cotton requires less spraying. These two points can be combined into a consideration of sustainable livelihood, defined as:

> "*A livelihood comprises the capabilities, assets and activities required for a means of living. A livelihood is sustainable when it can cope with and recover from stresses and shocks and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base*."
> Carney (1998)

While this definition has just two sentences it hides much complexity. 'Shocks' and 'stresses' can be diverse, extending beyond bio-physical features such as pest attack and drought, to market fluctuations (Carney, 1998 and 2002). In order to minimise these development workers have sought to encourage a diversification of livelihood options (Castro, 2002) founded on a thorough analysis of livelihood as set out in Figure 6. Assets (categorised for convenience under the headings of human, social, physical, natural and financial) available to households are analysed within the context of environment and institutional constraints and support, and it is only after this has been undertaken are possible interventions explored which can address problems.

The Bt cotton story provides an interesting set of dimensions to sustainable livelihood analysis (SLA), and this point will be returned to later. Of central, importance, of course, is the durability of the recorded economic and other benefits to date. Will they stand the test of time without damaging the environment? In order to provide some insights into this question the research conducted on the impacts of Bt cotton in South Africa from 1999 to 2005 will be explored. This is only for a period of six years, but it still 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 (Figure 7).

Figure 6. Analysis of livelihood with a view to deigning a suitable intervention.

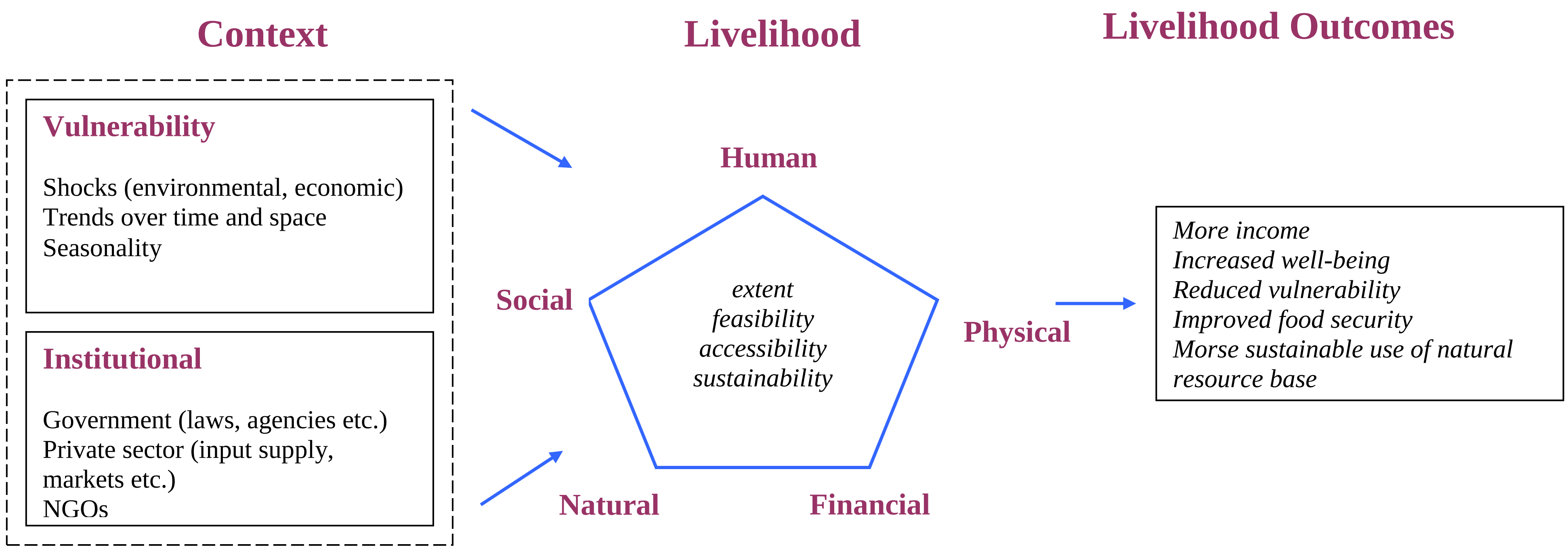
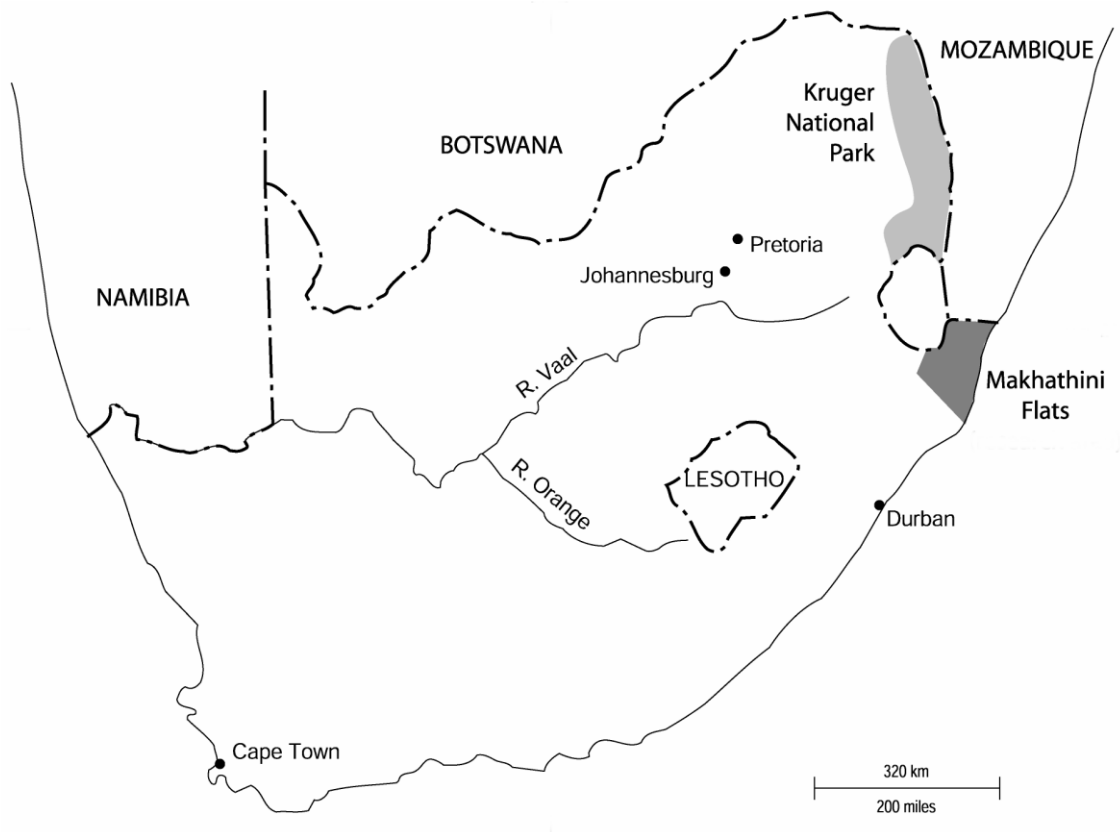


