THE ICAC RECORDER

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Update on Cotton
Production Research

Contents

Introduction

A lot has been published on the positive aspects of biotechnology. The ICAC has a complete section on biotechnology of cotton on its web site at <http://www.icac.org>. Some success stories in the press seem exaggerated. Any new technology has consequences. Take the case of insecticides. They provide protection against a variety of insects but must be used in accordance with the advice from entomologists to avoid up-consequences. Biotech varieties are approved in countries planting almost 60% of the world cotton area. Cotton farmers in these countries include educated, large growers in Australia and the USA, and small illiterate growers in China (Mainland) and India. Farmers have to adhere to recommendations from seed companies for managing the development of resistance and not to reuse seed for planting. The regulations are mandatory and legally binding on, but they have limitations. Biotech cotton has many advantages, but the technology also carries risks. Unfortunately the negative aspects of biotechnology have not been freely covered in scientific publications. The first article in this issue is devoted to the negative aspects of biotechnology, including concerns, apprehensions and risks related to cotton.

The ICAC has undertaken surveys on the cost of production for over 25 years. Currently, the data is updated every three years and repots have been published in 1992, 1995, 1998, 2001 and 2004. The Technical Information Section collects data from coordinating agencies in member countries and research institutions in countries that are not members of the ICAC. For the sake of consistency, the questionnaire designed in 1992 has been used each year since. Thirty countries participated in the recent survey and provided data for the year 2003/04. A summary of the data is presented in this article. The full report published in November 2004, can be purchased from the ICAC Secretariat at <publications@icac.org>. The weighted average of the data from 30 countries shows that the average cost of production of seedcotton in the world is US$0.33 per kg). There is little variation in the cost of production of seedcotton among countries including the USA where the cost of production of lint is one of the highest among major cotton producing countries in the world. The average net cost of production of lint, excluding land rent and seed value, is US$1.14 per kg. Costs of production by region and by country are also discussed in this article.

The third article in this issue of the *ICAC RECORDER* is about WideStrike™ cotton. The WideStrike™ insect resistant character received full registration from the U.S. Environmental Protection Agency in September 2004 for commercial production in 2005/06. WideStrike™ is a dual gene action character like Bollgard II. The two genes that have also been isolated from the soil bacterium *Bacillus thuringiensis* (Bt), are Cry 1Ac and Cry 1F. Cry 1Ac is the only gene in Bollgard while Bollgard II has Cry 2Ab in addition to Cry 1Ac. The addition of Cry 1F in WideStrike™ makes it different from the previously available Bt cottons and provides additional tool to protect cotton against more lepidopteron. WideStrike™ is most effective against three key pests: tobacco budworm, pink bollworm and cotton bollworm. In addition, WideStrike™ has an excellent efficacy against cabbage looper, soybean looper, saltmarsh caterpillar, and European corn borer and good efficacy against Spodopterans including beet armyworm, fall armyworm and southern armyworm. WideStrike™ also provides moderate control of black cutworm, almost equivalent to conventional insecticide control. Dow AgroSciences LLC developed WideStrike™ and has announced that the novel insect-resistant genes will be available to farmers in three varieties in the USA in 2005/06.

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India commercialized Bt cotton hybrids in March 2002. It is estimated that 6% of the 9.1 million hectares planted to cotton in 2004/05 in India were under Bt hybrids, a five fold increase over 2004/05 and a significant increase is expected in 2005/06. Increases in yields and reductions in plant protection expenditure are the two primary benefits for Indian growers. Dr. Palanisami Ramasundaram of the Central Institute for Cotton Research, Nagpur, India undertook a survey of cotton growers for two years and concluded that with the prevailing seed prices, the net benefit from adoption of Bt technology is a crucial factor in determining whether or not to plant Bt cotton. Poor refuge practices call for serious concerns about expanding area of Bt cotton and the impending release of other transgenic crops carrying the same source of resistance. More details of his work are in the fourth article.

Concerns, Apprehensions and Risks of Biotech Cotton

Genetically engineered cotton varieties were commercialized in 1996/97. ICAC estimates that 24% of the world's cotton area was planted to transgenic cotton varieties in 2004/05. The technology has many applications, and many biotechnology techniques can be employed to develop new products. Although the only varieties resistant to insects and herbicides that have been commercialized so far are genetically engineered, the wide array of biotechnology options available to researchers to develop new varieties rightly calls for these varieties to be named "biotech." In the past, ICAC called them "GE" (genetically engineered) varieties; however, genetic engineering does not cover all the biotechnology procedures that are employed or could possibly be employed to develop new varieties. Thus, ICAC, based on the recommendation of its Second Expert Panel on Biotechnology of Cotton, has corrected the name to "biotech varieties." The Second Expert Panel completed its report in November 2004. The report's executive summary was published in ICAC's five official languages in the December 2004 issue of the *ICAC Recorder,* and the full report can be ordered from the ICAC Secretariat at <publications@icac.org>.

