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Is there a role for Bt cotton in IPM for smallholders in Africa?

RORY J. HILLOCKS

Natural Resources Institute, University of Greenwich, Chatham Maritime, UK

Abstract
Cotton is an important crop in many countries in sub-Saharan Africa (SSA). Cotton varieties transformed with genes from *Bacillus thuringiensis* (Bt) are resistant to a number of lepidopteran bollworm pests of cotton. Bt cotton varieties have been widely adopted in Australia, China, India, the USA and elsewhere. To date, South Africa is the only country in SSA that has planted Bt cotton, but many other African countries are soon to do so. This paper reviews IPM in a number of African countries and considers the possible contribution that Bt cotton might make to IPM for African smallholders.

Keywords: *Cotton, Bt, IPM, Africa, GM-crops, bollworms*

1. Introduction

Cotton is widely grown in developing countries where it is largely a smallholder crop and often the mainstay of household income for rural communities in semi-arid areas. In many countries in sub-Saharan Africa (SSA), average yields are below 500 kg/ha of seed cotton, although the varieties have a yield potential under rain grown conditions of 3000 kg/ha. If more smallholders are to become commercially viable cotton growers, the yield gap has to be addressed and greater cost benefit must be obtained from applied inputs, including labour. IPM can contribute to this through better targeting of pesticides, and in some cases, decreased number of sprays. Although there have been successful IPM systems developed for large-scale cotton production systems in Africa, for instance in Zimbabwe (Brettell 1986; Jowah and Mubvuta 1993) and the Sudan (El Tigani et al. 1991), it has proved much more difficult to develop effective systems for smallholders. Part of the reason for this is the difficulty of knowledge dissemination to widely scattered communities in large countries with poor transport and communication infrastructures. Host-plant resistance derived from conventional breeding is a common component of IPM systems and is particularly suited to the smallholder sector because its adoption is not knowledge-intensive. Resistance to pest or disease is incorporated into the seed bought by, or supplied to, the farmer and no additional information or knowledge is required to grow the variety than was required for the pest-susceptible counterpart. Genetically modified crops (GMCs) have a similar advantage, in that the technology is incorporated into the seed.

Soybean, maize and cotton are the GMCs most widely grown around the world and the USA, China and Argentina currently have the largest area under GMCs (James 2002). At present, two traits account for most of the GMCs grown. These are insect resistance conferred by genes derived from the common soil bacterium *Bacillus thuringiensis* (Bt) and herbicide resistance (mainly to glyphosate or 'Roundup' hence' Roundup Ready'), which allows crops to be over-sprayed with the herbicide, killing the weeds but leaving the crop unharmed. At the time of writing, South Africa is the only country in SSA that grows GMCs, but several other countries are preparing the biosafety legislation to allow testing and release of GMCs. Bt Cotton is likely to be the first GMC released in many of these countries. Globally, after soybean and maize, cotton carrying genes for Bt toxin production, resistance to herbicide, or both, is the most widely grown GMC. The statistics are constantly changing as the technology becomes more widely adopted, but Bt cotton accounts for 13 – 15% of the world's 34 million ha of cotton and the proportion is much higher in the USA, Australia and China (James 2002). Cotton in the countries that were early adopters of the technology, is a major consumer of insecticides, mainly for the control of bollworms. Bt toxins currently available and those produced in Bt cotton, are most effective against lepidopteran pests and give excellent control of several cotton bollworms, including *Helicoverpa* spp. (Kraittiger 1996).

Correspondence: R. J. Hillocks, Natural Resources Institute, University of Greenwich, Chatham Maritime ME4 4TB, UK. Tel: 44 1634 883303.
E-mail: r.j.hillocks@gre.ac.uk

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This review examines the successes and failures of GM crops so far and for smallholders in Africa, assesses the potential of the technology to meet the future challenges of agricultural development.

2. Background to cotton pest management in sub-Saharan Africa

With a few differences between west, east and southern Africa, the pest management issues confronting smallholders are broadly similar throughout SSA (Hillocks 1995). The Sudan is the only country in Africa to experience widespread pest problems induced by over-spraying, where loss of natural enemies due to area-wide adoption of organophosphate insecticides (OPs) and later of synthetic pyrethroids (SPs), in the Gezira cotton scheme, led to massive infestations of whitefly (*Bemisia tabaci*) (Abdeldaffie et al. 1987). In 1993 pyrethroid resistance was identified in *H. armigera* on cotton in South Africa (van Jaarsveld 1994). Zimbabwe is one of the few countries in the world to implement an integrated resistance management [IRM] system, sufficiently soon after the introduction of SPs to prevent the development of insecticide resistance in the target pest populations (Duncombe 1975; Brettell 1986). In most of the rest of eastern and southern Africa, pesticide use has been too patchy in both time and space for insecticide resistance to become the major problem that it has in India (Armes et al. 1992; Chavan and Nimbukar 2003), Australia (Gunning et al. 1984; Forrester et al. 1993; Gunning 1994) and China (e.g. Shen et al. 1992). In countries where cotton is grown over large areas with heavy use of inputs, IPM has been introduced as an emergency measure to decrease pesticide use and restore some ecological balance, but in most African countries, IPM is viewed as a low-input, sustainable solution to pest management (Hillocks 1995).

