Summary of *Biotechnology and Agricultural Development*
Edited by Robert Tripp
(Routledge: London, 2009)

Note: This book is the product of the three year research project commissioned by Oxfam America with support from the Rockefeller Foundation. The objective of the research was to assess the socio-economic impacts of the adoption of Bt cotton for resource poor famers in developing countries. The desire to offer a study, located outside the polarized debate for various stakeholders to consult in making difficult and complex adoption decisions, motivated the pursuit of such a research project. There is a dearth of studies which consider the potential benefits and challenges in the adoption of Bt cotton, based on the experiences of resource poor farmers and comparatively across a number of countries with differing institutional contexts. The need for assessments lying outside the bipolar politicized debate on GMOs became obvious through Oxfam's work with cotton farmers in Mali.

We should note that the approach to assessing the socio-economic impacts of Bt cotton adoption employed by this study does not constitute a holistic approach to assessment. For example, it does not provide a rigorous assessment environmental, health, and gender impacts. It focuses on reviewing past claims made regarding economic impacts/performance and couples this with a focus on an assessment of the institutional context (including access to information, access to markets, the organization of inputs delivery and IPRs) to emphasize the critical importance of the performance of institutions in understanding the potential for resource-poor farmers to benefit from the adoption of this technology. It brings to the forefront that there is a balance of power involved around any agricultural technology, practice or system and that this balance of power can be tipped in favor or against resource-poor farmers. This volume makes a case for placing farmers at the center of decisions around crop variety adoption with the purpose of promoting equitable agricultural development.

The following provides a summary of the book. Each section corresponds to a chapter in the book. Each outlines the key issues of focus for the chapter, what the chapter provides and finally a brief sense of the overall observations and arguments made in relation to the issues of focus. The summary will not provide an in depth discussion of any of the key issues of focus, arguments or findings. It only serves to indicate what the book offers.

Chapter One: Biotechnology and Agricultural Development, Robert Tripp
Under a clear November sky, a group of West African farmers take a break from harvesting their cotton. The men survey the crop and dare to hope that the harvest will be better than last year, when a drought meant they were barely able to repay their loans for the expensive inputs used to produce cotton. The women participate in the harvest even though some of their own food crop fields still need attention and there are scores of tasks to be done at home. They need a good harvest, because cotton offers one of the few possibilities for earning the cash that is used to pay school fees and buy medicine and other essentials. In addition to their concerns about the harvest and the price they will receive, these farmers now find themselves at the centre of a worldwide controversy about agricultural biotechnology. The news they get on the radio and in discussions with other farmers is difficult to interpret, and the debates mostly take place far away, but the farmers hear there is a new type of cotton that resists some insects and lowers their need to buy insecticides. Some people argue that this will help them save money and keep up with other cotton-producing countries, while others say that it will put them at the mercy of powerful foreign companies and untested technologies.

The controversy goes well beyond genetically modified (GM) cotton and West Africa, and it has fundamental implications for the role of agricultural technology in poverty reduction. This book examines the experience of GM cotton in developing countries and draws lessons about the relevance of agricultural biotechnology for resource-poor farmers.

The term biotechnology can refer to a wide range of techniques that use biological processes for practical ends, including such long-standing practices as fermentation. But the more common references to biotechnology are often limited to a series of recent advances in molecular biology. The capacity to understand and describe the genetic makeup of an organism and, increasingly, to be able to manipulate genetic material has tremendous implications for medicine, industry and agriculture. The discoveries of this rapidly growing field have elicited a mixture of wonder, hope and apprehension, ensuring that biotechnology will be a subject of discussion and debate for the foreseeable future. While some aspects of modern biotechnology are relatively uncontroversial, the techniques of genetic engineering, and particularly the transfer of genetic material from one organism to another, have been the focus of considerable contention.

Many people in industrialized countries are sufficiently familiar with the concept of genetically modified organisms (GMOs) to at least offer an opinion on this complex subject. The degree of concern and attention is variable, however. Applications in medicine seem relatively well accepted. Several therapeutic proteins such as insulin and interferon are now regularly produced by GM bacteria, and vaccine for hepatitis B is manufactured using GM yeast cells (Han 2004). Applications in the food industry are also becoming commonplace; in cheese making, the enzyme chymosin produced by GM microorganisms is increasingly utilized in place of the traditional rennet (Adams and Moss 2008). News reports of the genetic manipulation of insects, trees, fish and mammals appear with increasing frequency, describing discoveries that are potentially life saving (mosquitoes unable to transmit the malaria parasite), profitable (trees that provide better pulp for paper making), frivolous (fluorescent tropical fish) and bewildering (goats whose milk contains spider silk), and these are usually met with relatively muted reaction. But no such complacency is evident when it comes to GM crops, which have always been at the centre of the controversy surrounding biotechnology.

It is not difficult to understand why transgenic crops attract considerable opposition. In North America and Europe, an increasingly urbanized population takes advantage of low food prices that are the result of industrial agriculture, but feels anxious about the demise of the family farm. In these circumstances, opportunities to defend the virtues of traditional farming are welcome, and the countryside offers strong symbolism in battles over globalization. In addition, there is measurable evidence of environmental damage caused by some modern farming techniques, compounded by several high-profile food scares, making consumers nervous about their industrialized food supply. The appearance of technology based on genetic manipulation and promoted by large chemical companies is not likely to make them feel any more confident, especially when the innovations (such as herbicide-tolerant varieties) are difficult to interpret or to recognize on the dinner table. And when the multinational corporations appear to be moving towards control of seed supply, concern can only grow.

But transgenic crops have also received considerable support. The majority of agricultural researchers and educators are favourably disposed to transgenic crops, although there are significant differences of opinion among them. Even though the current transgenic varieties are essentially confined to a few traits (particularly those expressing insect resistance or herbicide tolerance), there is evidence of positive environmental benefit, and agriculturalists look forward to a greatly expanded range of crop varieties that address some of farming's toughest problems, such as drought, as well as offering important consumer qualities such as nutritional content. The majority of farmers who have had access to transgenic crops have taken them up with enthusiasm. It is estimated that in 2007, 12 million farmers in 23 countries grew 114.3 million hectares of GM crops (James 2007). Both sides battle for public opinion, and although the early examples of transgenic crops were those designed for, and grown in, industrialized countries, the debate quickly involved the implications for farmers in developing countries. At times the battle has taken on moralistic dimensions. Monsanto's slogan for awhile was the pious 'Food, Health, Hope'; non-governmental organizations (NGOs) countered with campaigns such as Christian Aid's (1999) 'Selling Suicide'. Of course not everyone has seen the issue in such confrontational terms; more balanced reviews expressing varying degrees of support and caution about the new technology were produced by a number of organizations, including Oxfam (1999), The Nuffield Council on Bioethics (1999) and The Royal Society (2000). But the struggle to win public support is not likely to depend merely on the strength of evidence; the debate over GM crops obviously draws on much broader concerns than mere agricultural technology. A number of recent publications examine the way that the arguments in the debate over GM crops are constructed (Cook 2004; Panos 2005; Pearson 2006).

Despite the considerable emotion generated by the controversy, policymakers have to weigh the evidence (and the public's reaction to it) to make decisions about a nation's strategies towards GM crops. This is particularly challenging for developing countries, with diverse agricultural systems, pressing production needs, uneven records of serving their farming populations and often considerable susceptibility to the pressures of multinational corporations and international NGOs. Of course the circumstances vary greatly, and some countries such as India, China or Brazil have advanced technological capacity of their own and corresponding policy independence. But even here, the choices are not clear-cut; a recent study in India describes the commercial, political and technical forces that influence the intricate, and sometimes contradictory, policies at both state and national level that influence the promotion of transgenic crops (Scoones 2006). But as experience grows with transgenic crops in both developing and industrialized countries, there are increasing opportunities for assembling evidence that will be useful for the policy process.