Biotech cotton has multifarious advantages, and most papers and reports that have been published on this technology are favorable. The technology, however, does carry some risks, and unfortunately the negative aspects of biotechnology have not been properly covered in the scientific publications. This article is devoted to the negative aspects of bio-technology in cotton, aiming mainly to make people aware and therefore more careful, rather than to diminish the positive aspects of this technology. This discussion does not mean that the Technical Information Section of the ICAC is opposed to this technology. Only the concerns, apprehensions, and risks related to biotech cotton as a fiber crop are discussed in this article.

Gene Action Misuse

Many tools are available to utilize genetic variability from within species, across species and beyond species. The process of cutting and pasting genes (DNA segments), referred to as recombinant DNA, is so far the most popular technique. Varieties developed using the recombinant DNA technique are called genetically engineered varieties. The recombinant DNA technique involves isolating a gene and inducting it (with all the positive and perhaps still-unknown, negative consequences) into a non-related species. Bt cotton was developed utilizing a gene from the soil bacterium *Bacillus thuringiensis*. It is not the gene as such that actually gives rise to a new characteristic. All genes code for specific proteins, which actually do most of the work in the cell. The Bt gene codes for a specific protein, Cry 1Ac, in genetically engineered biotech varieties, the Cry 1Ac gene performs the function of killing Lepidoptera species. To ensure that the gene-coded protein is made in the right tissue at the current time, genes have switches, or promoters, that direct the cell when and where to make a particular protein. Genes present in the genome have these switches; the switches are turned on only in the right part of the plant. With genetic engineering tools, different switches can be attached to desired genes, directing them to work at a special tissue or remain dormant until they are activated.

The same technology, was employed by researchers in developing the "technology protection system" in cotton (gene terminator). The technology protection system was not commercialized but it would have been if farmers and other sectors of the cotton industry had not objected to the system worldwide.

Researchers started to develop a self-sterile seed system in 1993, three years before biotech varieties were commercialized. The technology advanced well and received a patent in 1998. The technology protection system was a clever three-gene system that forced plants to produce a toxin that was fatal to their own seeds. The complex array of gene promoters, which in a normal state were inactive, proved successful at all experimental stages in the lab and in the field. The variety with a technology protection system was able to produce viable seeds only when needed. The sterile seeds were treated prior to sale so that they would germinate like normal seeds but the resulting plants would not produce viable seeds. The treatment triggered an irreversible series of actions rendering the produced seed non-viable for planting. The toxin was produced late in the season, so that the seed's commercial value for oil extraction and livestock feeding was not lost. This technology protection system, as is evident from the name, was developed to stop the illegal spread of biotech seeds by making it impossible for farmers to plant the seeds the next year. This technology has not been commercialized so far, but similar tools could be employed in different forms in the future.

Organic Cotton - Disincentive

The U.S. National Organic Standards Board defines organic agriculture as an ecological production management system that promotes and enhances biodiversity, biological cycles, and soil biological activity. The system is based on minimal use of off-farm inputs and on management practices that restore, maintain, and enhance ecological harmony. One of the prerequisites for organic production is certification from a recognized certifying agency that the cotton has been produced following the organic cotton producing requirements set under the U.S. National Organic Standards Act. The primary requirements for organic production are to use materials and practices that enhance the ecological balance of natural systems. Organic cotton production was never large, but it was increasing slowly until biotech cotton was introduced. It was a common notion, prior to the commercialization of biotech varieties, that insect-resistant Bt varieties would provide a boost to organic cotton production. However, the National Organic Standards Board in the United States, on the advice of producers of organic products, regards biotech varieties as not eligible for certification as organic. This decision affected negatively the spread of organic cotton in the USA. With 80% of the U.S. cotton area under biotech varieties in 2004/05, the chances of producing organic cotton are much lower than they were prior to 1996/97.

In addition, organic cotton growers face the challenge of keeping organic produce separate not only from conventional produce but also from biotech produce during handling, ginning, and processing. This is in addition to requirements for distances between fields that prevent biotech varieties from crossing over to non-engineered conventional varieties. The chances of out-crossing with wild species are extremely low, but the chances of contamination with another variety simply grown under organic conditions are much higher. As long as biotech varieties are grown in the same area as organic cotton, organic producers are at risk of their crops being exposed to background levels of biotech varieties.

Another of the many consequences of insect-resistant biotech cotton to organic cotton is the restriction not to spray microbial insecticide (insecticides also made from *Bacillus thuringiensis*) on biotech varieties. The market for Bt insecticide has been significantly decreased, and biotech use has proved to be a disincentive for producers to continue producing the microbial insecticide. This has had the result that the organic producers have lost one of their most valuable pesticides.

Coexistence

Cotton is a fiber crop, but approximately 40 million tons of cottonseed is also produced annually, most of which is used to make vegetable oil for human consumption in developing countries. In principle, farmers should have a choice of the variety they grow, be it biotech, conventional, or organic. This assures the availability of a variety of products in the market. However, like the producer, the consumer is also entitled to choose the product he or she likes. The introduction of biotech cultivars makes labelly imperative for all countries, and the world in general. Many European countries and environmental groups are concerned about biotech products in the food chain and advocate labeling produce from biotech varieties. Some people even see such labeling as necessary for biotech products to survive and compete successfully with conventional products.