2.1. Tanzania

Tanzania is one of the larger cotton producing countries in SSA, where cash earned from its sale is vital to rural communities in the semi-arid areas in the north-west of the country. It is estimated that there are more than 400,000 growers with average holdings of less than one acre. The main insect pests are cotton bollworm (*Helicoverpa armigera*) (HBW) and spiney bollworm (*Earias* spp.) (SBW). The main pest control recommendation is for six insecticide sprays, applied at 2-week intervals from first flower (Nyambo 1989). A calendar-based spray schedule is the norm in many African countries, as it does not require the farmer to identify the pests concerned. The disadvantage is that insecticide may be used unnecessarily, decreasing the farmers profit margin and needlessly exposing the farmer and his community to toxic chemicals. Research at Ukiriguru Research Institute has shown that in some seasons, when bollworm pressure is low, there is no significant difference in yield between sprayed and unsprayed cotton (Nyambo et al. 1977). In practice, few cotton farmers in Tanzania apply more than one, two or at most, three sprays in a season. The timing of the applications is based on visible evidence of damage to the bolls or just the presence of insects, some of which may be beneficial, rather than pest species. If improvements are to be made in cotton yield and profit margins increased, then insecticide must be used more efficiently. This may be achieved by basing spray intervals on scouting for eggs, larvae or insect damage, and spraying when a defined threshold is reached. This has been shown to improve spray efficiency and increase profit margins (Matthews and Tunstall 1968). The difficulty is in getting farmers to appreciate the role of natural enemies and to scout their fields on a weekly (twice weekly is better) basis, so that sprays can be directed at the most vulnerable early larval instars of the bollworms (Nyambo 1989). In the absence of an effective extension system it has proved difficult to promote best practice in insect pest management in Tanzania. Among the cotton farmers in Tanzania who use insecticides, many apply their sprays at the wrong time, with poorly maintained equipment and sometimes with inappropriate chemicals (RJ Hillocks, unpublished).

2.2. Uganda

During the 1960s and early 1970s, Uganda was one of the largest cotton producers in SSA. By 1989 production had fallen by more than 90%, as a result of war and internal conflict. Production is now steadily increasing and there is a market for their high quality hand-picked cotton. High prices for cotton in the early 1990s encouraged private sector investment in the cotton ginning sector. World cotton prices subsequently plummeted and national production has not increased fast enough to meet the demand from ginneries. As in Tanzania, pest control is poorly carried out, giving little or no return on the investment on inputs. In keeping with the country's Plan for the Modernisation of Agriculture, private sector ginning companies have been encouraged to invest in raising crop management standards to increase the volume of seed cotton. Integrated crop management (ICM) projects funded by the United States Agency for International Develoment (US AID) and the UK's Department for International Development (DFID), are working with ginning companies in Uganda, promoting improved cotton management systems that incorporate IPM. Knowledge is disseminated through a massive number of on-farm demonstrations and training of cotton extensionists provided by the ginning companies. The trained extensionsists are then responsible for training the 6000 farmers who host demonstrations. Each farmer in turn is asked to introduce 15 – 20 of his neighbours to the technology. The IPM system developed for Uganda is based on delayed use of first insecticide spray to allow build-up of natural enemies. The first spray is often against aphids and the IPM alternative is to use soapy water, rather than insecticide. The soap solution is often sufficient to keep the aphids in check without a deleterious effect on the beneficial insects. Subsequent decisions on whether to spray or not, are based on scouting and simple damage thresholds. A wooden peg-board is used to record the number of plants that reach the damage threshold and the point at which spraying is required for each of the main pests is indicated on the wooden board. In addition to the bollworms, the other main pests are the leaf eating lygus bugs (*Lygus voselleri*) and the cotton stainer bug (*Dysdercus* spp.). The number of sprays can be decreased using the IPM system, from the recommended four at three week intervals, to two or three (Sekamatte et al. 2003). But even if the number of sprays is not decreased, and may even be increased over the fixed schedule in seasons with high pest pressure, better targeting leads to improved returns on the cost of insecticide (Matthews and Tunstall 1968; Sekamatte et al. 2003). The success of scouting in reducing pesticide use and improving spray efficiency to increase yields, depends on developing appropriate intervention thresholds that compromise between the ideal and those that are practical for the farmer to implement. Promotion of IPM in Uganda, just as everywhere else, depends on considerable effort and expense in farmer education. The cotton ICM programme is addressing the extension issue through the 6000 on-farm demonstrations. Farmers themselves are trained to disseminate the technology messages beyond their own demonstrations plots. The success of this method of promoting IPM has yet to be fully evaluated.