There are at least two important types of evidence that policymakers need to consider in making decisions about transgenic crops. One set of information is the data available on what might be called the externalities of transgenic crops – their effects on the environment and human health and the status of corporate control of agricultural technology. The second set of information is the impact that transgenic crops have on farmers and the agricultural economy. Although we will see that there is a significant area of intersection between the two concerns, it is the second that occupies most of the attention of the present book, which is specifically focused on the experience of resource-poor farmers in developing countries with this new technology.

The book examines one example of agricultural biotechnology: transgenic, insect-resistant cotton. (The technology is introduced at the end of Chapter 2 and described more fully in Chapter 3.) It focuses on the performance of this technology in developing countries. Given the breadth of issues related to biotechnology and the depth of the controversy that the subject engenders, it is important to provide the reader with a clear view of the assumptions that motivate the presentation that follows. The study has been conducted with an appreciation that biotechnology may be able to make significant and positive contributions to agriculture, but with a willingness to incorporate new evidence and to examine the priority currently assigned to transgenic crops. The narrow focus will not allow sweeping judgments certifying that transgenic crops are good or bad, appropriate or inappropriate. Given the complex nature of the arguments surrounding biotechnology, decisions about its future must ultimately be made by well-informed citizens in appropriate political forums.

Moreover, in focusing on developing countries and resource-poor farmers we are compelled to recognize the many factors that contribute to promoting equitable agricultural development. In that context, it is worth asking whether the introduction of a technology (no matter how ground breaking) would bring about meaningful improvements unless appropriate policies and institutions are also in place. Although it is certainly legitimate to promote specific policies that directly affect the introduction of biotechnology (Paarlberg 2001, 2008; Fukuda-Parr 2007), our conviction is that a much broader set of considerations must be addressed if this, or any, agricultural technology is to realize its full potential. This is especially the case if we are concerned about the fate of resource-poor farmers and the reduction of rural poverty. Simplistic support or opposition for a technology can mislead policymakers and donors by promising straightforward solutions to complex problems. Hence the analysis in this book emphasizes that expectations and apprehensions about biotechnology's relation to agricultural growth should be examined in a broad context that includes factors such as the organization of small-scale farming, the conduct of agricultural input and output markets, and the governance of technology generation.

With those considerations in mind, the rest of this chapter reviews three elements that contribute to the context of decision making about agricultural biotechnology. First, we briefly consider the ways in which technology can be seen as a driver of agricultural change and the extent to which a 'revolutionary' idiom is useful. Second, we examine some of the major concerns about the relationship between transgenic crops and the environment, human health and corporate control. These are not issues that the book's country case studies can address in any detail, but it is useful to examine them in relation to other instances of technological change and the nature of the agricultural institutions that are the book's concern. Third, we set the scene for the focus of the rest of the book by outlining the issues that should be taken into account in assessing the impact of a technology on resource-poor farmers and the agricultural economy. That discussion will help steer a course for the remaining chapters that avoids the temptation to make broad judgements about biotechnology, but attempts to use an analysis of how technology performance is shaped by local institutions in order to identify practical implications for agricultural policy.

Based on the considerations of technology as a driver of agricultural change and the utility of revolution paradigm, this chapter makes the following observations and arguments.

Commentators and authors have adopted various approaches in addressing this subject. The image of revolution is frequently used by the technology's champions to characterize the potential impact such crops might have for farmers in developing countries. This book will adopt a different approach. While not denying the novelty of transgenic crops, we emphasize that many of the economic, political and environmental challenges raised by the new technology are similar to those raised by more conventional technology. This stance is not meant to detract from the urgency of addressing technology-specific concerns but rather to underline the value of looking at the broader policies and institutions that govern technology generation for agricultural development.

Agricultural history has been punctuated by periods of fairly rapid technological change which may merit the term 'revolution', and biotechnology may occasion similar transformations, but there is value in recognizing the fact that single technologies are rarely responsible, by themselves, for bringing about significant agricultural advance. Technological change is usually more iterative and complex, and its impact on smallholders depends on the performance of institutions that govern access to markets, land and other resources. In addition, farmers' ability to take control of a technology and incorporate it in their production system depends on the responsiveness of the institutions responsible for carrying out research, providing information and offering a regulatory framework for input and output markets. These are the very institutions that are at the centre of debates about biotechnology, emphasizing that the relatively narrow concern of the impact of transgenic crop varieties should be approached by looking at many of the policies and institutions that govern broader agricultural development.

The book is organized in the following way. Chapter 2 provides an introduction to cotton, briefly reviewing the history of its cultivation, the institutional factors that determine production practices, the

governance of technology generation and the development of transgenic, insect-resistant cotton. Chapter 3 provides a review of the agronomic literature on the types, performance and sustainability of transgenic, insect-resistant cotton. Chapter 4 summarizes the literature on the farm-level impact of the introduction of transgenic cotton, focusing on yields, costs and variability of outcomes. Chapter 5 looks at the institutional correlates of the introduction of transgenic cotton, with particular emphasis on the seed and input industry, intellectual property regimes, input delivery and farmers' access to information.
The second part of the book is devoted to original case studies that examine the performance of transgenic cotton in developing countries. Chapter 6 reviews the data available about transgenic cotton in China but concentrates on the results of a study that examines cotton farmers' input choices. Chapter 7 reports a comprehensive study of the experience with transgenic cotton in two contrasting areas of India: Gujarat and Maharashtra. Chapter 8 summarizes a recent study of the performance of transgenic cotton in Colombia's two major cotton-growing regions. Chapter 9 provides a thorough review of the experience of smallholder cotton in South Africa. Chapter 10 provides a summary of the results from the case studies and discusses more general implications for policies and programs in support of smallholder agriculture in developing countries.

Chapter 2: Cotton Production and Technology, Robert Tripp

If genetic engineering is a technology fraught with controversy and symbolism, it would be difficult to find a more perfectly matched crop than cotton. Cotton cultivation has been at the heart of some of the world's most inequitable regimes and is a subject of debates regarding environmental pollution, peasant exploitation and the injustices of world trading systems; at the same time, cotton is a natural fibre whose cultivation can allow farmers in developing countries to take advantage of domestic and international markets and to achieve productive livelihoods. Just as the previous chapter tried to situate the subject of genetic engineering within broader concerns of agricultural policies and institutions, this chapter will try to identify those aspects of cotton cultivation that are major factors in the governance of cotton technology generation and use.

This chapter begins with a very brief review of the history of cotton cultivation and its potential contribution to livelihoods in developing countries. This is followed by an examination of some of the specific characteristics of cotton cultivation that help determine the type of technology available to farmers, in particular access to markets, labour and input credit. The discussion then shifts to review specific aspects of cotton production technology, particularly variety development, seed provision and crop management, with particular emphasis on insect control. The concluding section introduces the technological innovation that will be the subject of the remainder of the book: transgenic, insect-resistant cotton.

Cotton cultivation has been an important economic activity in both the Old and New Worlds for thousands of years. As textile industries grew and became more specialized, increasing demands were placed on cotton production. Where farmers benefit from equitable political and economic regimes, cotton cultivation offers opportunities for rural development. But the viability of smallholder cotton production in such circumstances depends to a considerable extent on the provision of adequate technology, which in turn depends on a range of institutions, including public and private research, input and credit markets, regulatory and intellectual property regimes, information provision, and farmer organization. Policies in support of agricultural development must envision a strategy that draws on these institutions.