Development of Resistance to Toxins

Once a Bt gene is inserted into a variety, the Bt toxin is produced throughout the cotton plant during the entire growing season. Consequently, target pests are exposed to high levels of the toxin continuously, a situation likely to elicit resistance faster than intermittent exposure to conventional insecticides. All sectors of the cotton industry, including pesticide companies and biotech technology owners, agree that it is only a matter of time before cotton pests evolve resistance to the Bt toxin. However, it is possible to delay resistance if farmers incorporate resistance management strategies into their cotton production systems. Otherwise, without effective management plans, Bt could be lost in just a few growing seasons. Thanks to the lessons learned from the intensive use of insecticides, the resistance problem was identified even before biotech varieties were commercially introduced. Accordingly, appropriate measures in the form of refuge crop and gene pyramiding were undertaken, and resistance has not emerged so far. But the threat is real and acknowledged by everybody.

An Unproven Technology

The use of biotechnology in crop plants is new and so far experienced by only 17 countries, most of which are developed. However, most of the biotech cotton area outside the United States is in developing countries, including China (Mainland) and India. The most intensive use of biotech cotton has been in Australia and the United States, where biotech cotton varieties have been grown for the last ten years. Ten years is too short a time to assess any long-term consequences of a new technology that is so different from the existing technology; researchers admit that there is insufficient scientific data regarding the long-term effects biotech varieties may have on the environment or on human health. Even though the technology might not have long-term consequences, the concerns are there.

Increased Use of Herbicides

U.S. data show that on average insecticides were applied to cotton 3 times per season to control the largest insects before the adoption of Bt cotton varieties in 1996. Five years later (2000/01), the Bt-planted area increased to 72% of the total cotton area, and insecticide use was reduced to 0.77 sprays per season against the target insects (Benbrook, 2001). Bt cotton definitely reduced insecticide use. However, the introduction of herbicide-resistant biotech varieties in cotton has the potential to increase herbicide use. Herbicide tolerance, both in cotton varieties in the United States and in crops elsewhere in the world, is the most-used trait in biotechnology so far. International statistics show that of the total area of 81 million hectares planted to biotech crops in 2004, 72% were under herbicide-resistant varieties (James, 2004). Herbicide-resistant varieties make it possible for farmers to give up other control measures and rely on selected post-emergence herbicides as the backbone of weed management systems in cotton and other crops. Farmers growing conventional non-herbicide-resistant varieties try to explore multi-tactic integrated options in order to avoid spending money on herbicides. The biotech cotton grower, however, will avoid spending additional money on other options after already investing in herbicide-resistant biotech seed. Farmers use herbicide-resistant biotech cotton, even if herbicides are already popular, because the biotech herbicide trait simplifies weed management. The increase in herbicide use is also due to the fact that farmers can spray on the herbicides up to the four-leaf stage of the plants. The development of Roundup Ready Flex allows farmers to spray Roundup Ready for a longer time, even beyond the four-leaf stage. Repeated use of specific compounds could result in the so-called "super weed."

Illegal Biotech Cotton with All of Its Consequences

Biotech varieties in Australia, the United States and other countries are sold to cotton growers under an agreement to follow refuge requirements, to not spread the seed to other farmers and to not retain seed for self-planting the following year. However, these conditions have been violated extensively in a number of countries. Farmers not only use saved seed for planting, but they pass it on illegally to friends and relatives. Zoning of varieties has been violated, and varieties have been cultivated on a large scale in areas where they were not approved or recommended. Realizing the potential of Bt cotton in India, certain unscrupulous agencies have exploited the situation through sales of unapproved Bt cotton or spurious seeds. In fact, such seeds were introduced into the market while the company that introduced legal biotech hybrids in India was still carrying out regulatory trials and waiting for government approval. Such seeds have been found in several Indian states and over a considerable area (Manjunath, 2004). Almost the same thing has happened in Argentina and China (Mainland) and continues to happen in other countries where biotech cotton is still not approved for cultivation. Illegal use of biotech varieties is a blatant violation of biosafety regulations, and could spoil seed purity, performance, and safety as well as the credibility of legitimate biotech products and technology. Illegal sellers can afford to sell their products at a much lower price, as their investment on research is meager. Biotech pirating could affect the confidence and enthusiasm of genuine technology developers, who invest a lot of time, talent, and money in developing new products and getting their approval through due regulatory procedures. At the same time, pirating will mislead and confuse users, who will not observe refuge requirements and could contribute to a bigger problem.