2.3. *Zimbabwe*

Researchers in Zimbabwe saw the early signs that red spider mite was becoming a problem, due to widespread use of insecticides on cotton and resistance to dimethoate. This led them to develop the acaricide rotation scheme which involved using a different compound in each of three zones and rotating the compound used every two years (Duncombe 1975). When SPs were introduced, regulations were formulated at the outset to prevent the development of resistance to the insecticides used against the target bollworm populations. To minimise the number of bollworm generations exposed to the insecticide, SP use was restricted to cotton and the allowed spray period confined to flowering and boll development. The delay in delivering the first broad spectrum insecticide allowed the build-up of natural enemies. This system prevented the appearance of resistance to SPs in *H. armigera*, long after it was seen in other countries. Pink bollworm (PBW) was controlled by legislation to ensure the destruction of cotton crop residues at the end of the season and observance of a closed season before cotton could be planted again. This prevented the seasonal carry-over of PBW. These measures were largely observed and straightforward to regulate when cotton was produced mainly by a small number of large estates. However, as cotton became increasingly a smallholder crop from 1980 onwards, the regulations became more difficult to implement (Jowah and Mubvuta 1993) and collapsed completely following land reform 20 years later (P Jowah personal communication).

2.4. *Francophone Africa*

As in East Africa, cotton production in French West Africa (FWA) is a smallholder enterprise, but organised very differently. Before the pressures of economic structural adjustment discouraged subsidy and encouraged market liberalisation, the cotton sector in FWA was vertically integrated. Input supply, credit provision, transport, ginning and marketing was handled by a single marketing company. Research and extension was provided by affiliated organisations. The cotton companies even contributed to community welfare in cotton villages. The entire output was exported to spinning mills in France and prices were supported by government intervention. Such a system facilitated extension and knowledge dissemination, resulting in widespread adoption of improved technologies, bringing substantial increases in cotton production (Lele et al. 1989; Levin 1999). Between 1981 and 1993 cotton production in the FWA region increased from 533,000 tonne of lint to more than 1.3 million tonne. Yields of over 1000 kg/ha of seed cotton were common and widespread adoption of pest control measures contributed to the high yields (Cauquil and Vaissayre 1993). Adoption of spray recommendations, using a minimum of three insecticide sprays per season, increased from 25% in 1970, to 80% by the end of the 1980s (Cauquil 1990). This success was due partly to the introduction of spinning disc, ultra-low volume (ULV) sprayers that increased spray efficiency with greatly reduced labour, eliminating the need to fetch large volumes of water (Cauquil 1987). The cotton companies were able to provide the extension back-up to ensure that the technology was understood and adopted. In FWA it was considered impractical to rely on farmers to carry out threshold-based spraying based on scouting. Instead the authorities opted for a calendar-based system in which spraying began on a fixed date (e.g., 40 – 45 days after planting). The recommendation was for four to six sprays, with cotton extensionists advising on the spray interval, depending on prevailing pest pressure, stage of crop development and potential yield (Cauquil 1990). While this system was clearly effective in managing insect pests, it cannot be described as IPM, and its success depended on close supervision by the cotton companies. With the difficulty of scouting for pink bollworm which remains within the boll, it is doubtful if a change to a scouting-based system would improve the cost – benefit of spraying in FWA. The alternative would be a complete change to an IPM-based system, with the emphasis on natural control, in which insecticide spraying was carried out only as a last resort and under close supervision by the ginnery or some other authority.

3. Why has IPM been difficult to implement on cotton in Africa?

The main reason for the failure of IPM to be widely adopted in Africa is that (with the exception of South Africa) insecticide spraying is already at a low level compared to levels that were reached in Australia, USA, India and elsewhere during the 1990s. Low spray frequency in Africa results from poor access to funds with which to purchase inputs. Because insecticide has not been widely used and cotton holdings are scattered among other crops and natural vegetation, insecticide resistance has not been a factor. So there is little incentive for adoption of IPM. Furthermore, poor infrastructure and inadequate extension provision makes it difficult for knowledge-intensive technologies to be adopted. Even in FWA, where effective extension services operated, it was considered impractical to base spray timings on action thresholds informed by scouting. In Zimbabwe, IPM was effective in the estate sector, but could not be effectively implemented among large number of scattered smallholders. The success of IPM with smallholders in China, owes much to the old communist system, which lent itself to a top-down authoritarian extension and area-wide adherence to a regulated farming system. In the case of Indian smallholders, insecticide use was widely adopted in response to active marketing by agricultural input suppliers. Resulting insecticide resistance led to increasing numbers of sprays to achieve the same level of control. The incentive for IPM adoption was therefore high and great savings have been made through its implementation by decreased expenditure on insecticides.

There have been some local successes, using IPM in the development of organic cotton schemes in some African countries. Under organic systems there is a high incentive for the adoption of IPM because synthetic pesticides are proscribed in order to qualify for organic certification (Hillocks 2002). Here IPM works by combining different non-chemical methods to achieve an acceptable level of control. Success depends on effective extension which is normally provided in these cases, by the agency managing the certification. The number of participants is usually small relative to the countries total number of cotton farmers. This type of general IPM system does not require specialist knowledge on the part of the farmer to identify pest and beneficial insects. The measures adopted are those that encourage the build-up of natural enemies and if an insecticidal intervention is required, a readily available natural product can be used, such as azadirachtin from the neem tree or rotenone from the fish bean plant (*Tephrosia* sp.).