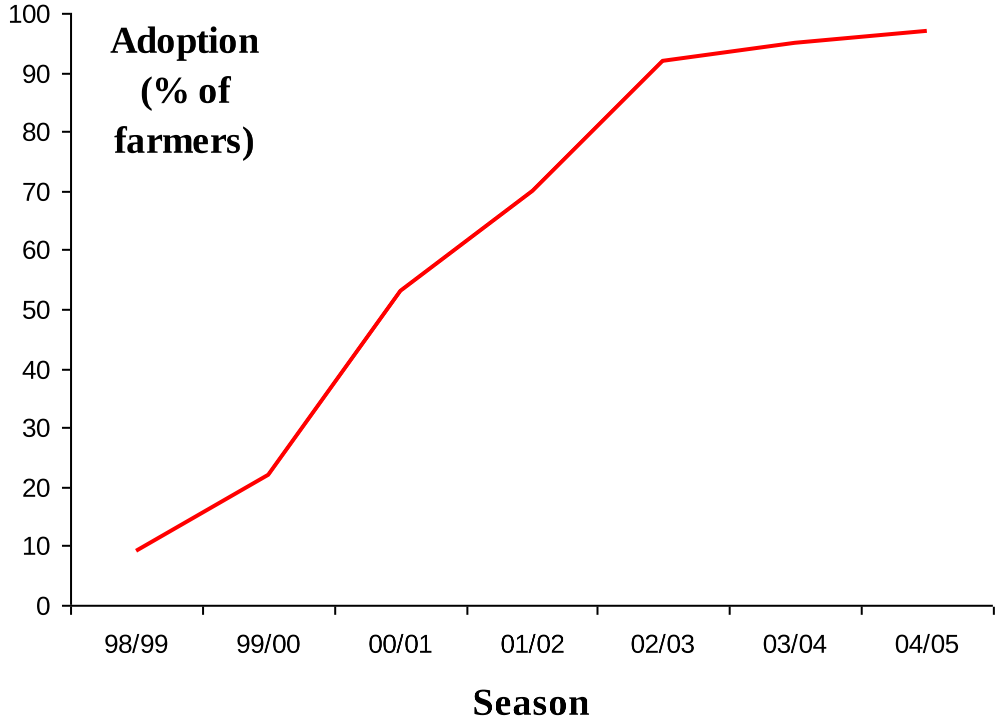
Figure 7. Location of Makhathini Flats, Kwa Zulu Natal, South Africa



South Africa remains the only African country to grow GM crops commercially, with Bt cotton first planted in 1997 (Wilkins *et al*, 2000). Large commercial farmers began adopting Bt cotton in the 1997/1998 season followed by resource poor farmers in 1998/1999 in Makhathini Flats. The Bt cotton variety in Makhathini is called NuCOTN 37-B with Bollgard^{TM} developed by Delta Pineland. Farmers in Makhathini first grew Bt cotton in the 1998/1999 cotton season and adoption of Bt cotton in the region has been rapid. By 2002, an estimated 92% of the smallholder cotton growers in Makhathini had adopted the Bt variety and this had increased to nearly 100% by 2004/05 as shown in Figure 8.

Kwa Zulu Natal is one of the poorest areas of South Africa and agriculture is the most important source of income in Makhathini. Rural households cultivate small plots of land (typically 1 to 3ha; one ha = 10,000 square metres) allocated to them by tribal chiefs. Cotton is a cash crop which occupies most of the farm area in Makhathini, and there are potentially 5,000 smallholder farmers of which around 1,400 used to grow cotton in any one year. However, that number has fallen in recent years to around 700 farmers, and the reasons for this are discussed later. Around 60% of farmers are women as a result of men migrating to urban areas for work.

Figure 8. Adoption of Bt cotton varieties in the Makhathini Flats.



One important facet of the cotton production system in Makhathini is the limited diversity of options available to farmers in terms of input supply and marketing. Up to 2002 all cotton producers in Makhathini had no choice but to use Vunisa Cotton (a private, commercial company) for purchasing inputs such as 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 paying farmers. There were no other cotton supply or cotton marketing companies in the area up to 2002. The arrival of a new cotton ginnery, NSK (Noordelike Sentrale Katoen) in 2002, with a capacity to gin 10 times more cotton than is actually produced by farmers, forced Vunisa out of the region. Given the low cotton yields in Makhathini there was simply not enough production to sustain the two companies, but unlike Vunisa, NSK does not provide credit and thus only the wealthier and more efficient farmers could continue to grow cotton. The shortage 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. However, it should be acknowledged that Bt cotton seed is more expensive than non-Bt seed. The price of Bt cotton seed stood at SAR 1,300 per 25 kg bag in 2005 as compared with SAR 464 per 25 kg in 2002 (a difference of 180%).

Cotton cultivation in Makhathihi is marked by relatively low yields of 600 kg/ha or less prior to the introduction of Bt varieties. The lack of irrigation is a major constraining factor especially as the area is vulnerable to drought. Pest attack is also a problem, and includes bollworm, leaf-eating insects such as grasshoppers, aphids and jassids. Farmers address pest attack by using insecticide, usually applied with a knapsack sprayer, but this is both costly and arduous. As well as the actual task of spraying, the necessary water often has to be transported from a distance of up to 10 kilometres (Ismael, *et al*, 2002b).

The results presented here are based on 3 separate, but related, studies of cotton production in Makhathini which took place between November 2000 and January 2006. The first of these was conducted in November 2000, and was based on a questionnaire survey of 100 smallholder farmers (Ismael *et al*, 2002a; Thirtle *et al*, 2003). The questionnaire was completed during face-to-face interviews in the field and at Vunisa Cotton premises, and while limited in scope data on the 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 compliment the first by addressing a number of important limitations (Bennett *et al*, 2003, 2006a; Morse *et al*, 2004, 2005c; Shankar *et al*, 2007, in press). In this case computerised records were obtained from Vunisa which detail 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. However, the number of records available did vary between seasons. Thus 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 once the Vunisa data had been checked and verified. The second study had a number of advantages over the first:

- sample sizes were much larger, thereby negating the obvious criticism that the first study was only based on a relatively small number of farmers.
- memory recall was not required and god quality data were available for 3 seasons.
- some limited data on labour costs were available, although it has to be admitted that the Vunisa records would only relate labour costs which had been paid for from credit. Family labour, or help from friends, for example would not be included.

The third study took place as part of the 'impact on livelihoods' research project described below (Morse and Bennett, in press). It 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. The difficulty with the third study was the lack of a comparative element as by the time of the research almost all cotton growers were planting Bt varieties.

Therefore, to echo a point made earlier it should be noted that gross margin in each of these three 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 more complete picture as all labour (family, help or otherwise) was costed at the equivalent daily rate for that task.