Opposition Due to Lack of Knowledge and Over Cautiousness

Genetically engineered biotech varieties resistant to insects have faced opposition from a number of organizations and individuals from the beginning, even before the technology was commercialized. The issues raised were mostly speculative, complex, and confusing. It was claimed that Bt protein might be harmful to humans, farm animals, other beneficial organisms, and soil. In India, such groups threatened farmers with serious consequences if they were to seed Bt cotton. They also held repeated public demonstrations against this technology in India, the United States, and many European countries. Unfortunately, the year when biotech varieties were introduced in India coincided with a new disease. The disease, commonly named as "parawilt," was found on Bt as well as on non-Bt hybrids, but biotechnology was blamed for the disease's occurrence. Later, it was revealed that parawilt was a physiological disorder that occurred when Bt hybrids were exposed to prolonged dry spells or unusually high temperatures during boll formation, followed by heavy rains. A similar allegation occurred in the United States when excessive leaf/boll shedding was attributed to a herbicide-resistant gene. Biotechnology has faced enough opposition, due to lack of knowledge and to unnecessary cautiousness, to create doubts and confusion in the minds of farmers and the public.

Biotech Cotton and Pest Complex

Bt cotton is effective against a variety of budworms and bollworms, but it is not effective in controlling many secondary pests. Experience in China (Mainland) shows that populations of secondary pests such as aphids, mites, thrips, lygus bugs, whitefly, and leaf hopper, increased in Bt cotton fields after the target pests—budworms and bollworms—had been controlled (Xue, 2002). It is known that the currently discovered Bt proteins Cry 1Ac, Cry 2 Ab, VIP, and Cry1F do not control sucking pests; insecticides have to be used to control them. However, when insecticides, particularly organophosphates, are used to target budworms and bollworms, they also kill some sucking insects. The situation may vary from country to country, but data show that organophosphates comprised almost 90% of the insecticides used on cotton in 2000/01. Therefore, there is an additional advantage of insecticide spraying: partial control of non-target insects. When biotech varieties are used, there is a possibility of recording higher populations of pests that are not Bt targets during the period of no insecticide sprays. This is what has been observed in the work reported by Xue (2002), and this was expected to occur in nature.

Supporters and opponents of biotech varieties agree that Bt genes provide good control of target pests. But once the targets pests are controlled, minor and non-target pests may emerge as major pests. When minor pests become major ones, they may change the pest complex situation, and pests that are more difficult to control than the target pests may emerge as major pests, bringing new and difficult problems. The possibility of sucking insects gaining higher importance is always there.

Biotech Cottons and Beneficial Insects

The insect-resistant biotech cotton varieties are specific to a group of insects that includes most bollworms and budworms but excludes natural predators and parasites. The active toxin binds to receptors in the insect's midgut cells. The binding creates pores in the wall of the insect's gut, allowing ions to equalize, ultimately causing the gut to lose its digestive function. Once the binding has taken place after ingestion, the insect's gut is paralyzed, forcing it to stop eating. After the stomach is immobilized, the cells break open and the pH of the stomach decreases as its fluids mix with the lower-pH blood. A lower pH allows the spores to germinate and colonize the rest of the insect's cells. The bacteria spread throughout the rest of the host by the bloodstream until complete paralysis of the insect occurs. This process takes anywhere from an hour to a week to kill the insect. Beneficial insects might feed on insects that have taken up the toxin but have not died yet, or might digest by-products of insects such as honeydew that are contaminated with toxin. No data show that biotech toxin could kill beneficial insects, but the toxin could harm beneficial indirectly in the two ways described above. The third, indirect, effect could be in the form of poor quality food if the transgenes reduce the quality of the host or prey insects that are available for feeding. This could be true particularly in cotton for the third and later generations towards crop maturity, when the amount of toxin is reduced and not all the target larvae will be killed.

Human Health and Environment

Biotech products have been tested for their effects on non-target insects, human health, and the environment in their country of origin. No ill effects have been found, but a notion still persists among countries and the public reluctant to adopt biotech products that the new technology carries potential threats to the environment and non-target insects. This issue may be more relevant to food crops than cotton, which is grown as a fiber crop. Unfortunately, biotech cotton has been treated like biotech food crops, since its byproducts are used for food and feed. In addition, biotechnology applications have not reached their peak, and future products could create such problems, particularly if something like antibiotic genes is inserted into cotton or other food crops for ease of distinguishing transformed plants from non-transformed types, or for the production of pharmaceutical substances.

Technological Limitations

Breeding, the art and science of developing new varieties, has been untaken for centuries, and genotypes and cultivars drastically different from their wild ancestors and relatives have been developed. Developments have been achieved in agronomic performance, including higher yield and better fiber quality in cotton, contributing to productivity and quality improvements. While breeding can bring drastic changes, biotechnology applications, at least so far, have been limited to specific changes in the existing genotypes and cultivars. Conventional breeding will always carry a large gene pool to exploit genetic variability according to an area's growing conditions, since, for example, certain varieties perform better under sandy soils while others perform better under rainy or drought conditions. Molecular genetic engineering breaks down the incompatibility barriers among different forms of life and makes it possible to transfer a gene or genes from one level of life to another. However, certain limitations will always apply to biotechnology, and sometimes conventional breeding will prove to be better.