Whether cotton is grown organically or conventionally is not significant, more important is that best practice is followed in all aspects of crop management. When improved crop management leads to increased yields it may be necessary to protect those yields from insect attack, by one means or another. This is why the promotion of integrated crop management (ICM) is more appropriate for smallholders than promoting just IPM (Meerman et al. 1996). Pest management alone cannot deliver increased yields in situations where yields are well below potential, due to poor crop management. It has been argued that African farmers do not need Bt cotton to reduce reliance on pesticides as the same can be achieved by properly implemented IPM schemes (Kuyek 2004). While there are successes in using the principles of IPM to decrease pesticide use on cotton, the funding and infrastructure are lacking in most Africa countries, to develop the capacity of extension services and farmers to implement such a programme on a large scale.

4. Benefits of Bt cotton

4.1. Economic benefits

The widespread and rapid adoption of Bt cotton in the USA, Australia and China has occurred because it enabled farmers to decrease the number of sprays applied for bollworm management, which has had economic and environmental benefits. Bt cotton was reported to have given US farmers an average net income increase of US$20/acre (James 2002; Gianessi et al. 2002). Concerns have been expressed that the main beneficiaries of Bt cotton have been the companies marketing GM seeds. However, one study in the US estimated that the largest share of the benefit (42 – 59%) went to cotton farmers and the combined share going to Monsanto and associated seed firms ranged from 26 – 44% (Traxler and Falck-Zepeda 1999). The reported benefits have not been confined to large-scale production systems. Similar economic benefits have been reported from China (Pray et al. 2002) and India (Qaim and Zilberman 2003). In South Africa, cotton smallholders on the Makhathini flats were reported to have benefited from Bt cotton to the tune of US$25 – $51/ha (Ismael et al. 2002). In Mexico in 1998, farmers with small- and medium-sized cotton holdings benefited from growing Bt cotton by $295/ha compared to their neighbours growing conventional varieties. Although yields were only slightly higher with Bt cotton, the major gains due to having a higher grade than was obtained from the conventional varieties and to savings on pesticide (Traxler et al. 2003).

4.2. Decreased pesticide use

There seems to be little doubt that the replacement of conventional cotton varieties with Bt hybrids, leads to a decrease in pesticide use for control of lepidopteran pests. The extent of the decrease depends on the pest spectrum and seasonally varying pest pressure. The present Bt toxins are effective mainly against the lepidopteran pests. The Cry1Ac gene contained in Bollgard 1 is more effective against the bollworms than against some of the leaf-eating caterpillars but control of these other pests was greatly improved by the introduction of Bollgard II, to which the Cry2Ab gene was added (Table I) (Perlak et al. 2001). In China, where insecticide resistance in the main pest (*H. armigera*) resulted in the number of sprays rising to 20 by the late 1990s, the widespread adoption of Bt cotton decreased the number of sprays to seven (Huang et al. 2002). Pray et al. (2002) reported that pesticide use in China in 2001, expressed as kg/ha of formulated product, was 66% less on Bt cotton than on non-Bt cotton. In Mexico the adoption of Bt cotton decreased pesticide use by 50% with adopting farmers spending on average, US$100 less on pesticide (Traxler et al. 2003). In 1997 Bt cotton was adopted by 52% of growers in the Comarca Lagunera region of Mexico, who required no pesticide sprays, while those growing conventional varieties applied insecticides an average of 1.57 times. In 1998 when pest pressure was higher, Those growing Bt cotton required two fewer sprays than those growing conventional varieties (four to six sprays).

4.3. Increased yields

While it is well documented that deployment of Bt cotton leads to decreased pesticide use, the case for increased yields is less clear. Yield is affected by many factors other than pest attack. The Bt varieties introduced have to be well adapted to local conditions. If they are not, then they will not out-yield the locally adapted conventional varieties. Cotton varieties grown in East Africa have been selected for resistance to the cotton jassid for instance, and American varieties with hairless leaves suffer severe damage from this pest. Varieties that have been successful with smallholders in Africa are indeterminate. This has two advantages: firstly they have the capacity to compensate for adverse conditions leading to boll shedding. Secondly, they have an extended boll-splitting period, so that harvesting can be spread over several weeks. These are quite different from the determinate varieties that produce their crop over a short period, more suitable for machine harvesting. Because of generally poor levels of crop management among cotton smallholders in Africa, Bt cottons are unlikely to deliver yield gains without addressing the crop management issues. There have been well-published cases in India, where Bt cotton varieties have failed to deliver yield benefits sufficient to cover the purchase price of the seed and savings on pesticide have been insufficient to deliver an overall cost benefit (Quayum and Sakkhari 2004). In China improved pest control with Bt cottons has been reported to deliver a 10% yield advantage over conventional varieties (James 2002). However, Dhong et al. (2004) report that yield increases generally in China with Bt cotton have been marginal and that net revenue gains were due primarily to savings on pesticide. In South Africa smallholder yield gains due to growing Bt cotton of between 18 and 60% have been reported (Morse et al. 2004). The larger gains occurring in seasons with greater bollworm infestation.

4.4. IPM compatibility

Most of the common insecticides that depend on contact with the pest for their action have some

Table I. Bollworm pests in the major cotton growing countries in sub-Saharan Africa.