Table 2.3 Area in hectares (and per cent of total cotton area) planted with transgenic, insect-resistant cotton, (single trait or stacked), by year

Country	*2004*	*2005*	*2006*	*2007*
China	3,700,000 (66%)	3,300,000 (65%)	3,500,000 (66%)	3,830,000 (69%)
India	1,307,000 (16%)	3,247,000 (38%)	5,423,000 (65%)	6,475,000 (73%)
Argentina	54,000 (20%)	51,000 (13%)	25,000 (8%)	91,000 (22%)
Colombia	11,436 (17%)	25,910 (35%)	23,691 (42%)	20,883 (45%)
Mexico	65,231 (60%)	79,824 (61%)	54,750 (47%)	58,619 (53%)
South Africa	28,932 (81%)	13,275 (61%)	14,310 (79%)	10,113 (89%)
Australia	58,057 (29%)	214,662 (70%)	247,295 (78%)	131,688 (80%)
USA1	2,903,836 (54%)	3,465,461 (61%)	4,019,620 (66%)	3,267,642 (75%)

Source: National statistics and estimates collected by country consultants. (Includes estimates of legal and illegal planting.)
Note:
1 USA is for upland cotton only, based on data from AMS (Agricultural Marketing Service), various years.

Cotton technology development was initially the province of innovative farmers, who selected superior varieties and devised improved methods of crop management. By the late nineteenth century publicly supported agricultural research began to contribute to technology generation, and this was complemented by private investments in plant breeding and later in the development of crop management inputs. The extent to which these research innovations benefit smallholders is related to the responsiveness of public research institutions and the transparency and efficiency of private input markets. Both input and output markets are usually subject to some type of regulation, but regulatory regimes can be constituted in a manner that promotes the interests of the politically powerful or they can be more supportive of farmer concerns. Agricultural technology is increasingly subject to intellectual property rights, which need to strike a balance that provides adequate incentives for innovation while protecting farmers' interests. Similarly, the provision of information by public extension needs to be managed to strike a balance between providing authoritative technical advice, on the one hand, and building farmer skills and capacities, on the other. The extent to which new technology can serve the needs of smallholders thus depends on various dimensions of farmer control, reflected in the effectiveness of public research, the equitability of markets, the reflection of farmer interests in regulatory regimes, and the capacity of farmers to demand and utilize new information.

Control of technology is a function of the balance of power among public institutions, private enterprises and farmers. This balance is subject to realignment with the advent of transgenic crops and deserves careful attention. Certainly, the most interesting example to date for developing countries is transgenic, insect-resistant cotton. Most cotton farmers are already dependent on input markets for seed, fertilizers and pesticides, so we can see how transgenic cotton affects existing input provision systems. Insect control is one of the most intractable problems facing cotton farmers, and it is important to understand how they adapt the innovation to their production systems. Chapter 3 looks more closely at the technology itself and Chapters 4 and 5 examine the literature on the first several years of transgenic cotton cultivation. The rest of the book provides updates on more recent experience with the technology.

Chapter 3: Agronomic Performance, Ann M. Ahowalter, Shannon Heuberger, Bruce E. Tabashnik, Yves Carriere

Transgenic cotton producing insecticidal toxins is a highly effective technology in the battle to control pest damage to cotton. However, its effective deployment requires an understanding of the methods used for developing transgenic cultivars, the types and efficacies of available toxins, the factors that affect the expression of those toxins in different cultivars and environments, and the adjustments to crop management practices that may be required in some growing conditions. In addition, because insects are capable of evolving resistance to transgenic toxins, its deployment requires careful research to identify appropriate resistance management strategies.

The development of transgenic cultivars is a long process, requiring many steps of selection and testing. The process can produce cotton cultivars with a wide range of agronomic characteristics, but like all plant breeding efforts, transgenic cultivars must be targeted towards specific environments and conditions. A limited but growing number of toxins have been used in transgenic cultivars. Each toxin or combination of toxins targets specific types of insects, with various levels of efficacy. A toxin's efficacy is determined in part by several factors affecting transgene expression, which may vary temporally and among cultivars and plant parts. Transgene expression can also be affected by temperature or nitrogen availability. The performance of a transgenic cotton cultivar is influenced by the type and degree of pest pressure during the growing season. One of the benefits of transgenic cotton is that it usually allows farmers to use less synthetic insecticide. This can facilitate a resurgence in the natural predators of other pests or contribute to lowering insecticide resistance in target pest populations. However, reduced insecticide use can also allow secondary pests previously controlled by synthetic insecticides to become more prevalent.

Even when appropriate transgenic cultivars and crop management practices have been identified for local growing conditions, resistance management is needed to enhance the sustainability of the technology. The most common strategy for delaying evolution of insect resistance is the deployment of refuges of non-transgenic cotton or other suitable host crops. The design of appropriate refuge strategies depends on the biology of the target insect and the inheritance of its resistance to the toxin. This information is used to identify the type, size and crop composition of the refuge.

Overall, transgenic cotton can be very effective and, as with any new technology, care must be taken to appropriately integrate the technology into existing agricultural practices. Careful choice of cultivars is required to match local growing conditions, and appropriate transgenes need to be identified to target specific pest problems. Transgene expression and toxin efficacy in different genetic backgrounds, environments and crop management practices need to be more fully understood. The investment in developing and deploying appropriate transgenic cultivars must be matched by a commitment to design and implement resistance management strategies. Although much of the initial research on transgenic cotton may be done elsewhere, the ability to take full advantage of transgenic cotton cultivars depends on local research and technical capacities and on the availability of adequate information for farmers.

Chapter 4: Assessing Economic Performance in the Field, Robert Trip

The purpose of this chapter is to review information related to the performance of *Bacillus thuringiensis* (Bt) cotton during the early years of its cultivation in order to examine the impact on smallholder farmers. We will consider data on farm-level outcomes (yields, costs, pesticide use) and analyse adoption patterns. In Chapter 5 we will assess the nature of technology development, input markets, information provision and regulatory performance. Both chapters are based on a review of published literature and surveys of current usage of Bt cotton in the eight countries that have been growing the crop for at least five years.

Assessing the impact of a transgenic crop can be an exceptionally complex task, even if the analysis is focused, as it is here, on the implications for resource-poor farmers. Although it would appear a simple matter to compare the results (yields, income) of those farmers who use the new technology and those who don't, there are many complications. First, agricultural seasons are characterized by great variability (in rainfall, insect populations, etc.) so the results from any one year may not be representative. Second, the farmers who are the first to adopt a new technology may have other practices or resources that set them apart from their neighbours, making a side-by-side comparison problematic. Third, the adoption of a new technology may be so rapid that there are few farmers left to serve as a control group; there are several instances where this is the case for Bt cotton. Fourth, a technology such as Bt cotton is not so much yield-enhancing as yield-protecting, and its efficacy will depend on the level of pest attack and the use of other pest control practices. All of these factors can be addressed to some extent by careful survey design and statistical methods, as well as by the use of as broad a range of data as possible. Nevertheless, we must be aware that this type of impact assessment is an imperfect process. In addition, the agronomic and genetic factors discussed in Chapter 3 may be responsible for significant differences in performance between Bt varieties, or may interact with differences in crop management.

Besides the problems of dealing with dynamic and variable farming practices and circumstances, there are other methodological problems in assessing farm level technology impact (Smale *et al.* 2006a). These include: problems in sampling; reliance on partial budgets that do not provide a comprehensive assessment of all the factors that affect farm-level decision making and household welfare; inadequate treatment of externalities affecting the environment or health; and inadequate treatment of institutional factors affecting the provision of the technology or the marketing of outputs. The analysis provided in this book cannot hope to deal with all of these factors, although we will try to pay particular attention to institutional concerns in the following chapter.