Private Sector Owns the Technology

Many aspects of genetic engineering and molecular breeding are owned by the private sector. This includes fundamental as well as practical utilization of products developed using biotechnology applications. Certain issues like "Only Monsanto has a patent to transform cotton" have been of great concern to all countries. Companies still own genes, which no one else can use without their consent. Such conditions are limiting the use of biotechnology applications in developing countries. In contrast, most of the developing countries benefited from the "green revolution" in a short time because the public sector acquired the technology quickly and spread it to farmers. This is not the case with biotechnology. The primary objective of the green revolution was to produce more food and alleviate poverty. Therefore, farmers were the primary beneficiaries and they produced more food without increases in the cost of production. In contrast, the private sector views biotechnology mainly as a source of income and a way to compete with other companies, and only secondly as a tool to solve problems. The monetary intent is apparent from the technology fee, which is different in different countries for the same Bt gene. The fee is related not to the cost of development but to savings on insecticides used and the financial conditions of farmers. For this reason, the technology fee for the Bollgard gene is higher in Australia than in the United States. Also, the technology fee in Australia has been changed more than once.

Technology is Expensive

Agricultural technological innovations like the green revolution came at various stages, always bringing with them some cost in developing and acquiring that technology, but nothing like the cost of biotechnology products. Further, if the technology was acquired through seed, the cost was paid only once, except in the case of hybrid seed in corn or commercial cotton hybrids in India. This condition was not coming from technology developers but it was a genetic issue where nothing could be done except to produce planting seed every year. For biotech crops, farmers have to pay for insect- and herbicide-resistant technology every year, which makes the technology more expensive. Argentina commercialized Bt cotton in 1998, but so far Bt varieties cover less than 25% of the area. High cost is limiting many countries' use of this technology. The high cost of technology also encourages the illegal use of technology products. Biotechnology research is expensive and if started, particularly under limited resources in developing countries, could be done at the cost of other research.

Search for Newer Genes

It has been ten years since insect-resistant and herbicide-resistant cottons were commercialized. The only two new biotech cotton products commercialized since then belong to the same two categories. The search for additional genes may have been initiated even before the commercialization of biotech cottons, but no new form of biotech cotton (other than insect- and herbicide-resistant ones) is expected to be released in the next five years. New genes are needed but how far we can go to explore and utilize new genes is another consideration. ICAC's Second Expert Panel on Biotechnology of Cotton observed that the difficulty in identifying new genes with classical traits is the most important limitation to the use of biotechnology.

Production Systems are a Limitation

Cotton is grown under a variety of growing conditions and production systems. Cotton in general is a small growers' crop, as most farmers in developing countries own only a small piece of land. Private companies can sign direct contracts, something that is very difficult, to do under small-scale farming systems. Additionally, insect- and herbicide-resistant biotech varieties are not suitable for all production systems. The target pests do not exist everywhere, and many countries just do not need them. It would be a pity to impose the use of biotech cultivars in these areas and countries.

Need for Public Participation

The Cartagena Protocol was adopted in January 2000; it entered into effect in September 2003. One hundred eleven countries had ratified the Protocol by the end of 2004. The essence of the Protocol is "to ensure an adequate level of protection in the field of the safe transfer, handling and use of living modified organisms resulting from modern biotechnology that may have adverse effects on the conservation and sustainable use of biological diversity, taking also into account risks to human health, and specifically focusing on transboundary movements." Article 23 of the Protocol specifically addresses the issue of public awareness and participation, stating "The Parties shall: (a) Promote and facilitate public awareness, education and participation concerning the safe transfer, handling and use of living modified organisms in relation to the conservation and sustainable use of biological diversity, taking also into account risks to human health. In doing so, the Parties shall cooperate, as appropriate, with other States and international bodies; (b) Endeavor to ensure that public awareness and education encompass access to information on living modified organisms identified in accordance with this Protocol that may be imported." The Protocol also says that parties "shall, in accordance with their respective laws and regulations, consult the public in the decision-making process regarding living modified organisms and shall make the results of such decisions available to the public, while respecting confidential information in accordance with Article 21. Each Party shall endeavor to inform its public about the means of public access to the Biosafety Clearing-House." Public awareness and participation have become key in the acceptance of biotech products. The Food and Agriculture Organization of the United Nations has done elaborate work on public participation in the decision-making process regarding adoption of biotech crops. FAO's electronic forum on biotechnology at http://www.fao.org/biotech/Conf10.htm provides a lot of information on biotech issues. Their 12th conference, to be held in May/June 2005 in Canada, is entirely focused on public participation issues.

New Products and New Concerns

Biotechnology in a broad sense includes genetic engineering, tissue culture, embryo rescue, marker-assisted breeding, and many more applications. There are two kinds of concerns about biotechnology: concerns about available products and concerns about biotechnology. Many people agree that biotechnology applications are not always risky and dangerous, while transgenic biotech products carrying non-related genes are. Thus, even if researchers concerned convince people of the safety of available products currently, new concerns will arise as new products are developed and marketed. Biotechnology applications are technologies that will continue to be controversial for a long time.