Country	Cotton area [000 ha]	HBW	PBW	RBW	SBW	No. of sprays
Mali	516	X	X		X	5
Benin	415	X	X		X	6
Nigeria	403	X	X		X	3–4
Tanzania	392	X	X		X	2–4
Zimbabwe	364	X	X	X	X	4
Burkina Faso	351	X	X		X	7–8
Chad	312	X		X	X	5
Cote d'Ivoire	285	X	X		X	6
Mozambique	213	X	X	X	X	4–5
Cameroon	202	X	X	X	X	5
Uganda	200	X	X		X	2
Zambia	125	X	X	X	X	5

Modified from James (2002). HBW = *Helicoverpa* bollworm; PBW = pink bollworm [*Pectinophora gossypiella*]; RBW = red bollworm [*Diparopsis castanea*]; SBW = spiny bollworm [*Earias* spp.].

deleterious effect on the populations of beneficial insects (e.g., most pyrethroids) . However, insecticides differ in the extent of their effect across species and some of those with a narrower spectrum of activity are more suited to IPM. Ground-applied systemic insecticides are more IPM-compatible because only phytophagous insects are likely to ingest a lethal dose. Most naturally occurring compounds with insecticidal properties such as rotanone and pyrethrum are broad spectrum in their action and therefore not IPM compatible. The toxins produced by Bt cotton varieties are only ingested by the phytophagous insects and, therefore, like the soil-applied systemics, they have little effect on beneficial insects. Furthermore, the Cry1Ac protein binds specifically to receptors in the gut of lepidopteran insects and has no known deleterious effect on beneficial arthropods (Betz et al. 2000). Some studies have shown that beneficial insect populations are greater and more active as biocontrol agents in Bt cotton than in non-Bt cotton sprayed with insecticide (Li et al. 2003). A study conducted in Hubei province of China found that there were 66% more spiders in unsprayed Bt cotton compared to non-Bt cotton grown under IPM (Deng et al. 2003). It seems there may be suppression of natural enemies in Bt cotton compared to non-Bt cotton when both are unsprayed (Sun et al. 2003), but this is likely to be due to the availability of prey and hosts species. When Bt is used together with IPM to encourage natural enemies, control of bollworms and insect pests not targeted by Bt toxin should be enhanced.

5. Bt cotton in developing countries

Despite reports from China, India and South Africa that Bt cotton has improved the lives of smallholders, the introduction of Bt cotton into developing countries has not met with universal approval. There are some organisations such as GRAIN, campaigning against the introduction of GM crops in Africa. The forthcoming introduction of Bt cotton in French West Africa is seen as a threat rather than an opportunity for smallholders (GRAIN 2004). The sources of information on the benefits of Bt cotton for smallholders have to be closely examined. Technology transfer in the case of GMOs is controlled by vested interest. China is the only country in which public sector investment has led to the release of locally produced Bt cotton varieties. Elsewhere in the world the technology is 'owned' by Monsanto with limited involvement by Delta and Pine Land Company. Dow Agrosciences and Syngenta are soon to release their own insect resistant transgenic cottons. The concerns expressed by groups opposed to GMO technology should be looked at objectively to ensure that the prejudice against the technology by European consumers, is not being foisted on communities in developing countries, without the knowledge, information and representation to make their own choices.

5.1. India

Cotton growing in parts of India has been thrown into crisis by the increasing cost of pesticide use as the number of spray required has escalated in an attempt to compensate for the appearance of resistance in populations of the primary pest, *Helicoverpa armigera* (Chavan and Nimbalkar 2003; Ramasubramanian and Regupathy 2004). Smallholders unable to meet the increased cost of pest control in their cotton were initially enthusiastic when Bt cotton varieties became available in 2001. The approval of MAHYCO Bt cotton hybrids, MECH 12, 162 and 184, containing Monsanto's *Cry1Ac* Bt gene and results from field trials conducted between 1998 and 2001, was generally welcomed by the Indian scientific community (Mohan and Manjunath 2002). However, the rapid spread of Bt cotton in India, the world's third largest cotton producer, has been controversial. For a start the Bt seed has been distributed illegally. Individual farmers who wish to grow Bt cotton must enter into a contract with Monsanto that stipulates that seed will not be reused but fresh seed purchased each season. Breaches of this agreement have been widespread, apparently without prosecution. This is similar to what happened with soybean in Argentina, where Monsanto took little action initially when the round-up ready seed spread rapidly and illegally. Once the technology had been widely adopted, Monsanto applied pressure on the Argentinean government to enforce the terms of the seed contracts and payment of the technology fee. Leaving aside for the present the issue of multinational companies control over farmers rights to seed, the question most pertinent to this review is, has the Indian cotton farmer benefit from using GMCs?

There are conflicting reports from India concerning the benefits of Bt cotton. ISAAA (quoted by James 2002) claims that in large-scale field trials conducted in 2000/01 the yield advantage for Bt cotton was 38%. Yield gains of up to 80% for Bt cotton compared to conventional varieties have been claimed (Qaim 2003; Qaim and Zilberman 2003) in field trials conducted in 2001. Such large yield gains due to growing Bt varieties do not seem to have been transferred into farmers fields. A study conducted with 225 farmers in the Warangai district of Andrah Pradesh, concludes that the Bt variety yielded 25% less than the non-Bt variety with only a slight reduction in pesticide use (Quayum and Sakkhari 2004).