It is impossible to provide a simple assessment of the field-level impact of a technology such as Bt cotton. Its introduction to a wide range of farming environments, through many different commercial cotton varieties and seed provision strategies, has yielded various results. Although the technology has proven generally successful in providing additional protection against several important cotton pests, the implications of this performance have been variable. In situations where farmers had used large amounts of insecticide to control these pests, there was usually a significant reduction in expenditure and often a modest increase in yield. In situations where fewer resources were normally devoted to insect control the major impact was often an increase in yield, as the Bt toxin provided extra protection. Such gains are welcome, although the net economic impact depended to a great extent on the cost of the technology, and in cases where this was high the financial gains were sometimes less than might have been expected. As with most agricultural technologies, the impact of Bt cotton is also affected by variations in local conditions (e.g. pest populations, weather) and by various tradeoffs (such as those implied by the choice of particular varieties or pest control regimes). Nevertheless, the balance of the experience in those countries that have had the chance to test Bt cotton is that farmers have favoured the technology, often enthusiastically, and rates of adoption have increased over time.

These general observations are also relevant for the experience of resource poor farmers, but some additional concerns deserve attention. Although Bt cotton can help make up for inadequate pest control practices, in situations where poor cotton management or unfavourable climate result in low yields, the impact of this technology will be modest or variable. Although the technology provides inbuilt resistance against certain insects, this protection must be purchased before planting; the higher the price, the riskier the decision for a resource-poor farmer.

In addition, the technology must be provided in cotton varieties that are well adapted to farmers' conditions, and those farmers must have enough information to allow them to choose the most appropriate seed. They must also know the capabilities and limitations of the technology and be able to adjust their management practices accordingly; Bt cotton can be a valuable component of a crop protection strategy, but it cannot substitute for the skills and knowledge required to address broader pest management challenges.

The impact of Bt cotton on the productivity of smallholders thus depends to a considerable extent on the conditions under which the technology is made available to them. The local seed industry must be able to offer appropriate cotton varieties, and this requires access to plant breeding capacity and a supportive intellectual property regime. The industry must be sufficiently competitive so that resource-poor farmers can afford the technology. The input delivery system must be competitive and transparent and farmers must have access to sufficient information about the products on offer. And farmers' ability to integrate Bt cotton into their pest control strategies requires access to good quality crop management information and experience. These conditions are determined by local agricultural institutions, and Chapter 5 looks at how those institutions have contributed to the recent experience with Bt cotton.

Chapter 5: Institutional Performance, Robert Tripp

This book emphasizes that the impact of an innovation such as Bt cotton should not be assessed simply in terms of yields or production costs but also with respect to the interactions with the institutions that govern farmers' access to the technology. This chapter reviews the literature and presents other relevant information on the major institutional consequences of the early years of Bt cotton production. The issues examined include: the effect on the seed and input industry, the role of intellectual property regimes, the organization of input delivery and farmers' access to information for managing the new technology.

Adequate institutions are required to support farmers' use of a new technology such as Bt cotton. The performance of such institutions determines the extent to which small farmers are able to gain access to, and gain some control over, the technology.

Transgenic technology must be incorporated into plant varieties well adapted to local conditions and this implies that plant breeding capacity must be available in the local public or private sector. Small countries with correspondingly limited seed markets face particular challenges and the experience to date with Bt cotton is that such countries may have to rely, at least initially, on varieties provided from elsewhere. Countries without a strong local seed industry will be less able to take advantage of Bt cotton and adapt it to local circumstances.

Competition among seed companies is important. In countries with large markets, technology owners have licensed the transgenes to various seed companies who incorporate them in their own varieties. The ability to license technology and maintain a competitive seed market depends on the existence of some type of intellectual property protection mechanisms or other regulation or legislation that prohibits unauthorized appropriation of the technology. There is a delicate balance, however, between providing enough protection so that innovators have adequate incentives and seed producers are not subject to unfair competition; and ensuring that the advantages of the initial technology provider are not converted into a monopoly.

Issues of regulation and competition are also relevant for input delivery. Input supply is particularly important for cotton farmers, and even though Bt technology may lower the use of insecticides, most cotton farmers still depend on external suppliers for a range of inputs. Such supply may be organized through the state, the private sector or various types of producer association. In all cases, adequate transparency and choice are required so that farmers have a range of options and opportunities to learn from experience in order to improve their production efficiency. The evidence to date indicates that the introduction of Bt cotton has not generally been accompanied by improvements in the provision of inputs for cotton farmers.

The performance of the seed sector, the adequacy of legal and regulatory systems, and the organization of input delivery mechanisms have an impact on the quality of information available to farmers. We have seen that cotton pest management is an exceptionally complex challenge and even though innovations such as transgenic insect resistance can make an important contribution, cotton farmers still need both opportunities to strengthen their own capacities and access to reliable advice. Again, there is little evidence that the initial introduction of Bt cotton has been accompanied by significant improvements on these fronts. As we have seen, there are significant differences among the countries that use Bt cotton, and the rapidly growing use of the technology has had important interactions with local institutions. As this book is most concerned with the impact of transgenic cotton on smallholders, we must look in greater detail at the most recent developments in those countries where smallholders have experience with Bt cotton.

The following chapters (6–9) provide a summary of the recent experiences of smallholders growing Bt cotton in China, India, Colombia and South Africa. They provide further evidence of the role of local institutions in determining the effectiveness of new technology.

Chapter 6: China, Jikun Huang, Ruijian Chen, Jianwei Mi, Ruifa Hu, Ellie Osir

China's biotechnology program has grown into the largest such initiative in the developing world. A study by the Center for Chinese Agricultural Policy (CCAP) shows that the government's annual spending on agricultural biotechnology reached 1.65 billion yuan in 2004 (equivalent to US $199 million). The Chinese program has generated a wide array of new technologies. Genetically modified (GM) varieties of more than 20 crops have been approved for environmental release and/or field trials. By the end of 2006, China's Biosafety Committee (CBC) received more than 1,500 applications and approved 1,024 of these for trails or commercialization. Among this growing range of crops and technologies, *Bacillus thuringiensis* (Bt) cotton is the most prominent example.

Farmers were introduced to Bt cotton varieties in 1997, some containing a transgene developed by the Chinese Academy of Agricultural Sciences (CAAS) and others containing Monanto's transgene. Bt cotton spread rapidly in Hebei, Shandong and Henan, in China's northern cotton belt. By 2001, it accounted for 99 per cent of the cotton area in Hebei and 97 per cent in Shandong. In Henan it covered 90 per cent of the cotton area by 2005. Bt cotton was introduced in 1998 in the southern provinces of Anhui and Jiangsu. By 2007, Bt cotton accounted for 85 per cent of total cotton area in Anhui and 92 per cent in Jiangsu. There are also small amounts of Bt cotton planted elsewhere including Xinjiang in the West where bollworm is not a serious problem and Bt cotton is not recommended. By 2007, Bt cotton cultivation had expanded to 3.8 million ha, accounting for about 69 per cent of cotton area. The cotton holdings in China are very small; a survey by CCAP in 2007 found the average size of cotton farms (including cotton and non-cotton land) was only 0.75, 0.67 and 0.50 ha in Shandong, Henan and Hebei, respectively. It is estimated that more than 7 million smallholder farmers grew Bt cotton in 2007.

Previous studies have shown that Bt cotton has significantly raised cotton productivity and farmers' income. Farm-level surveys in northern China show that the adoption of Bt cotton has raised cotton yields and allowed farmers to reduce their insecticide use (Huang *et al.* 2002c, 2004). Moreover, farmers planting Bt cotton report fewer incidences of poisoning from insecticide applications (Huang *et al.* 2002c; Hossain *et al.* 2004).