Table 2. Summary of Bt cotton studies in Makhathihi

Study	Period	Non-Bt adopters : Bt Adopters	Costs included	References
1	November 2000 Memory recall	1998/99: 74:17 1999/00: 32:59	Seed and insecticide only	Ismael *et al* (2002a) Thirtle *et al* (2003)
2	2000 to 2003 Vunisa records (no memory recall)	1998/99: 1196:87 1999/00: 329:112 2000/01: 254:245	Seed, insecticide and some labour costs	Bennett *et al* (2003, 2006a) Morse *et al* (2004, 2005c) Shankar *et al* (2007, in press)
3	2005/06 Household survey	Adopters only (100)	Seed, insecticide and all labour	Morse and Bennett (in press)

Some of the findings (mean and 95% confidence intervals) of the three studies exploring economic impact of Bt cotton are shown in Figures 8 to 10. The first of these graphs, Figure 8, shows the yield and revenue (yield X price) data. In all two seasons of study 1 and the three seasons of study 2 the yields were significantly higher for Bt plots relative to non-Bt and this resulted in a significant increase in revenue. In both of these studies the relative decline in yields for season 1999/2000 relative to the others is due to that season being very wet. Thus the smaller sample of study 1 does mirror quite well the picture obtained from the much larger Vunisa dataset. The average yields for Bt cotton in 03/04 and 04/05 are higher than in the previous seasons and this is probably due to the elimination of more marginal cotton farmers (NSK no longer provided credit) plus the availability of more complete records for fewer farmers compared to the Vunisa dataset. As would be expected the revenue data mirrors the yield data.

Figure 9 presents some of the main costs for growing Bt and non-Bt cotton. These are seed, insecticide and labour (spraying, weeding and harvesting where available). Not all labour activities are presented here (e.g. land preparation and planting), but these are the ones where differences were noted. For both 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 a mixed one. In study 2 the Bt plots clearly have less labour for spraying than non-Bt, for the obvious reason that less insecticide is required, but do have a greater harvesting labour cost as yields are higher. Weeding labour costs are much the same for Bt and non-Bt, as perhaps might be expected. In general the extra cost of the seed and harvest labour is reclaimed through less expenditure on insecticide and spraying. Overall the costs of growing Bt and non-Bt are comparable.

Figure 8. Mean (plus 95% confidence limits) yield and revenue from Bt and non–Bt plots for the 3 studies in Makhathini.

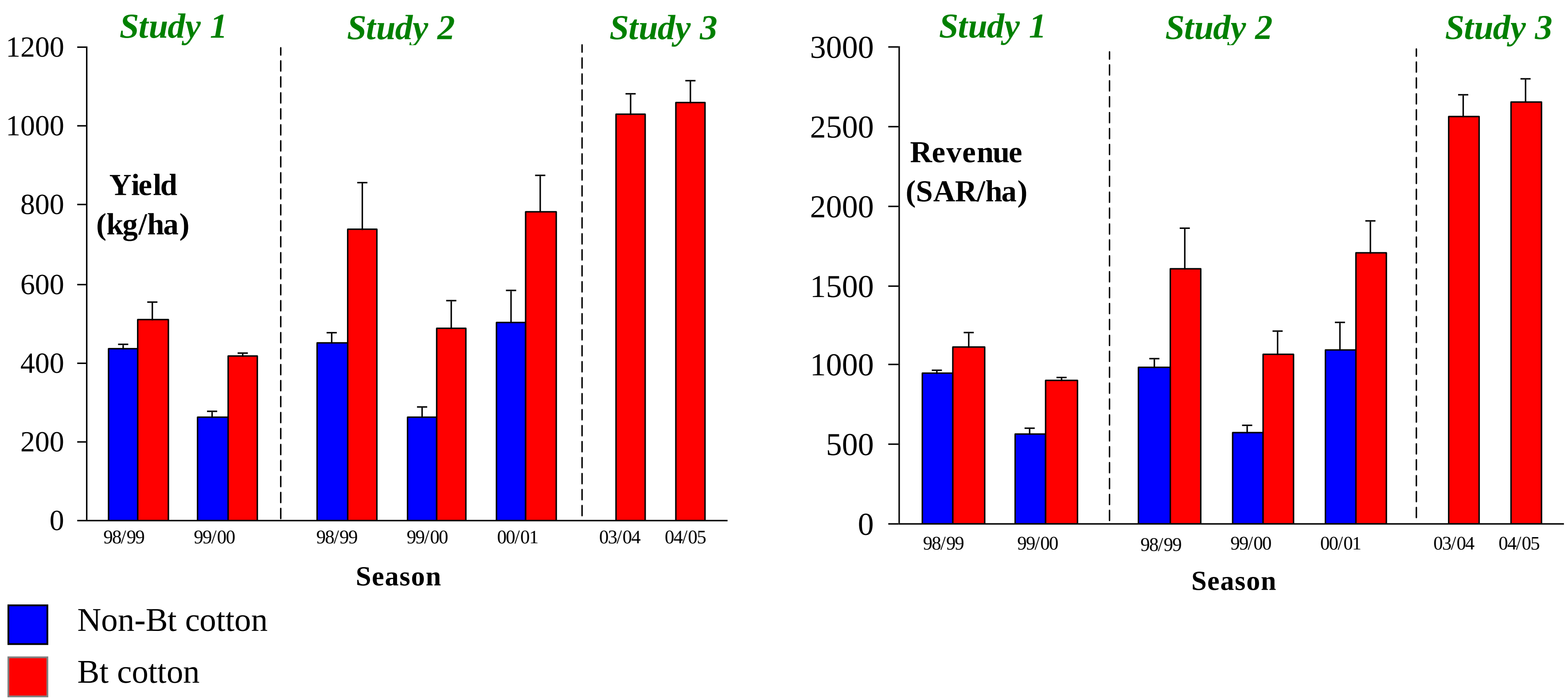


Figure 9. Comparison of seed and pesticide costs of growing cotton between Bt and non-Bt plot.