Qaim (2003) says that medium-term projections show sizeable welfare gains for the overall economy in India from the adoption of Bt cotton, with farmers being the main beneficiaries. Barwale et al. (2004)

have published data on the AgBioForum website comparing yield and pesticide use between Bt and non-Bt cotton in five Indian States. Yield gains ranged from 42% in Andrah Preadesh to 72% in Madhya Pradesh. The yield gains were achieved with a decrease in the mean number of insecticide sprays of between 1.3 and 2.7, giving a financial gain of between 15,000 and 24,000 Rupees/ha. Barwale *et al.* (2004), who represent the Maharashtra Hybrid Seed Company, list the following benefits of Bt cotton for Indian smallholders: Good bollworm control, higher yield and boll retention than non-Bt hybrids, cost savings on pesticides, with no adverse effects on non-target insects or adjacent non-Bt cotton. However, not everyone agrees that this has been the case in the areas where widespread adoption has already taken place. Farmers growing Bt cotton have come out in protest in several states in India, where Bt cotton has failed to deliver the expected profits [http://www.grain.org/research/btcotton.cfm?id = 211].

Farmers in some districts of Andrah Pradesh (AP), particularly in Warangai District, claimed in the 2002 – 2003 season that they obtained lower yields from their Bt cotton than from their non-Bt varieties. In response to these claims, crop performance was closely monitored by the Coalition for the Defense of Diversity and the Deccan Development Society, assisted by a number of other NGOs in three Districts of AP, with a sample of 164 farmers. Qayum and Sakkhari (2004) presented the detailed report of this study which showed that while pesticide use was marginally decreased by the use of Bt cotton and yields slightly increased, overall profits were 9% less from the Bt cotton than from non-Bt due to the additional cost of the Bt seed. These results are contrasted with the study by consultants, AC Nielson, conducted for Monsanto, that reported a 92% increase in profits from growing Bt varieties compared to the non-Bt varieties. There may be several reasons for the reported failure: Most of the 1200 farmers in AP who grew Bt cotton purchased the variety MECH-162 and the poor performance may have been more to do with this particular variety than Bt varieties as a whole. Also, there may be crop management issues that need to be explained to farmers in order to make the most of Bt varieties, not least that they should be used within an ICM framework.

5.2. South Africa

The dissatisfaction with Bt cotton felt by Indian farmers in the Warangai does not seem to be repeated elsewhere in Asia. In South Africa smallholders have been growing Bt cotton for a number of seasons on the Makhatini Flats. The Council for Biotechnology Information has published articles on its website quoting local farmers whose income has been increased since they switched to Bt cotton. A study conducted between 1998/99 and 2000/01 concluded that there were substantial benefits from Bt adoption (Thirtle et al. 2003). Cost savings were made in decreased pesticide use and in decreased labour requirement for spraying, while average yields increased. Other benefits were; decreases in requirements for water and a fall in reported cases of insecticide poisoning (Bennett et al. 2003; Morse et al. 2004). However, although Bt cotton seems to have contributed substantially to improving the livelihoods of the cotton smallholders at Makhatini, it should be noted that the average cotton holding is large compared to most of SSA. On average Bt non-adopters had holdings of 4 ha, while the adopters had holdings of between 6 and 8 ha. Percentage adoption among the farmers with larger holdings was 57%. Non-adopters said that the cost of the seed was the main constraint and there was doubt expressed by adopters that they would continue to purchase Bt seed if the costs were to increase (Ismael et al. 2001). The average holding even for non-adopters at Makhatini would be large compared to less than 1 ha that is typical in Tanzania for instance.

5.3. China

China as the largest cotton growing country in the world, producing around 25% of the world's output. Despite being a smallholder crop in China with average holdings of less than 0.5 ha, cotton yields are high at over 1000 kg lint/ha. The cotton bollworm (*H. armigera*) is by far the most serious insect pest and it became resistant to insecticides due to widespread spraying, first with organophosphates and later with pyrethroids. Spray frequency increased as resistance began to appear until more than 20 sprays per season was not uncommon by the mid 1990s. This provided a strong incentive for adoption of Bt cotton among the 13 million cotton farmers. Commercialisation of Bt cotton was approved in 1997 and adoption was rapid. It was estimated that by 2001 there were 4 – 5 million farmers growing one of several Bt cottons (Huang 2002). There are now 22 varieties produced by the Chinese Academy of Agricultural Sciences that are licensed for use in all the cotton growing provinces. In addition Monsanto and Delta Pine Land are licensed to market five of their Bt cottons in four provinces (James 2002). The main advantage to smallholders has been the huge decrease in the number of sprays required (Huang et al. 2002; Pray et al. 2002). For the average cotton farmer with 0.4 ha, the additional income generated from growing Bt cotton compared to non-Bt cotton was estimated at US$140. The national economic benefit from growing Bt cotton was estimated at around US$750 million in 2001 (James 2002). In addition to the financial benefits, widespread use of Bt cotton has also given health benefits. The massive use of insecticides on cotton in China by the 1990s led to many cases of pesticide poisoning. In 2001 the percentage of farmers suffering pesticide poisoning was 4% among Bt adopters compared to 12% for non-Bt cotton growers (Pray et al. 2002). There is some evidence of an increased gene frequency of Bt resistance genes in populations of *H. armigera* collected from Provinces in China where Bt cotton has been most widely planted. In 2002 one resistant individual out of 234 screened was detected in samples from Anci County in Hebei Province (Li et al. 2004).