Despite these large gains from Bt cotton, there are questions regarding farmers' ability to take full advantage of the technology. China's seed industry is growing and diversifying, and an increasing number of Bt cotton varieties are available, but it is not clear if the seed market is sufficiently transparent and well regulated to provide farmers with enough information about the products on offer. How do seed markets operate in China and how do they affect farmers' selection of Bt cotton varieties? Are there differences in the quality and performance of seed from different sources? How do farmers make decisions on the seeds they plant? Answers to these questions are important for policy makers interested in reforming China's seed sector.

Similar questions can be asked about the extent to which Bt cotton has allowed Chinese farmers to adopt more efficient insect control practices. Despite the fact that Bt cotton significantly reduces insecticide use, several studies show that farmers are still overusing insecticides to control cotton pests (Huang *et al.* 2002b; Pemsl *et al.* 2005). How do insecticide markets function and how do they affect farmers' purchasing habits? What are farmers' sources of information for making decisions on the type and amount of insecticide to be used? How do farmers decide to apply insecticides to control pests in their fields? Answers to these questions are required to enhance the extent to which Bt cotton can reduce insecticide use.

The goal of this chapter is to answer these questions about the seed and insecticide input sectors and their impact on Bt cotton practices. The chapter is organized as follows. The second section describes the data used in this chapter. The third section discusses the evolution of China's seed sector and particularly the cotton seed market. The fourth section examines farmers' seed practices, including seed purchasing, the nature of local seed markets, farmers' knowledge of varieties and the performance of different varieties in farmers' fields. The fifth section analyses the nature of the insecticide market, discusses issues related to insecticide choice and examines farmers' decisions regarding insecticide use. The last section concludes with a summary of major results and policy implications.

Bt cotton has made a significant contribution to Chinese cotton production. Introduced at a time when bollworm damage and increasing insecticide use were threatening the future of the industry, the new technology provided effective pest control and allowed farmers to increase their productivity. The technology spread rapidly through those cotton-growing areas where it was most needed. But a decade after its introduction it is time to assess what has been learned and to identify policy priorities.

Bt cotton spread so rapidly because publicly available transgenes were available to seed companies while China was experiencing the emergence of the private seed sector. If Monsanto's joint ventures had been the only source of Bt seed then the technology would have spread more slowly, but public biotechnology research also provided Bt transgenes to plant breeding institutes and seed companies who incorporated them in new varieties. A large number of small and medium-size companies ensured that seed was widely available. But both the multinational's and the public sector's technologies were used by many seed companies without authorization, and without compliance with China's seed and biosafety regulations. The short-term result for farmers has been largely positive, with wide availability and low seed price. But the seed market has become so complex that farmers have trouble identifying superior varieties and often prefer to save the seed of the varieties that perform well. In addition, neither private nor public research has sufficient incentives to introduce new technology if they feel that any licensing agreements will be violated in an unregulated seed market.

Privatization also benefited the pesticide sector, and Chinese farmers have wide access to products at low prices. But these low prices encourage over-use, and although Bt cotton greatly reduced the need for insecticide, there is evidence that farmers are still using more chemicals than they need to control pests. In addition, the unregulated use of trade names and (until recently) the lack of a requirement to describe an insecticide's active ingredients on the label mean that farmers have little ability to identify high-quality products or to learn from their experience.

These conditions help us identify several areas that deserve the attention of policymakers. First, reforming agricultural input markets is a high priority. Both seed and pesticide markets need to be made more transparent. China's seed and biosafety regulations were designed to support a competitive seed sector, but there has been little enforcement. Similarly, new regulations in the pesticide sector are well intentioned, but must be backed up by adequate enforcement. The unrestricted proliferation of seed and pesticide firms is not necessarily compatible with a competitive and efficient input market. It may be that further regulations are necessary, or that more restrictions are needed to control market entry, but investment in on-the-ground enforcement capacity for regulations already in place would be an important step forward.

In addition, it will be necessary to strengthen consumer capacities. Farmers find it difficult to identify reliable products in the input markets. The enforcement of regulations should put pressure on businesses to develop commercial reputations that help farmers recognize the seed or chemical companies that are in the market. Attention could also be given to helping input dealers acquire more information about their products so that they can advise their customers.

But it will not be possible to rely solely on a well-regulated private input market to provide sufficient information. The public extension and research services need to offer more information to farmers about the crop varieties and crop management technology that is available. Farmers should have more access to tests and demonstrations of new technology. The recent policy to stop extension agents earning part of their income from commercial activities in input and output markets is welcome and should be enforced in its implementation. In addressing complex problems such as pest control in cotton, extension stations need to be supported to help farmers learn how to take best advantage of agricultural input markets and to improve their own crop management skills.

Chapter 7: India, N. Lalitha, Bharat Ramaswami, P.K. Viswanathan

India grows more *Bacillus thuringiensis* (Bt) cotton than any other country in the world. While this is partly a reflection of the fact that India is the world's largest cotton producer, it is also an indication of the rapid spread of the technology since it first became available in 2002. While India was cautious in introducing the technology, it has subsequently found wide acceptance among farmers.

Cotton is grown on 9.5 million ha by about 4–4.5 million farmers (with an average cotton holding of little more than 2 ha) in nine states in India. Although it has the largest cotton area, India's production has been characterized by relatively low yields, reflecting the marginal environments in which much cotton is grown, the fact that only about one-third of the crop has access to irrigation, and inadequate crop management. However, the introduction of Bt cotton has coincided with increasing cotton yields and production in the past few years.

In this chapter we are particularly interested in the seed and pesticide markets that help determine farmers' ability to take advantage of Bt cotton. The goal is to understand whether there are gaps in the information utilized by growers in making decisions about crop management. These gaps could arise because of market failures or deficiencies in other institutions such as government regulation, product testing and agricultural extension.

The chapter is based on a farm-level survey carried out during the 2007–08 cotton season in two states, Gujarat and Maharashtra. Although cotton is widely grown in India, these two states together accounted for 55 per cent of cotton output and 60 per cent of cotton area in 2007. In addition, they provide a useful contrast for the study; Gujarat is one of the more advanced cotton-growing states, with widespread access to irrigation, while Maharashtra is home to many of the most resource-poor cotton growers, farming on marginal land. An additional contrast is that Gujarat is the first place that unauthorized Bt cotton seed was sold, at least as early as 2001, before the release of the authorized varieties. Gujarat continues to have the highest concentration of unauthorized Bt cotton varieties and thus provides an interesting opportunity to follow the progress of an underground seed market.

In Gujarat, the farm survey was carried out in five leading cotton-growing districts (Ahmedabad, Bhavnagar, Rajkot, Vadodara and Surendranagar) which together account for 65 per cent of cotton area in the state. This choice was partly determined by the fact that we had done an earlier study of cotton farmers in these districts in 2003–04 and could thus assess changes in the intervening years. The study in Maharashtra was done in traditional cotton-growing areas in the Vidarbha region, covering five districts (Wardha, Amaravati, Akola, Yavatmal and Buldhana) which together account for about 40 per cent of the cotton area in Maharashtra.

In each district, approximately 40 cotton growers were randomly selected through a three-stage process. Within each district, four *talukas* (an administrative unit smaller than a district) were randomly selected and within each taluka, two villages were randomly sampled. The target was to sample five cotton growers within each village. In Maharashtra, the sample design accommodated more than five growers in some villages because of concerns over attrition during the length of the survey.