Figures are means and 95% confidence limits

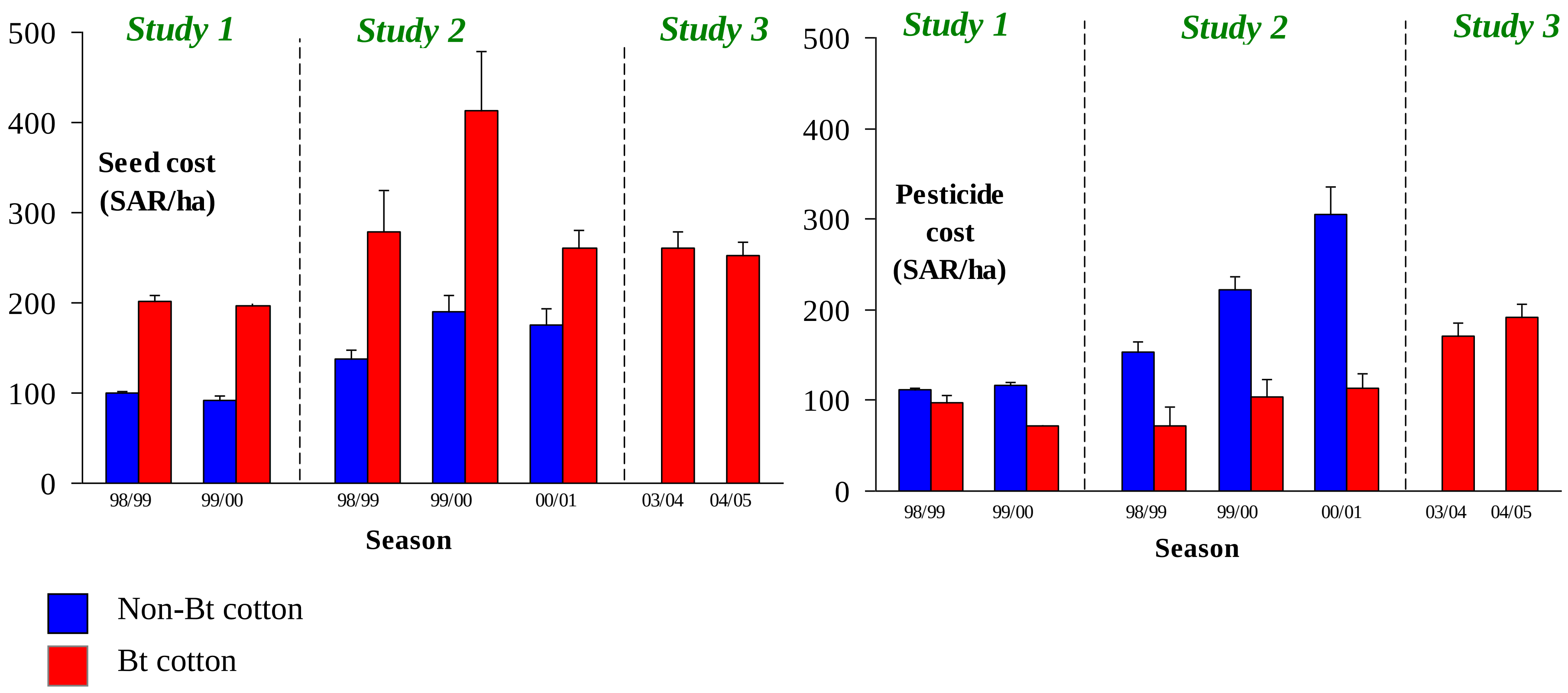
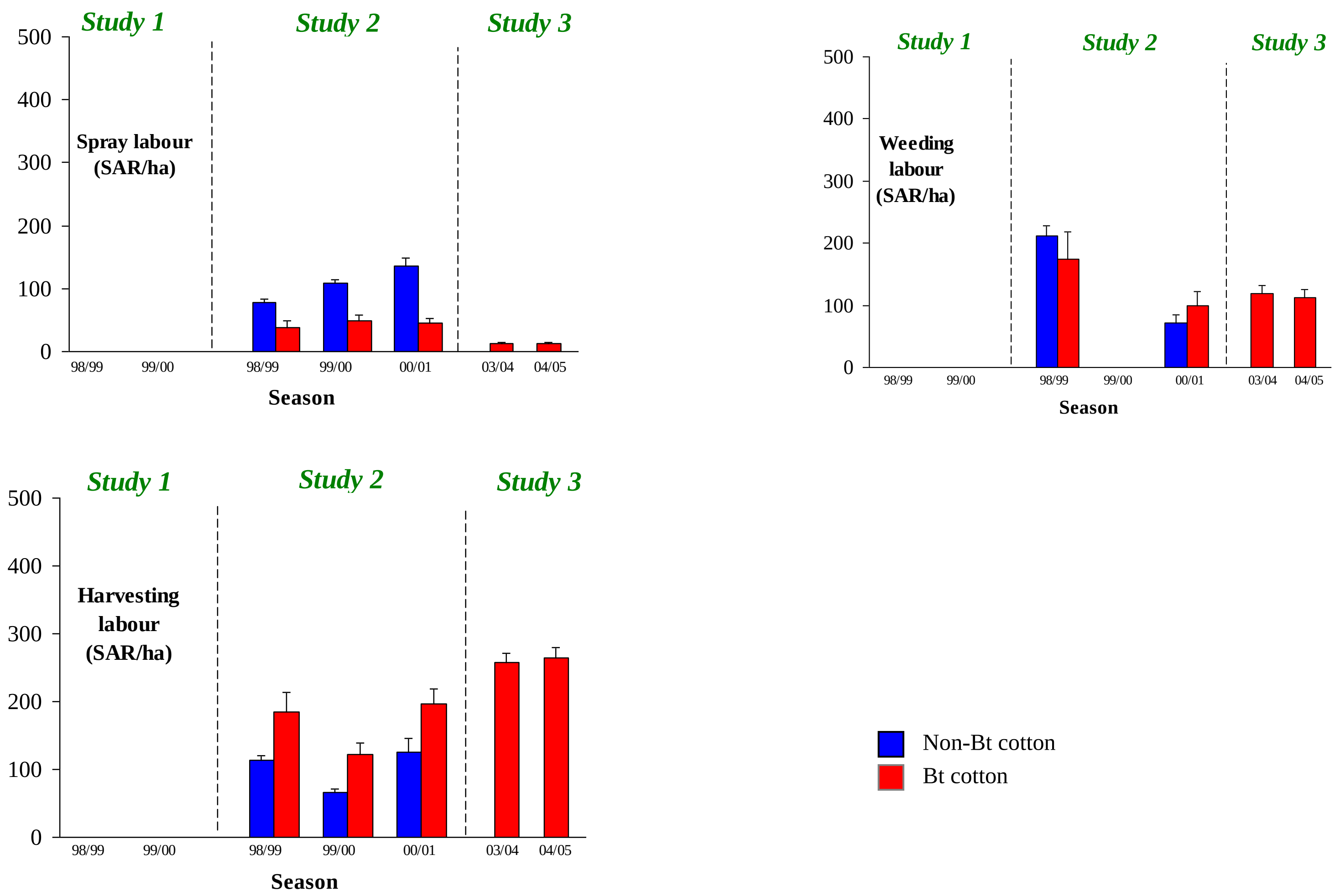


Figure 10. Comparison of some labour costs of growing cotton between Bt and non-Bt plot. Figures are means and 95% confidence limits



One interesting feature of Figure 9 is the suggestion that insecticide costs per hectare for both Bt and non-Bt cotton have 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 have increased between 1998/99 and 2004/05, with an R^2 of 34%. Much of this, of course, will be due to inflation and this explanation is supported by the data for spraying labour which suggest, if anything, that this expenditure has declined over the same period reflecting the need for less pesticide as a result of growing Bt. An increase in price could also be linked to a change of product away from bollworm products towards those which target pests attacking vegetative plant parts.

Table 3. Results of regressing insecticide cost (SAR/ha) against season

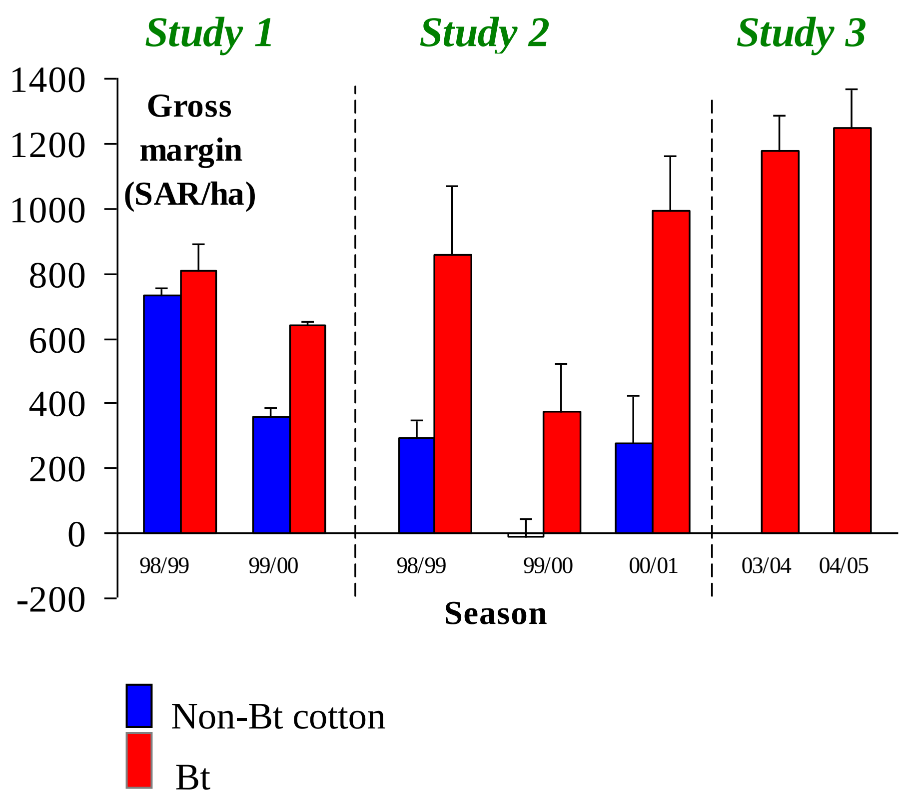
	Coefficient (SE)	t-value	P-value
Intercept	35.11 (10.98)	3.2	<0.01
Season	30.27 (3.4)	8.91	<0.001