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Update on Cost of Production of Cotton in the World

The International Cotton Advisory Committee (ICAC) has undertaken surveys on the cost of production for over 25 years. In the beginning, data were collected at irregular intervals but for the last 15 years data has been updated in 1992, 1995, 1998, 2001 and 2004. The sources of data are coordinating agencies in ICAC member countries or the related government agencies/departments and cooperating researchers/institutions in countries who are not yet members of the ICAC. For the sake of consistency, the questionnaire designed in 1992 has been used each year since. The questionnaire accommodates most variations in production practices and different norms of input applications. Thirty countries participated in the recent survey and provided data for the year 2003/04. Cotton production conditions vary within countries, and 11 countries provided data for more than one set of production practices, bringing the total number of responses to 51. A summary of the data is presented in this article. The full report can be purchased from the ICAC Secretariat at <publications@icac.org>.

Cost of Production in the World

The cost of producing a hectare of cotton ranges from less than US$400 in a number of countries to almost $4,000 in Israel. The data from 30 countries showed that on average $1,139 are spent to grow, harvest and gin one hectare of cotton. The world average land rent for a hectare of cotton is $241 thus reducing the ownership cost to a grower to $898/ha. Additional income from seed sold after ginning reduces the net cost to $732/ha. Ownership costs for seedcotton/ha (excluding land rent, ginning, economic and fixed costs) comes to $617/ha.

With a world average yield at 642 kg/ha in 2003/04, the net cost per kilogram of lint (excluding land rent and seed value) in the world was $1.14/kg. The cost of production increases to $1.52/kg of lint if the farmer does not own land and has to pay rent for cotton production. The data from 30 countries showed that on average, a farmer spends $0.33/kg to produce a kilogram of seedcotton, indicating that ginning, economic and fixed costs are expensive.

Cost of Production by Region

Cotton production costs per kilogram of lint are the highest in Europe and the lowest in Australia and South America. The European data is from Bulgaria and Spain; Greece did not participate in the survey. However, the cost of production in Greece is close to that in Spain. None of the Central Asian countries provided data for the survey. But, the average of eight Asian participating countries that planted 53% of world cotton area in 2003/04 indicates an average net cost of production of US$1.14/kg. The net cost of production in North America, including Mexico and the USA, is 130% of the world average.

Table 1: Net Cost of Producing a Kg of Lint by Region

Region	Cost/ha ($)	Cost/kg ($)	% of World
North America	1,090	1.48	130
South America	995	1.09	95
Africa	513	1.40	123
Asia	700	1.14	100
Europe	3,362	3.72	326
Australia	1,937	1.08	95
World	732	1.14	

Ten countries from Africa, including Benin, Cameroon, Côte d'Ivoire and Togo from West Africa, participated in the survey. The average cost of producing a hectare of cotton in Africa is less that 50% of the cost in North America, but due to lower yields, the cost per kilogram of lint is more than all other regions except Europe. Argentina, Brazil, Bolivia, Colombia, Paraguay and Peru participated in the survey from South America where production costs are almost equal to Australia.

The cost of producing a kilogram of seedcotton is highest in Europe and lowest in Australia. Farm gate production costs in Asia, Africa and South America are more than 150% of costs in Australia. In the USA, farmers can produce seedcotton at comparatively low cost, but the costs of ginning, plus economic and fixed costs make it relatively expensive to produce cotton in the USA. The cost of producing a kilogram of seedcotton is close in Asia, Africa and South America.

Table 2: Ownership Cost of Producing a Kg of Seedcotton by Region

Region	Cost/ha ($)	Cost/kg ($)	% of World
North America	682	0.34	103
South America	884	0.32	97
Africa	395	0.36	109
Asia	626	0.34	103
Europe	1,890	0.70	212
Australia	887	0.21	64
World	617	0.33	

Variation in Cost of Production Within Countries

Costs of production vary significantly among regions within countries. The cost of production data from Turkey and the USA are discussed by region.

USA

While all other countries produce the cost of production data by geographical location, the USA presented the cost of production data based on production practices. The U.S. cotton area from the southeast to the west of the country is divided into five sets of production practices, and the cost of production varies among regions. In the USA, yields are the highest in the Fruitful Rim, almost double that of the national average, and that is why cost/kg is the lowest in this region. Average yields in the Prairie Gateway region are only one fourth of the Fruitful Rim and almost 50% of the national average which makes it expensive to produce a kilogram of lint.

Table 3: Cost of Producing in the USA

Region	Cost/kg ($)	% of US Average
Heartland	1.08	73
Mississippi Portal	1.27	86
Fruitful Rim	1.02	69
Prairie Gateway	2.15	145
Southern Seaboard	1.44	97
National Average	1.48	

Turkey

In Turkey, the cotton producing areas can be divided into four main regions. Production practices do not vary significantly among regions but pest pressures are quite different among regions. The Southeastern Anatolian Project area (GAP) is comparatively a new production area where a large irrigation system has been built. Pest pressure is low and insecticide use is the minimum among all regions. Yields are the highest and now almost half of the cotton produced in Turkey comes from the GAP region. Pesticide use is the highest in the Çukurova region and the average number of insecticide applications usually exceeds 10 per season. Lands rent is high, but since the net cost per kg given below does not include land rent, net cost per kg is comparatively low. The share of cotton production in this region has fallen. Lower yields in Akdeniz (Antalya) region, and high insecticide costs make it difficult for farmers to continue producing cotton.