The study involved three visits to each farmer. The first visit took place shortly after planting and data collection focused on farm and household characteristics and current and historical variety choices. The second visit came during the growing season and focused on insect control practices, including a careful recording of all use of insecticide. (Farmers had been provided with notebooks during the first visit to help record their insecticide practices.) The final visit was shortly after harvest; it completed the inventory of insecticide use as well as collecting yield and other data. As many farmers have several plots of cotton, we recorded basic data about all the plots. However for detailed analysis on crop management, such as decision-making about seed choices, insecticide practices, harvesting and post-harvest management practices, we focused on a maximum of three plots for each farmer, choosing the largest plots that provided information about the range of variety types the farmer was growing.

The rest of the chapter is organized as follows: we first look at the utilization of Bt cotton by summarizing some of the most important characteristics of the cotton farmers in our sample and the nature of the Indian seed market, followed by an examination of the patterns of Bt cotton adoption and its impacts on yields. The next section looks more closely at how cotton farmers choose the seed they will plant; it reviews the types of Bt cotton available to farmers and then looks at the criteria they use in making seed choices. The following section examines how farmers use insecticides and the relationship between Bt technology and insecticide use. The chapter closes with some conclusions about the ability of farmers to take advantage of Bt technology.

Although debates about approval procedures and environmental concerns meant that India was relatively late in introducing Bt cotton, the subsequent diffusion of the technology has been very rapid. Farmers' willingness to pay a much higher price for the seed (and little evidence that farmers abandon the technology once they try it) indicates that the Bt hybrids contribute to cotton productivity. Our survey data support this conclusion.

One of the reasons that the technology was able to diffuse so rapidly throughout India's varied cotton-growing environments was the long tradition of public sector and, more recently, private sector plant breeding capacity. This meant that a very wide range of germplasm was available that could incorporate the insectresistance transgene. One of the factors that contributed to the technology owner's decision to license the transgene to other seed companies was, paradoxically, an unauthorized plant breeding effort that demonstrated the importance of tailoring Bt varieties to particular environments.

Because India's cotton farmers had long experience with seed markets, and the majority were accustomed to buying commercial hybrid seed every year, the introduction of Bt hybrids did not require any major changes. Nevertheless, farmers' behaviour in Bt seed markets in the two states of this study exhibits important differences, determined in part by the character of the seed market before the entry of Bt and in part by state government policies on regulatory enforcement. Cotton seed markets in Gujarat had been dominated by hybrids from the public seed corporation and a small number of private firms, none of which had immediate access to the Bt technology when it first became available for licensing. This vacuum was filled by the sale of unauthorized Bt varieties that had been developed in Gujarat, and the state government chose not to attempt control of this underground market. As a result, unauthorized varieties constituted the majority of Bt cotton area in Gujarat, and it is only recently that their dominance is declining in favour of seed from authorized companies. Although Gujarat has always been one of the more advanced cotton-producing states, its farmers are slightly behind in learning about what is currently available in the legitimate seed market. In contrast, cotton farmers in Maharashtra had been served by a more diverse set of seed companies before the introduction of Bt technology, and many of those companies were able to bring Bt versions of their popular varieties to market quite quickly. At the same time, the state government adopted a much stricter policy of seed law enforcement, and the sale of unauthorized Bt varieties was discouraged. Because cotton farmers in Maharashtra are generally smaller and poorer than their counterparts in Gujarat, and because they did not have access to the unauthorized varieties, their adoption of Bt technology has been slower, but they have the advantage of facing a seed market that is less confusing than Gujarat's. In addition, they are more conscientious in following refuge requirements. The technology has now spread widely, even among resource-poor farmers, although the small minority who have not yet tried Bt cotton in Maharashtra appear to be those with smaller landholdings.

Cotton seed markets in both states offer farmers many (some would say too many) choices. Nevertheless, there is evidence that in both cases the majority of farmers' decisions to try new varieties are either taken in an attempt to experiment on a fraction of their land or to adopt a variety that has become generally popular in previous seasons. This is not to say that the situation is perfect. Despite the importance of a considerable number of commercial varieties in each state, there are also many lesser-known varieties about which it is difficult to get information. The underground market is particularly chaotic, with a profusion of names and nicknames to describe the products, and this seems to be related to somewhat less precision in the process of variety selection in Gujarat.

Although Bt cotton contributes to yield increases, its original purpose was to lower the requirements for insecticide use. The major differences in insecticide management found in the study are between states and not between variety types. Gujarat farmers used much more insecticide in 2007 than did their counterparts in Maharashtra. We have no evidence on the relative importance of pest pressure or farm management strategies in explaining these differences. The more modest differences in insect management between Bt and non-Bt varieties in Maharashtra is difficult to interpret. The Bt growers spray less frequently than the non-Bt growers for bollworm, but spray more often for sucking pests. On the other hand, the Bt growers make somewhat fewer total insecticide applications and use a considerably lower quantity of insecticides.

It is not clear to what degree the farmers' insecticide practices respond to actual pest pressure or are determined by custom, misinformation or influence from pesticide markets. What is clear is that farmers have many fewer resources and opportunities to test alternative pest management strategies (in contrast to their experimentation and information exchange related to variety choice). There is virtually no extension advice available to help farmers develop more efficient insect control practices, and most information about insecticides comes from dealers. Despite the widespread access to, and productivity contributions of, transgenic cotton, there are few mechanisms that allow farmers to learn how to use the new technology as part of a more rational approach to insect control.

Chapter 8: Colombia, Patricia Zambrano, Luz Amparo Fonseca, Ivan Cardona, Eduardo Magalhaes

Colombia has a long tradition of growing cotton. In the 1970s cotton was the nation's second most important crop, after coffee, but its place in the rural economy gradually declined. The current annual production of about 45,000 mt of fibre is only one-quarter of the output registered in the days when cotton was at its peak. However, the Colombian government has recently placed renewed emphasis on the crop, recognizing cotton's important role in generating rural employment and its contribution to the country's textile, apparel and fashion industries.

Colombia has two distinct cotton-growing regions. About 60 per cent of the national harvest comes from the northwest of the country, on the Atlantic coast, where the crop is planted from July through October and harvested in January through March. The remaining 40 per cent of the cotton harvest is from the south-central interior of the country, where cotton is planted in February or March and harvested in July through September.

Phytosanitary regulations require that all farmers register their cotton plots with one of the local cotton associations, and almost all farmers are affiliated to one of them. An umbrella organization, the Colombian Cotton Confederation (CONALGODÓN), represents the majority of these producer organizations. It promotes the interests of cotton farmers and ginneries in discussions with the government and with others in the textile industry. It negotiates with the industry and the national government regarding the domestic price paid to farmers and it manages a fund based on a cotton production levy (0.5 per cent of the value of fibre and 1 per cent of the value of cotton seed) that is used to support research and development in the cotton sector and the provision of information. It also collects and analyses statistics on the national cotton sector and promotes the use of Colombian cotton.

As part of its efforts to support the cotton sector, the Colombian government entered into discussions with Monsanto about the possibility of introducing transgenic cotton. Colombia has a biosafety framework and a Technical Committee for Biosafety has been in operation since 1998, under the leadership of ICA (Colombian Agricultural Institute), the government regulatory authority, with participation from other institutions such as the Ministry of Environment. ICA has a well-established seed regulatory framework and a system for plant variety protection which are quite effective for the country's major commercial crops. In addition to transgenic cotton, Colombia also grows two other genetically modified products, herbicide-tolerant maize and blue carnations.

Monsanto's 'Bollgard' cotton was approved for commercial release in Colombia in 2003 and first planted in 2004. Since that time its use has increased.