R^2 (adjusted) = 34%   F = 79.36 (df = 1, 628) P < 0.001
Seasons are 1998/99, 1999/00, 2000/01, 2003/04 and 2004/05.

In terms of gross margin (revenue – costs) the clear benefits of a greater yield for Bt cotton with costs that are more or less the same as growing non-Bt results in Bt plots having a higher gross margin than non-Bt (Figure 11). This gross margin differential of between 387 SAR/ha (1999/00) and 1,090 SAR/ha (2000/01) was statistically significant for each of the two studies and season, but in both studies should be seen as an overestimate as not all labour was included. In the third study no comparison between Bt and non-Bt plots was possible, and it should also be noted that the farmers included here could arguably be better off considering that none of them required credit. However, it is clear that the gross margin of Bt cotton has held at around SAR 1,200 per hectare; much higher than that recorded for any of the non-Bt plots in studies 1 and 2.

Therefore the evidence does point to a clear economic advantage in growing Bt cotton compared to non-Bt. In the seasons where comparisons were possible the two studies, using quite different methodologies, point to this advantage. Each of the studies has its own limitations, but together the picture is convincing. The increase in gross margin is a result of higher yields rather than lower costs. Plant resistance, be it based on GM or not, is efficient in the sense that there is less dependence upon farmers making the right decisions over what, how and when to spray. The technology reduces the chance of error. Even one of the most critical studies of the impact of Bt cotton in Makhathini which was based on a very limited sample size (just 10 farmers growing Bt and 10 growing non-Bt), much smaller than any of the studies reported here, still pointed to a marginal economic benefit from growing Bt cotton (Hofs *et al*, 2006). Their mean yield for Bt cotton was 760 $\pm$ 301 kg/ha and 671 $\pm$ 209 kg/ha for non-Bt.

Figure 11. Gross margin of Bt and non-Bt plots.



Bt COTTON AND LIVELIHOODS

In a survey conducted in Makhathini from October 2005 to January 2006 a total of 100 farmers were interviewed about the impacts of the additional income from Bt cotton on their households (Morse and Bennett, in press). Selection was structured on the basis of ensuring a representative sample of male and female household heads, and random within those categories. The process was based upon the list of members supplied by the Hlokoloko Chairman, and farmers were interviewed using semi-structured questionnaires. The aim of the questionnaire was to gain an understanding of what had changed in the region since the introduction of Bt cotton, farmer's perceptions (positive and negative) of Bt cotton, how any income or time benefits were used and other economic data to quantify costs and benefits of Bt adoption. The questionnaire focused on two cotton seasons, 2003/2004 and 2004/2005, and thus did rely to some extent on memory plus the analysis of any records the farmers may have had. The Hlokoloko Chairman does encourage the keeping of records and indeed that was one of the main reasons for selecting this association. However, by the time of the research almost all of the farmers had adopted Bt cotton and thus it was not possible to include a comparative element by interviewing non-Bt growers. Some descriptive statistics for the sample of 100 respondents are provided as Table 4.

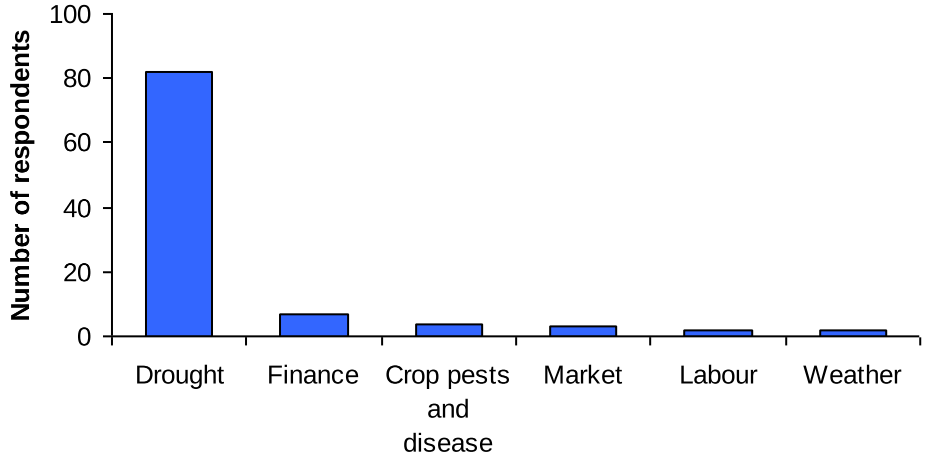
Table 4. Descriptive statistics for the 100 respondents growing Bt cotton.
(after Morse and Bennett, in press)

Parameter	Mean (SD)
Average age of respondent	47.57 (10.32)
Household size (persons)	8.62 (3.86)
Male adults in household	2.47 (1.72)
Female adults in household	2.73 (1.49)
Children (<12) in household	3.72 (2.47)
Number of years farming cotton	7.2 (5.98)
Total area owned (ha)	3.87 (2.93)
Total area under cotton (ha)	2.88 (1.6)

The 37% male and 63% female structure of the sample reflects the gender proportion in the area, and the average age of respondents was 47.6 years. Each household had 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. This crop is clearly a major contributor to household livelihood.

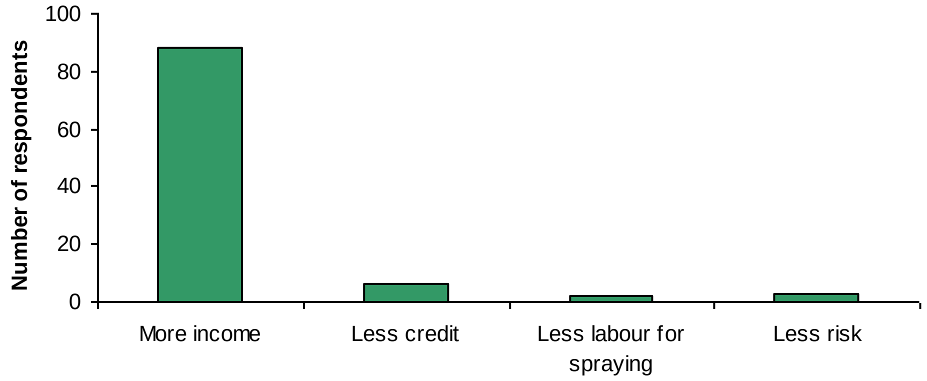
When asked about the main constraints to growing cotton (Figure 12) it is perhaps not surprising that most of the respondents cited drought. More surprising, given the absence of credit provision since Vunisa had left Makhathini, is that only seven respondents cited lack of finance, but there is something of a circular argument here as this group were arguably the better off and thus did not need credit. Other problems mentioned included crop diseases and scarcity of labour. No respondent mentioned insect pests as a main problem, but this may be because their use of Bt cotton had greatly reduced the impact of bollworm, the main cotton pest.