Table 4: Cost of Producing in Turkey

Region	Cost/kg ($)	% of National Average
Southeastern Anatolian Project (	1.16	87
Çukurova	1.16	87
Ege (Aegean)	1.44	108
Akdeniz (Antalya)	1.58	118
National Average	1.34	

The data in tables 3 and 4 show that the variation in the cost of producing a kg of lint among regions/production systems is higher in the USA than in Turkey. Variations in cost of production in the USA emerge from variations in yields among production systems. Production conditions among regions in Turkey are similar, which reduces variations in the cost of production. The region-wise cost of production data from India for the North (Irrigated), Central (Irrigated), Central (Rainfed) and South (Rainfed) zones showed that variations in the cost of production was over 50% of the lowest in the North zone to the highest in the South zone. Again, the main reason for higher cost per kg is lower yields in the South. If yield differences are not high between regions, costs of production are about the same, as is the case in Argentina and Colombia.

Inter-country Comparisons

Thirty countries participated in the ICAC survey; Argentina, Australia, Bangladesh, Benin, Bolivia, Brazil, Bulgaria, Cameroon, China (Mainland), Colombia, Côte d'Ivoire, Ethiopia, India, Iran, Israel, Mali, Mexico, Nigeria, Pakistan, Paraguay, Peru, Philippines, South Africa, Spain, Sudan, Tanzania, Togo, Turkey, USA and Vietnam. Benin, Brazil, Colombia, Côte d'Ivoire, India, Mexico, Philippines, South Africa, Togo, Turkey and USA provided the cost of production for more than one set of production practices or region. Thus, the total number of entries comes to 51. In this paper, nine countries are discussed in detail; Argentina (Santiago del Estero-irrigated), Australia (Irrigated Upland), Brazil (Cerrado), China (Mainland), India, Mali, Pakistan (Punjab), Turkey and USA. Data from countries was not complete, so for

Table 5: Cost of Land Rent and Seed Value

Country	Land Rent/Ha (US$)	Seed Value/Ha (US$)
Argentina (Santiago del Estero-irrigated)	-	68.0
Australia (Irrigated Upland)	-	318.0
Brazil (Cerrado)	139.0	174.0
China (Mainland)	544.0	249.0
India (National Average)	188.0	102.0
Mali	-	30.0
Pakistan (Punjab)	171.0	241.0
Turkey (National Average)	334.0	378.0
USA (National Average)	118.0	148.0

comparison purposes, the Secretariat estimated data for the opportunity cost of inputs/operations.

The data from Argentina is for irrigated conditions in the province of Santiago del Estero. The Australian data are for irrigated cotton in New South Wales. The data from Brazil is for the central west region, the most productive cotton area in the country. The data from China (Mainland) is the average of the three production regions. The national average data from India, Turkey and the USA have been used for comparison among countries.

Land Rent and Value of Seed

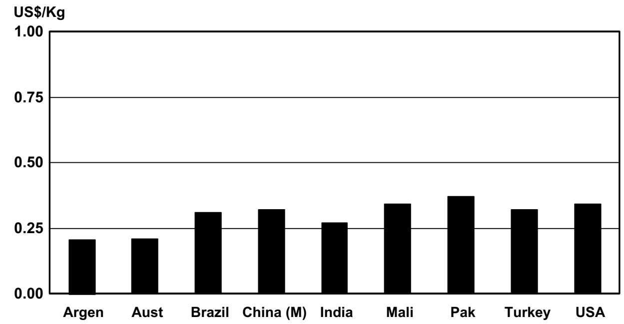
In many countries, some farmers own land and some rent. Farmers legally agree on a price for land for using it for one year. Cotton is around six months at the maximum, and other crops can be gown on the same land after cotton picking is over. A variety of crops are grown in most countries. Crop rotations can be long term or short term but land is rented for on yearly basis, so efforts are made to use the land year around. In the ICAC survey, respondents were asked to provide the cost of rent for cotton only. Similar farmers may or may not sell the seed after ginning, and they were asked to report the opportunity value of seed received after ginning. The survey assumes that farmers hypothetically gin seedcotton in a custom ginning system and sell the lint and seed separately.

Land rent and seed value are the two most important factors that affect costs per kilogram of seedcotton and lint. Share-cropping is popular in Australia so no data are available on land rent while land rent is almost 30% of the total cost of producing a hectare of cotton in China (Mainland). Land is also expensive in Turkey and rent per hectare is almost double that of India and Pakistan. Data on the value of seed is available from all countries, and the differences are significant. The value of seed is based largely on the quantity of seed produced per hectare, but the price of seed per kilogram also seems to vary greatly among countries, as evident from India and Mali.