This chapter analyses the recent experience with Bt cotton. It is based partly on CONALGODÓN secondary data, but the majority of the chapter reports the results of farm-level surveys carried out during the 2007–08 seasons in the coastal and interior regions. On the coast, the survey was done in the department (*departamento*) of Córdoba, which accounts for the majority of coastal cotton production, and the department of Sucre, which contributes a much lower share of the production but has a particularly high proportion of small-scale cotton farmers. The study also included the department of Tolima, which accounts for about 79 per cent of cotton production from the interior region (see Figure 8.1). The three departments account for more than 80 per cent of Colombia's cotton production.

The next section of this chapter introduces Colombia's cotton farmers and describes how they obtain their inputs. The following section examines the nature of Bt cotton adoption. The next section looks more closely at the economics of cotton production and uses this analysis to help explain adoption patterns. The final section presents some conclusions about the place of transgenic cotton in Colombia.

The farm-level survey carried out during the 2007–08 season in Colombia demonstrated that farmers using Bt cotton had higher yields than those using conventional varieties, and despite generally higher costs of production per hectare, their costs per ton of fibre were lower than those of conventional variety growers. It is not possible to attribute all of the productivity gains of Bt growers to the transgenic technology but it would certainly appear that it has made a positive contribution to those who have been able to use it.

The results of a single year's survey are not conclusive, given the many differences in production practices, economic resources and climatic conditions. Nevertheless, the higher productivity of farmers growing Bt cotton is evident across the three departments surveyed. In addition, the fact that farmers using the transgenic technology get generally higher yields is consistent with the results of smaller studies carried out in previous years by CONALGODÓN. However, the yield contributions of the Bt technology are much easier to demonstrate econometrically in the interior region than they are on the coast, where adoption is not as high and a number of other socio-economic and environmental factors played important roles in determining cotton yields during the year of the study.

The nature of the increased productivity is somewhat different from what might be expected. Rather than saving farmers significant investment in insecticides, the technology's principal advantage appears to be its yield enhancement, presumably by providing extra protection from insect attack. Despite this protection against certain insects, Bt growers in two out of the three departments surveyed spent more on insecticides than the farmers growing conventional varieties. Damage from other insects required high investment in chemical control. Much of this higher investment by Bt growers is simply a function of their superior resources and ability to acquire inputs, although some may be related to the fact that the chemical controls eliminated by Bt would have had some carryover effect on other insects, which eventually required attention. In addition, high insecticide application is part of the cotton growing culture in Colombia, and the mere use of transgenic seeds has not yet made a significant change in this practice. Farmers' main complaint about the technology is precisely that the release of the new varieties has not been accompanied by knowledge transfer that would allow better management of these varieties.

The linkage between higher yields and additional investment is confirmed by our analysis of the adoption patterns for the technology. In the first place, the highest rates of adoption of Bt cotton are found in Tolima, which previously suffered the greatest incidence of pests controlled by Bt cotton, particularly pink bollworm and tobacco budworm. In addition, Tolima is the most economically advanced cotton-growing department, where the vast majority of farmers have access to irrigation and modern machinery. On the other hand, the coastal departments that have lower rates of adoption are characterized by rain-fed agriculture and less access to machinery.

These differences between departments are similar to differences noted between adopting and non-adopting farmers. The former tend to have more resources that can be devoted to cotton production, a better standard of living, more education and higher incomes. On the other hand, those farmers who grow conventional varieties tend to be from smaller, more diverse farms that depend to a somewhat greater extent on agriculture as a source of income.

Despite these differences, there are many cotton farmers with relatively small holdings who are taking advantage of Bt cotton. One of the most important factors is the position of the cotton producer association. These producer associations are an important part of Colombia's cotton sector, and their technical and financial capabilities can make an important difference in terms of access to Bt cotton. Those associations that are better organized, more stable and with better access to various sources of credit, are more likely to be able to offer access to Bt cotton. If a smallholder is affiliated to a strong association, this facilitates access to the technology, but many of these farmers are members of smaller and less stable producer associations. The larger associations may offer other advantages as well, such as access to precision seeders that allow farmers to lower the seeding rate for this expensive input. Access to credit is one of the most important challenges for farmers all over the world, and the strategy of grower associations in Colombia goes a long way towards addressing that problem. Attention to smallholders' needs requires strengthening those associations that serve this sector of the farming population.

Bt cotton should allow farmers to make a reduction in insecticide use, but this has not been the case. There are several explanations. One is the continuing presence of other pests, principally the boll weevil but also pests such as armyworm and white fly, which require insecticide applications. A second reason may be the absence of attention to strategies that can lower the dependence on insecticides. Most farmers follow the advice of private extension agents for their insecticide choices, as well as for most other aspects of crop management. Farmers cannot obtain insecticide on credit without the written permission of the extension agent. On the one hand, this system helps guide farmers' control measures and limits the possibility of using inappropriate products. On the other hand, the extension agent has no incentive to teach the farmer or build his or her crop management skills. In addition, the extension agent may be open to influence from input distributors who wish to promote their products. Although the extension agents must behave responsibly (and can be dismissed by the farmer), they also have incentives for recommending more (and more expensive) inputs. It must also be remembered that the association earns part of its income from input sales.

Thus further progress in achieving more rational insect control in Colombian cotton will depend on addressing several challenges. One is finding the right balance between the expert advice of private extension agents (who undoubtedly make a positive contribution) and the necessity of building farmers' own capacities to make judgements about pest control. A second is the challenge of ensuring that the associations that play such an important role in credit provision have incentives that direct them towards sharing the rewards with farmers for lower costs of production (and less dependence on environmentally hazardous chemicals), rather than relying on commissions from chemical sales to earn their profits.
A third challenge is to strengthen the program for boll weevil control that must rely to a considerable extent on farmers' willingness to comply and collaborate, and on the committed support of producer associations.

Finally, the experience with Bt cotton in Colombia has provided an important new technology for cotton farmers, but has revealed weaknesses in farmers' access to seed and their lack of information about options. The transgenic seed requires a significant investment from farmers, and not all of them are able to afford the new varieties. The transgenic varieties are all imported; the company has become essentially a monopoly supplier of seed which allows it to maintain high prices. More important, despite some field days and meetings, most farmers do not have an adequate chance to learn about the advantages and disadvantages of new varieties. There is no independent mechanism that allows widespread testing and evaluation of the varieties offered to farmers. The recent problems with one of the new stacked varieties illustrate this weakness. In addition, there is little incentive to incorporate useful transgenes in locally adapted cotton varieties because of the small size of the market. This is of little interest to the technology owner, and in any case the public research service does not currently have the resources to be a partner in such an endeavour. With innovations such as grower associations and new ways of providing extension, there is certainly the possibility that the Colombian cotton sector could grow back towards its former importance.

Transgenic cotton can make an important contribution here, but more choice, competition, and information for growers can help redress the current imbalance that finds farmers overly dependent on a single technology supplier.

Chapter 9: South Africa, Marnus Gouse

In 1997 South Africa became the first country in Africa to commercially produce a modified (GM) crop, insect-resistant (Bt) cotton. Even though both large-scale commercial farmers and small-scale, resource-poor farmers contribute to the cotton crop, the South African Bt cotton experience has been a subject of international interest because it presents the first case of smallholder GM crop adoption in Africa. Research describing this experience has focused on the Makhathini Flats in northern KwaZulu Natal, one of only two areas in South Africa where small-scale farmers have been producing cotton in a relatively sustainable manner for the past three decades. The majority of the literature has reported impressive adoption rates and positive economic returns, suggesting that South African smallholders benefited from the introduction of Bt cotton. However, some observers have questioned these claims by pointing out that smallholder cotton production in South Africa did not expand (indeed, the total South African cotton area drastically declined) and the programs that provided smallholders credit and extension advice failed after the introduction of the new technology. This chapter endeavours to shed light on the South African Bt cotton experience and to explain the performance of the Bt technology in the historical, political and institutional context of the Makhathini Flats and, more broadly, the South African cotton sector. It begins with an introduction to the South African cotton sector, describes the introduction of Bt cotton and its impact on the seed industry, reviews studies analysing the farm-level impact of Bt cotton and examines the institutions that govern access to inputs and information for South African farmers.