Figure 12. Main constraints to growing cotton as perceived by the respondents.
(after Morse and Bennett, in press)



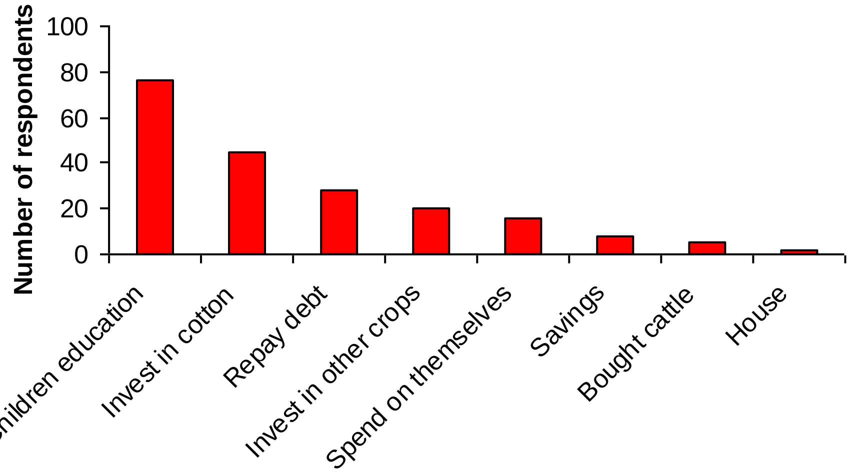
When asked about the main benefits of growing Bt cotton, most respondents listed income (Figure 13). Other responses included 'less credit', 'less risk' and 'less labour'.

Figure 13. Perceived benefits from growing Bt cotton.
(after Morse and Bennett, in press)



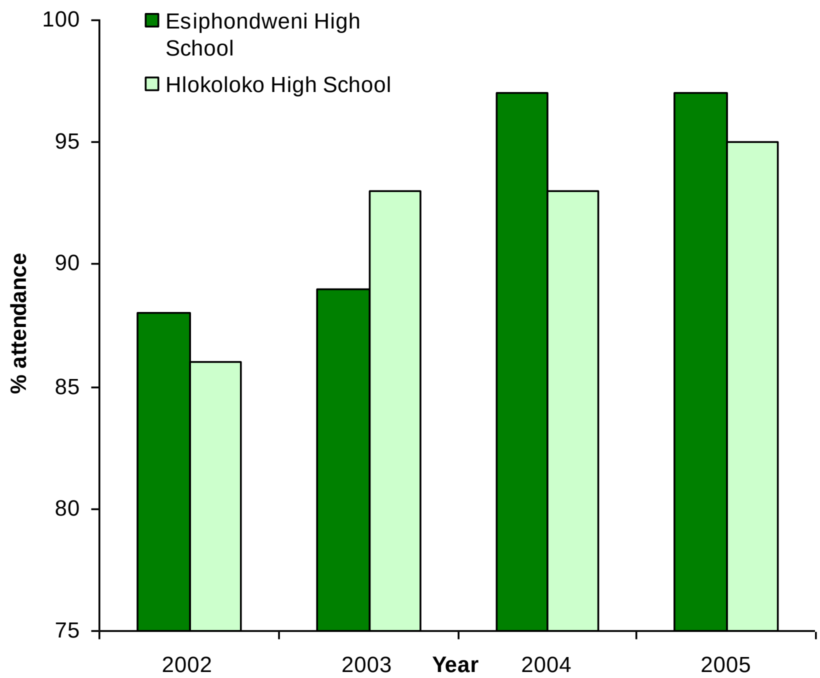
This finding certainly chimes with an analysis of the economics of growing non-Bt and Bt cotton outlined above. When asked what they did with the additional income (Figure 14) the largest number of responses involved investment in their children's education with the next most popular category being investment in cotton.

Figure 14. Uses made of the additional income from growing Bt cotton. (after Morse and Bennett, in press)



Other responses included repaying debt, investment in crops other than cotton and expenditure on themselves (entertainment, electronic goods and clothes). Thus it is apparent that most of the responses suggest that the extra income is being used for investment, either in people (education) or for income generation. The increased investment in education is an especially interesting finding, and in order to check this conclusion children's attendance for two schools, Esiphondweni High School and Hkloloko Primary School, were analysed from 2002 to 2005and are shown in Figure 15.

Figure 15. Attendance at Esiphondweni High School and Hkloloko Primary School between 2002 and 2005 ((after Morse and Bennett, in press)



According to the school masters from Hlokoloko Primary School and Esiphondweni High School the increased ability of Bt growers to pay school fees meant that children attended school more frequently. Hence between 2002 and 2005 percentage attendance had risen from 86% to 97% for Esiphondweni and 86% to 93% for Hlokoloko. However, there is a downside to this story as the increased yields of Bt do mean that children are more likely to be away from school at the harvesting time. According to the schoolmaster at the Mboza Primary School:

> *"Bt cotton has caused a boom among farmers… pupils buy new uniforms from their cotton picking earnings and school fee payment is more regular and has improved dramatically…. In the past 2-3 years involvement in cotton picking has increased… cotton picking is a favourite for pupils because it is fun, they earn money and it is less drudgery…. Some, however, end up sacrificing their education for money, but generally the effects are positive…..*"
>
> Interview with schoolmaster Hlokoloko 20/09/05

The other 'good news' dimension to the Bt story in Makhathini is the use to which farmers claim to make of the additional income. Top of the list is clearly investment in their children's education. This is followed by increased investment in cotton, other crops and the repayment of debt. Investment in non-cotton crops would help to diversify livelihoods. There is less emphasis on investment in physical assets but there is evidence that farmers are investing in more land and structures such as houses. There is no evidence to suggest that farmers are disposing of the additional income in less productive pursuits. An increased investment in education can only be seen as a positive development in Makhathini, and is born out by data from schools which show a trend of increased attendance. However, on the more negative side there is some circumstantial evidence that higher yields from Bt cotton do mean that children are kept out of school more often during July to September (the harvest period).

Is the livelihood impact of Bt cotton any different from the impact of any other technology that would enhance agricultural income? There was no evidence to suggest a qualitative difference and the same benefits would have presumably accrued if a new 'conventionally bred' variety of cotton had been introduced with resistance to bollworm. The Bt gene reduces the need for insecticide but any resistance to bollworm would have done the same although the efficiency of the resistance is obviously important. Frankly whether the resistance has come from a bacterial source or conventional breeding utilising cotton germplasm would not be an immediate issue for Makhathini farmers. What is readily apparent to them is the gains from growing Bt cotton and the support structure in terms of credit availability and the price they obtain for their produce. The rapid adoption of Bt cotton is testament to its popularity.