6. What are the obstacles to successful adoption of GM technology in Africa?

6.1. Low levels of crop management

In order to increase cotton yields among African smallholders the standard of crop management must be raised. There are a number of components of an integrated crop management approach that could do this, depending on the existing standards of crop husbandry. In some places, simply planting in rows instead of broadcasting can increase yields by optimising plant density and facilitating weeding. The next step is to ensure that planting takes place within 3 weeks of the recommended optimum date (this is often not done because the need for food security dictates that food crops must be sown before cash crops). Timely thinning and weeding is essential for profitable cotton growing. Delays in weeding occur because of competition for labour from food crops. Fertiliser application can be important to maximise yields, but cotton is often grown without fertiliser in Africa. The response to fertiliser is complex and depends on soil type, planting date, rainfall, weed management and insect pest pressure. Finally, when a good crop has been established through attention to these aspects of management, the yield may need to be protected from pest attack. If that protection is to be achieved with purchased insecticide, obtaining an economic return from their use, depends on at least having an adequate yield worth protecting, and then on applying the insecticide correctly. Applying insecticide correctly and obtaining the maximum cost benefit through spray timings based on economic threshold levels of insect populations, or crop damage, is complex and knowledge-intensive. It is for this reason that Bt cotton could be of benefit to the African smallholder. Bt cotton is a way of protecting the yields gained from improved crop management and should be seen as just one component of ICM. It is not a means of obtaining improved yields with poor levels of crop management. In much of Africa the main reason for poor cotton yields is that those fundamental issues of crop management are not being addressed. In this situation Bt cotton is just an additional input expense which cannot be recovered through improved yield.

6.2. Cost of the Bt seed

Cotton is often an unpopular crop with African smallholders. They grow it if it gives them a reliable source of income and when there is no alternative. African smallholders rely largely on planting and cultivating by hand and on hand-picking. Cotton is labour intensive and hand picking is arduous and unpleasant work. In many African countries Government-backed Cotton Authorities used to provide incentives to grow cotton by providing access to subsidised fertiliser (which may then have been diverted to food crops) and other inputs. Seed would be provided free and the seed cotton harvested would be transported to the ginnery, the farmer only had to get it to a nearby buying post. In the aftermath of structural adjustment policies, seed is still often provided free because private ginning companies competing for seed cotton do not want to introduce a further disincentive to cotton growing by selling cotton seed to their growers. Under these circumstances, farmers will be reluctant to pay for Bt seed with the possible addition of a ‘technology fee’. Technology fees in South Africa have been roughly $50/ha. This is only slightly less than the cost of insecticide for the same area of cotton (Kuyek 2004) and no-one has suggested that growing Bt cotton necessarily eliminates completely the need for insecticide. In Zimbabwe, where land reform has led to the expansion of the smallholder sector, there is unlikely to be much of a market for expensive biotechnology products. However, the situation may be different for cotton than for Bt maize, because there is more vertical integration in the Zimbabwean cotton industry, with the main cotton company, Cotco, supplying growers with input packages (Keely and Scoones 2003).

6.3. Traditional farmers rights to seed

With the exception of the problem of paying for cotton seed, which has been tried and abandoned (at least temporarily) in some African countries such as Uganda, seed rights are perhaps less of an issue with cotton than with some other crops. Farmers are used to selling the ‘seed cotton’ by weight to the cotton buyer. As the seed is 60% of the weight and new planting seed is provided at the start of each season, there is no incentive to keep seed. However, for Bt cotton in addition to paying the ‘technology fee’, farmers will be expected to sign a Technology Use Agreement (TUA), containing tight regulations governing how they may use the technology. Monitoring these contracts by GM technology companies may prove more difficult in Africa where many farmers are illiterate and farms located in remote areas, than in India or Brazil, for instance. Ensuring that farmers understand the implications of the agreement they enter into when purchasing Bt seed may become an issue. For crops other than cotton where farmers in Africa are more used to keeping their seed and exchanging seed with neighbours the issue of TUAs may be more problematic.

6.4. Absence of adequate seed multiplication and distribution systems

One of the major obstacles to increased crop production in Africa is poor access by farmers to high quality seed. Tripp (2002) has expressed the view that without policies that support the development of strong and equitable input markets, biotechnology is unlikely to reach many smallholders. Structural adjustment policies led to the disbanding of most of the parastatal commodity authorities that provided inputs on credit and a subsidy on inputs in general. Although agricultural marketing was liberalised, the private sector has failed to provide the required investment in service provision. In rural areas of Africa, there is an almost complete absence of agricultural input suppliers, and the more remote the areas, the more acute the problem. The reasons for this are the poor road infrastructure and because suppliers will not invest in agricultural input supply until they are sure of the demand, and demand will not be created unless the private sector invests to stimulate agricultural output. This problem is particularly acute with seed. With the exception of hybrid maize and vegetable seed, there is little investment in seed multiplication and distribution. Cotton is perhaps the one exception because ginning companies provide seed to their growers and variety development and seed certification is funded from export levy. In most African countries the ordinary farmer is the seed source, except when foundation seed of a new variety is released from a Research Institute. Where countries have tried to grow more than one cotton variety, it has proved impossible to prevent mixing of the seed, once the ginning sector was liberalised. This issue will become more acute when some farmers are growing Bt cotton and others are growing conventional varieties.