The Makhathini Flats experience has been hailed as proof that GM crops can benefit smallholders in Africa. Research has clearly shown that the Bt cotton technology works and that both large-scale and smallholder farmers can benefit, especially in seasons with high bollworm pressure. The fact that South Africa has a functioning regulatory framework for GMOs made it possible for cotton farmers to benefit from advances in biotechnology. Even though cotton production has decreased significantly over the past decade (due in large part to low relative prices), the market share of GM varieties has not decreased, despite the availability of conventional varieties. In fact, farmers have indicated that if it had not been for these technological advances the decline in the cotton sector would have been much more dramatic. However, while technical solutions can help address problems such as lack of knowledge, limited access to inputs or evolution in pest pressure, it must be stressed that no technology (GM or otherwise) can resolve the fundamental institutional challenges of smallholders and agriculture in Africa. The particular case of the Makhathini Flats, and the wider story of cotton in South Africa, emphasizes that while all agricultural systems require adequate investment and appropriate technologies, their viability is determined by the policies and institutions that facilitate sustainable and profitable production. Trends in agricultural prices tend to be cyclical, and it is quite possible that the South African cotton sector will be booming again in a few years. If that happens, it will be policies and institutions, as well as technologies, that will determine the direction and equitability of cotton farming's revival.

Conclusions, Robert Tripp

This chapter has two purposes. It begins with a brief summary of some of the major findings of the four country case studies, in the context of what was learned from the literature reviews in Chapters 4 and 5, and it then goes on to suggest some broader implications regarding the role of transgenic crops in agricultural development.

There are obvious limitations on the possibilities of drawing general conclusions from just four cases examining a single transgenic crop. In addition, both the crop and the technology of our example have some quite distinctive characteristics, especially in the context of small-farm agriculture. Cotton is a cash crop; farmers are accustomed to using large quantities of purchased inputs to grow the crop, and they are paid for their harvest in accordance with norms and prices determined by a global industry. The technology, for insect-control, addresses a very important problem for growers, but one that is exceptionally complex and admits to no simple, one-shot solutions.

The four countries themselves are also somewhat special, and not perfectly representative of the developing world. China and India are the two largest Asian countries, and between them they include a significant proportion of the world's resource-poor farmers. But both countries have experience and capacity in agricultural technology generation and delivery that is virtually unmatched in the rest of the developing world. The other two examples, Colombia and South Africa, are middle income countries with dualistic agricultures. Although the histories of support to smallholder farming are very different in these two countries, the fact that large-scale farmers are able to exert pressure on governments and technology providers means that smallholders often benefit from the infrastructure and flow of innovations resulting from these demands.

Of course these countries were not chosen at random for our study; at this relatively early stage in the career of transgenic cotton they were virtually the only candidates. They are the 'early adopters', and just as it is useful to ask how the farmers who are early adopters of a technology differ from their neighbors, and what their characteristics indicate about the prospects for broader technology diffusion, we can ask the same question about early-adopting countries. One of the principal messages of this book has been that because these countries have the requisite institutions they have been able to take the lead in adopting transgenic cotton. Similarly, imperfections and past histories of markets, regulations, research and extension lead to inefficiencies that can help explain instances when a country has not been able to take full advantage of the new technology.

The next section reviews the performance of Bt cotton in the four case study countries. The following section summarizes the relationship between the institutions that determine the capacity to manage transgenic cotton and the farm-level results observed in the case studies. Finally, the discussion broadens to explore what the assessment of institutional performance in Bt cotton can contribute to evaluating the prospects for the wider application of transgenic crops for resource-poor farmers.

It is important to emphasize that a few quick changes to allow the entry of transgenic crops is not the answer for promoting poverty reduction among smallholder farmers. The new technology can certainly make a contribution, but much more attention needs to be focused on the development of local institutions. These include institutions that support public and private capacity for technology generation;

technology delivery through markets, extension and regulations; and farmer capacities to demand services, participate in markets and comprehend the technology they are using.

Edgerton (2006) argues that we can be deceived into believing that certain technologies define historical periods, cause revolutionary change and then are replaced by entirely new discoveries. 'In recent years one could be forgiven for believing that there was no invention going on outside information and biotechnology' (ibid: 188). Attention to conventional techniques and infrastructure, and the human capital to support them, is not an attractive prospect for policymakers or donors who want to focus on 'cutting-edge' technology. But in many countries that kind of attention is exactly what is required if transgenic crops are eventually to make a significant contribution to small-scale farming. While we may indeed be on the threshold of the 'Biotechnology Age', the reality of smallholder farming indicates that other conventional technologies will complement, contribute to and (more often than not) be more relevant than transgenic crops for the foreseeable future.

A recent study of technology diffusion in developing countries notes that many older technologies (such as power grids and transport networks) were provided by the state, and their current use within a country is only weakly correlated with income (World Bank 2008). In contrast, many newer technologies require less infrastructure and are often provided by the private sector, but their diffusion is more highly correlated with income. There are a few outstanding examples of rapid diffusion (mobile phones being the most prominent), but the general experience is that although new technologies may achieve rapid initial penetration, they often spread slowly in developing countries. The report identifies a number of factors that influence technology diffusion, including the microeconomic and governance environment, financing for innovation and human capital. Although the study does not include agricultural technology, many of these factors are similar to those identified for transgenic crops. If we see activities such as conventional
plant breeding, seed production and information provision as 'older technologies', then one of the report's recommendations is particularly relevant.

> Because of the complementarity of technologies and infrastructure, countries where older technologies have yet to penetrate deeply may also face limits to the extent to which other technologies are able to diffuse. Therefore, the authorities should focus on ensuring that publicly supported technological services are available as widely, reliably and economically as possible, whether they are provided by the state or private firms (World Bank 2008: 14).

The services required for supporting biotechnology are largely dependent on local institutions. 'Institution building' is a concept with an undistinguished career in the development industry. If institutions are seen as 'the rules of the game' (North 1990), then we must recognize that these rules cannot be imposed, but rather evolve in response to local circumstances. This calls for a change in the strategies and competencies of national governments and donors. It means that assistance cannot only be concerned with new laboratories but also with the capacity to organize research that responds to the needs and demands of various types of farmers; there is not simply talk of public–private partnerships but encouragement of sustained, hands-on interaction between public entities and local businesses; investments do not simply support extension campaigns but also identify opportunities for farmers to organize and lobby for services; there is not just increased availability of farm inputs, but attention is given to farmers' capacities and rights as consumers; and donors do not simply transplant biosafety regulations, seed laws and intellectual property regimes from elsewhere but rather develop local skills to negotiate relevant rules.

If we return to the West African village described in this book's introduction, we recognize that there is a great deal that needs to be done to provide a more secure and productive harvest for those farmers. Transgenic crops may make an important contribution, but even their most ardent supporters should agree that many other things must be in place in order for farmers to take full advantage of the technology. Many of the institutional concerns described in this book deserve more immediate attention. The strengthening of these institutions is required for equitable agricultural development, even where there is no immediate prospect for transgenic crops. This requires a re-ordering of priorities for development assistance and national policy, otherwise we are in danger of putting the cart before horse.