Bt COTTON AND SUSTAINABILITY

Is there any evidence to suggest that growing Bt cotton is unsustainable? Gains in income are certainly positive, and it appears as if the households use the income constructively by investing in physical and human assets. Could this be just a short-term benefit? Much depends here upon the meaning of sustainability and there are many definitions. In order to provide a flavour of this diversity a few comments spanning six years between 1989 and 1995 (the period just before and after the influential 1992 Rio Earth Summit) are shown as Figure 16. All manner of factors are included, from the central importance of maintaining profitability and production to the need to reduce or eliminate inputs such as pesticide. The latter point in particular is often employed to link sustainable agriculture with organic farming (Rigby and Cáceres, 2001). However, some of the comments in Figure 16 stress that sustainable agriculture does not necessarily mean that pesticides are not used. Yet Bt cotton would appear to satisfy both the need fro profitability and a reduction in pesticide. Indeed profitability was enhanced with Bt cotton and the technology undoubtedly reduced the need for insecticide. However, critics would point to a further key point stressed in some of the quotations i.e.futurity, the need to ensure that production/profitability continue into the future, and it's here, they argue, that Bt cotton and indeed GM crops in general are problematic as it is not possible to determine what the effects may be at some point in the future. Will genes escape and produce 'super weeds', or will GM crops turn out to be carcinogenic? A more recent 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 fail at least in some places such as Europe as they are not yet "*socially acceptable*". However, GM crops are presumably "*socially acceptable*" in a number of countries and thus, by definition, sustainable provided they remain economically viable and environmentally sound.

Figure 16. Some definitions of sustainable agriculture.

"…profitability, consumer safety, resource protection, and viability of rural America."
Kelling and Klemme (1989)

"What is sustainable agriculture after all? The only sustainable agriculture is profitable agriculture. Short and sweet."
Ainsworth (1989)

'Sustainable' means the capability to continue producing food and fibre indefinitely and profitably without damaging the natural resources and environmental quality on which all of us depend.
Schaller (1989)

"For a farm to be sustainable, it must produce adequate amounts of high-quality food, protect its resources and be both environmentally safe and profitable. Instead of depending on purchased materials such as fertilizers, a sustainable farm relies as much as possible on beneficial natural processes and renewable resources drawn from the farm itself."
Reganold *et al*. (1990)

"…the concept of sustainable agriculture does not exclude the use of fossil fuels and chemicals: it only requires that the criteria of appropriateness and sustainability be applied to the whole system."
Wilken (1991): quoted in Frans (1993)

"A sustainable agriculture is one that equitably balances concerns of environmental soundness, economic viability, and social justice among all sectors of society."
Allen *et al* (1991)

"Sustainable agriculture refers to the use of agricultural land in such a way to ensure that over time no net quantitative or qualitative loss of natural resources occurs."
Fresco and Kroonenberg (1992)

"Sustainable agriculture consists of agricultural processes, that is, processes involving biological activities of growth or reproduction intended to produce crops which do not undermine our future capacity to successfully practice agriculture."
Lehman *et al* (1993)

"…sustainable agri-food systems are systems 'that are economically viable, and meet society's need for safe and nutritious food, while conserving or enhancing … natural resources and the quality of the environment."
Science Council of Canada (1991): Cited in Lehman *et al* (1993)

"Only the most hard-bitten of intensive commercial farmers would now accept that conventional agriculture is sustainable."
Gibbon *et al* (1995)

"One of the key charges of the environmental activists is the claim that high-yield farming is 'unsustainable'. This has resonated with the public, probably because it implies a lurking, hidden threat. Actually … high-yield farming is more sustainable than organic farming… We also have strong evidence that high-yield farming can continue producing higher and higher yields on into the future."
Avery (1995)

Putting social acceptability aside for one moment what does the Makhathini work say about sustainability of Bt cotton? Unfortunately given the time period of but 5 years it is impossible to make a definitive statement one way or the other. Cotton is a non-food crop, with the notable exception of cottonseed oil extracted from the seeds, and so for the purposes of this discussion issues that could arise from human consumption of Bt cotton products will be ignored.

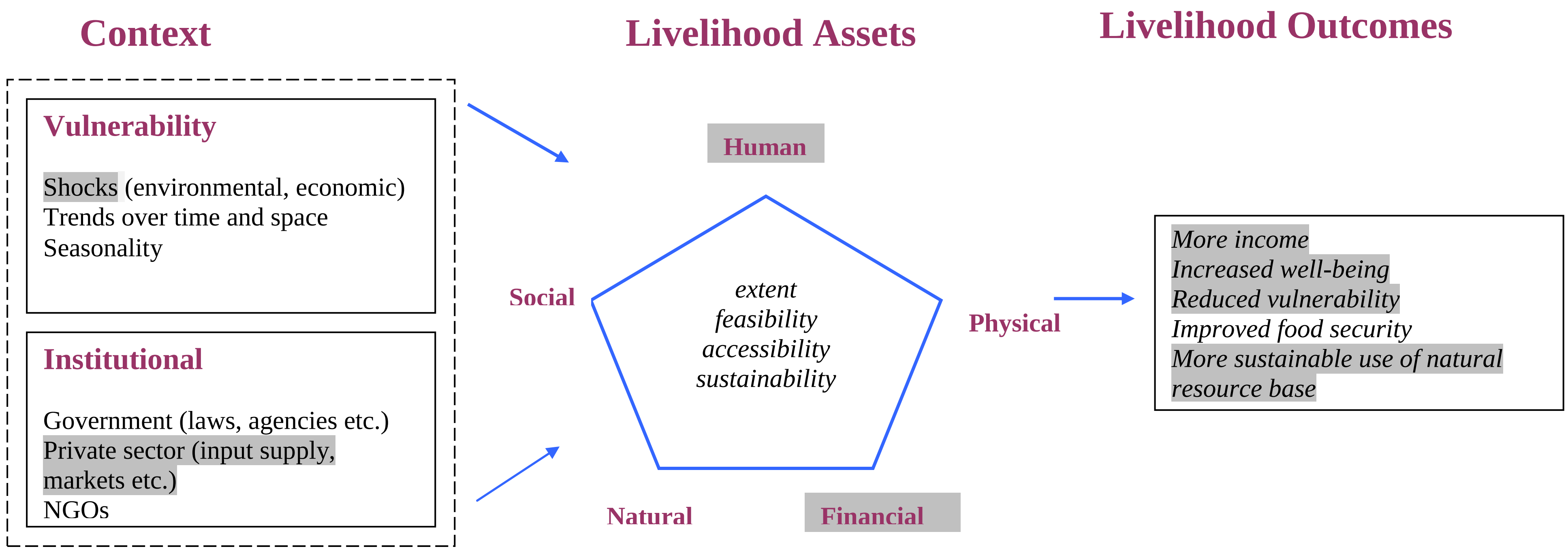
There is certainly no evidence as yet for gene escape into wild relatives of cotton and neither is there any evidence that the Bt-based resistance is any more or less sustainable to breakdown than resistance bred through conventional means. Plant resistance to insect pests can break down if the selection pressure is strong enough, but to date and despite more than 500,000 squares miles of Bt-engineered crops worldwide there has yet to be a breakdown of Bt-based resistance (Gujar *et al*, 2007) with the one exception of the diamondback moth (*Plutella xylostella*). Li *et al* (2007) suggest that based upon measured incidence of bollworm resistance genes this could happen 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 something of a mystery (Biello, 2006).