6.5. Pest control spectrum of Bt cottons

There are a number of different Bt genes encoding for proteins that differ in the range of their toxicities. Even within the Lepidoptera some pests are affected more by one toxin group than by another (see Table II), and as has been seen with the stem borer, *B. fusca*, some important pests are tolerant to known Bt toxins. While it can be inconvenient that not all lepidopterous pests are equally susceptible to Bt toxins, this specificity is one of the advantages of Bt technology in IPM because mammals and most beneficial insects are unaffected. African smallholders, particularly those who do not use insecticides at present, or who only use one or two sprays per season, will be reluctant to invest in Bt cotton seed if they still continue to suffer significant yield loss from non-lepidopterous pests. Part of the reason for the rapid adoption of Bt cottons in China is the predominant pest status of *H. armigera*, a bollworm that is well controlled by Bt toxins. The same can be said for Bt cotton in Mexico, where pink bollworm was the predominant pest in some states and difficult to control before the introduction of Bt varieties. The poor performance of Bt cotton in Andrah Pradesh was partly explained by the need for more sprays to control sucking pests on Bt cotton than on non-Bt cotton (Quayum and Sakkhari 2004). In Uganda the Lygus bug (*Taylorilygus vosseleri*) is an important pest. Aphids and thrips can also be significant early season pests in SSA and other sucking pests such as the cotton stainer (*Dysdercus* spp.) are also widely distributed in Africa. Evidence from both China and the USA indicates that lygus bugs are more numerous in Bt cotton than in non-Bt cotton (Li et al. 2003; Welman and Cote 2004). Wu et al. (2002) go as far as to say that *L. lucorum* has become a key pest in transgenic cotton fields in northern China. Another study showed that in addition to *L. lucorum*, populations of *Aphis gossypii* and *Thrips tabaci* were elevated in unsprayed Bt cotton compared to sprayed non-Bt cotton (Sun et al. 2002).

Table II. Estimated level of mortality due to Bollgard cotton in the USA.

	Control [%][1]	
Pest	Bollgard I	Bollgard II
Helicoverpa zea	90	92
Pectinophora gossypiella	99	99
Spodoptera exigua	< 20	95 – 100

[1]% Mortality of newly hatched larvae (Modified from James (2002)).

6.6. Implementation of resistance management strategy

Where Bt cotton varieties have been widely adopted, such as in Australia and the USA, the contractual requirements include implementation of strategies to delay or prevent the development of resistance to Bt toxins in the target insect populations. The primary strategy that farmers are responsible for is the inclusion of refugia. This entails growing an agreed proportion of non-Bt cotton where there is no selection pressure on insect populations to evolve resistance to the toxin(s). The mandatory refuge requirements for bollgard cotton in the USA, are either 5% unsprayed refuge, that can be external or embedded, or 20% sprayed refuge (Matten and Reynolds 2003). In most countries in SSA, cotton holdings are small and scattered and farmed plots tend to occur in patches surrounded by natural or semi-natural vegetation. The agricultural ecosystem is therefore more diverse than is found in developed country agriculture and natural refugia may be sufficient to prevent the development of resistance to Bt toxins in pests such as *H. armigera* that have a wide host range. Nevertheless, one theoretical model shows that in West Africa resistance management with refugia would be required to delay the appearance of Bt toxin resistance in *H. armigera* (Nibouche et al. 2003). The case may be different for pink bollworm which has a narrower host range confined to the Malvacae.

6.7. Ability of authorities to implement biosafety regulations

Biosafety may be less of an issue with cotton than with food crops, although cotton seed oil is used as a component in locally consumed margarine in several African countries. South Africa and Kenya are the SSA countries that have made most progress with biosafety regulation. The importation, containment, testing and release of GMOs is regulated internationally under the terms of the Cartegena Protocols. Many developing countries are now developing their own protocols and capacity building to conform to Cartegena. Kenya has benefited from the Insect-Resistant Maize for Africa (IRMA) project, that has supported infrastructure development and capacity building for the implementation of biosafety regulations to meet the challenges of developing and evaluating Bt maize and other GM crops. While there may be no objections from farmers or local consumers in Kenya to the deployment of GM crops (see De Groote et al. 2004), regulation and inspection to prevent contamination of food crops intended for export, may become an issue in the future.

7. Conclusions

Bt cotton is a technology with the potential to benefit African smallholders but successful deployment of the technology depends on a number of factors:

- Implementation of bio-safety regulations, particularly with respect to regulation of seed multiplication and distribution.
- Farmers understanding that Bt cotton alone cannot deliver yield increases if basic crop management is poor.
- That Bt cotton is promoted as a component of ICM systems.
- Farmers understanding that insecticide spraying to control non-lepidopterous pests may still be required if the full benefit from Bt varieties is to be realised.
- Proper regulation of resistance management strategies. This will become more important, the more widely Bt cotton and maize are adopted, and it may be advisable to implement them at the outset, even though they may not at first be necessary (due to natural refugia).

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