Perhaps the biggest 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. However, it should be stressed that this was the case before the introduction of Bt cotton and has not been caused or necessarily exacerbated by that technology. Bt seed does cost significantly more than non-Bt and critics have pointed to an increase in debt as crop or market failure makes Bt growers more vulnerable (Biowatch, 2004; Grain, 2005).
A complication with this simple picture is that Vunisa did not begin offering credit when Bt cotton was introduced. Nevertheless while the Biowatch/Grain point is valid it is important to note that this vulnerability would equally apply to an increase in cost of any input. For example, 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. An increase in land preparation or labour costs would equally make farmers more vulnerable. The deeper issue alluded to in the Biowatch/Grain critique is the narrowness of the livelihood base – a reliance on just one crop. If the livelihood base was wider then households would be able to cope with failure of one component.

A summary of the livelihood impact of Bt cotton is shown as Figure 17, with key points shaded. Bt will help address an important shock, e.g. pest attack, and enhances human life (through education) and financial capital. This can result in a suite of benefits such as more income and increased well being, but the whole system is predicated upon input supply (including credit for many farmers) and the market. The asset base available to farmers prevents them from widening their livelihood options.

What of the future? Predictions are invariably dangerous, but concerns can always be raised. Will the yield advantage of Bt cotton continue and if it does will the farmers perhaps see in reduction if price for their cotton as a consequence of the law of supply and demand? More yield resulting from almost all farmers growing Bt means more cotton for NSK to purchase and will they not compensate by lowering price? It hasn’t happened yet but will it? Who can say?

Figure 17. Analysis of livelihood with respect to Bt cotton.



PROSPECTS

Development as it is known today is generally regarded as born in the early post-second World War period. Rightly or wrongly its birth is often taken to be President Truman's programme for peace and freedom (1949) which stresses four major courses of action that his presidency pursued. The fourth of these states:

> "*Fourth, we must embark on a bold new program for making the benefits of our scientific advances and industrial progress available for the improvement and growth of underdeveloped areas.*
>
> *More than half the people of the world are living in conditions approaching misery. Their food is inadequate. They are victims of disease. Their economic life is primitive and stagnant. Their poverty is a handicap and a threat both to them and to more prosperous areas.*
>
> *For the first time in history, humanity possesses the knowledge and skill to relieve the suffering of these people.*
>
> *The United States is pre-eminent among nations in the development of industrial and scientific techniques. The material resources which we can afford to use for assistance of other peoples are limited. But our imponderable resources in technical knowledge are constantly growing and are inexhaustible.*
>
> *I believe that we should make available to peace-loving peoples the benefits of our store of technical knowledge in order to help them realize their aspirations for a better life. And, in cooperation with other nations, we should foster capital investment in areas needing development.*"

Here there is a strong sense of a Western-led trusteeship – "*help them realize their aspirations*" – as well as a clear emphasis on the application of technical knowledge and capital investment (modernization) coming from the west as means of meeting peoples aspirations "*for a better life*". Some have seen Bt cotton as one such technology with the capacity to catalyse a progression to a "*better life*", and while it can make a positive contribution, at least in the short to medium term as evidenced in Makhathihi, the reasons for under-development in Makhathihi are far deeper than can be addressed by just one agricultural technology. Development is replete with claims that a single technology or 'package' of technologies can radically transform the lives of the urban and rural poor. However, the reverse of this argument is that Bt cotton cannot be dismissed as being irrelevant. When compared to crop varieties bred for resistance to pests and disease through conventional means, Bt cotton has performed well and has proven to be popular with farmers in many countries. Whether the gains are sustainable in the long term has yet to be seen, but the trends so far are positive. The Makhathihi case study indicates that quality of life for individual poor farmers is improved by a GM crop. It also shows that there is a generational element insofar as the younger generation are benefiting through education.

However Bt cotton can be regarded as a special-case in the GM debate. It is (mostly) a non-food crop, and the basis of the technology is to reduce insecticide use which is a key goal of many in the attainment of sustainable agriculture. Bt achieves this goal and enhances profitability. It would seem to be a technology that provides benefits for farmers in both the developed and developing worlds. Nevertheless extrapolation to other forms of GM in agriculture is not possible. GM crops which have resistance to herbicides (e.g. Liberty link and Roundup Ready crops) are of quite a different nature to Bt. In this case the technology replaces other, more expensive, herbicides and possibly human labour. Thus farmers who may not have used any herbicide and employed people to weed their fields may be encouraged to replace that input with herbicide and thereby reduce income for people hiring themselves out as labourers. This could be both socially and environmentally damaging, even if farmers enhance their gross margin. For farmers who already use herbicides the technology replaces one type of selective and expensive herbicide with another which is not selective and/or cheaper. Also, given the selective herbicides do require some skill in application to ensure that the application rate and timing are correct, perhaps also involving 'tank mixes' of different products, the use of a general non-selective product requires less thought and the scope for accidents is reduced.

CONCLUSION

GM crops elicit a wide range of responses, from claims of miracle products which will alleviate poverty at a single stroke at one end of the spectrum through to a view that they will devastate agriculture and the environment. As with many similar debates, especially in relation to technology, the reality lies somewhere in between these extremes. GM crops cannot alleviate poverty at a stroke and neither is there evidence that by themselves they will cause the same scale of damage that has occurred with the indiscriminate use of pesticides and fertilizer or with the removal of hedgerows and woodlands to allow larger field sizes. Evidence to date suggests that Bt cotton can generate an increase in gross margin for resource-poor farmers and does reduce insecticide use, and these gains have been sustained over relatively short periods such as 5 years. However, the jury is still out. Will these benefits continue or will the pests overcome the resistance? Will the markets maintain the price of cotton as production increases? There are no answers, but these issues are no different from those linked with other non-GM technologies. Fertilizer and irrigation increase yields, and so 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. Conventionally-bred resistant crop varieties have existed for years, and some have shown a breakdown of resistance to pathogens. What is so different about Bt cotton? Why do GM crops generate such heated debates?

"*Every advance in civilization has been denounced as unnatural while it was recent*"
Bertrand Russell

One issue is the transfer of genes between widely-separated species. For some this is simply unnatural and unethical and thus GM crops will never be acceptable no matter what the evidence for their benefits. Will this change? Time will tell. The issue of an adverse environmental impact is problematic. The creation of super weeds is not impossible but the greater problem concerns the possibility of expanding GM crop agriculture into areas of wilderness, such as forests and grasslands, and thus compromise further the Earth's capacity to cycle and store carbon and other elements.

In the case of Bt cotton, the major change has been its replacement of conventional cotton in many cotton-producing countries rather than an expansion of cultivation.

Other issues of significance also require further investigation. Of particular significance is the effect of Bt crops on food chains and on human health. This is especially relevant to Bt crops which are directly consumed. Bt cotton does, however, have some impact on food chains because cottonseed is fed to animals, is used as a substrate/mulch for growing mushrooms and is processed to produce cottonseed oil. There is no evidence to date for related animal or human health impairment but critics would argue that problems may ensue with long term consumption.

Bt crops including Bt cotton continue to be controversial. The debate continues.

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