Cost of Seedcotton by Country

The cost of producing a kilogram of seedcotton is $0.21 in Argentina and Australia and US$0.37 in Pakistan. The cost is high in Pakistan due to high opportunity costs for irrigation water and comparatively high costs for fertilizers. The average cost of producing a kilogram of seedcotton in India is $0.27. In all other countries, the cost of producing a kilogram of seedcotton is either equal to the world average of $0.33/kg or within a margin of four cents.

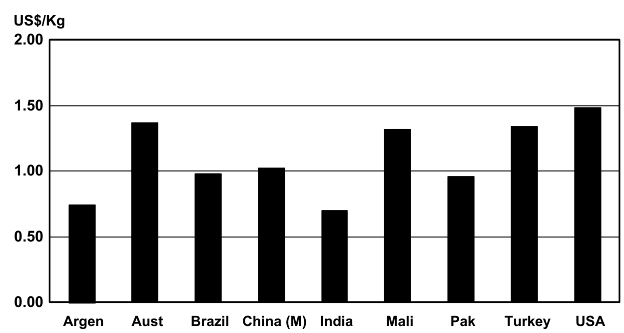
Cost of Production of Seedcotton



Cost of Lint by Country

The data from the nine countries discussed here shows that there is substantial variation in the net costs of producing a kilogram of lint. The cost of production is the lowest in India and highest in the USA. In India, the average of four regions shows that net cost per kilogram of lint, excluding land rent and seed value, was only $0.70/kg. The net cost is low in India due to the high value of seed that finds many uses in the country. Within India, the cost of production ranged from $0.50 to $0.86/kg. Production costs are the lowest in the North where cotton is grown under irrigated conditions and yields are higher compared to the Central and South regions of India. The net cost of producing a kilogram of cotton is comparable among Brazil (Cerrado), China (Mainland) and Pakistan (Punjab). Net costs of production are close to each other in Australia and Turkey i.e. $1.37 and $1.34/kg respectively. In the USA, on average $1.48 is spent to produce a kilogram of lint. The cost of production of seedcotton and lint shows that the cost of ginning, economic costs and fixed costs are more expensive in some countries than in others.

Net Cost of Lint



Some Caveats

The cost of production data come from actual surveys of farming practices in some instances such as the USA and Australia. While some countries undertake sample surveys, cotton researchers complete survey forms in others. The source of data for individual input costs or operations can vary greatly from country to country. When and how the opportunity costs of inputs and operations are calculated is also a source of variation among countries. Therefore, it is possible that the ICAC cost of production data represent potential costs rather than actual costs.

Ideally, one could measure the cost of producing cotton using a uniform method of collecting data and measuring the cost of all inputs and operations through to the production of seedcotton and lint. In order to calculate the net cost of lint or ownership costs of seedcotton production, complete data on land rent are needed, as well as the value of seed after ginning. However, no uniform data are available other than for a very small number of countries.

No opportunity costs are available for some inputs/operations. Land is a basic requirement to grow cotton, but in some countries there is no land rent system. Cotton companies in most West African countries provide planting seed free to cotton growers. Production technology is free in most countries but not in a country like Australia where cotton consultants are hired by cotton growers. Family labor employed in field operations and government subsidies on inputs are other critical factors making comparisons difficult and sometimes invalid among countries.

Cotton is produced in many parts of the world under a variety of production conditions, different climates and different systems of economic organization. Cotton produced in two countries at the same cost may not fetch the same price. Cotton produced in Egypt is not the same quality as in other countries and will be sold at a higher price.

Summary

Costs of production and cotton prices are the most critical factors that affect farmers and help them to decide how much area they will plant to cotton. According to survey data collected by the ICAC, the average cost of producing a kilogram of lint in the world in 2003/04 was US$1.14. The cost of producing a kilogram of seedcotton was US$0.33. The data from nine countries discussed in detail in this article shows that the cost of producing kilogram of seedcotton does not vary greatly among countries. The difference is only 2-3 cents/kg of seedcotton. Differences among countries for lint costs/kg are much greater. Ginning costs, economic costs (management and administration, interest on capital invested, repairs and general farm overhead) and fixed cost (depreciation cost of power supply, irrigation system on the farm, tractors, spray machinery and farm implements) increase the cost per kg of lint. Farmers need to look at ginning, economic and fixed costs to reduce the cost of production rather than inputs and field operations. The highest costs of production are in Europe, followed by Africa and North America. According to data from 30 countries that participated in the ICAC survey in 2004, it is least expensive to produce cotton in India and Argentina.

WideStrike™ Approved for Commercial Production

The WideStrike™ insect-resistant character received full registration from the U.S. Environmental Protection Agency in September 2004 for commercial production in 2005/06. WideStrike™ is the only other insect-resistant biotech cotton approved for commercial production, since the registration of Bollgard II in December 2002. Like Bollgard and Bollgard II, WideStrike™ received deregulated status from the U.S. Department of Agriculture in July 2004, meaning that varieties carrying the WideStrike™ genes may be freely moved and planted by growers.

WideStrike™ is a dual-gene-action variety, like Bollgard II. The two genes active in WideStrike™, which were also isolated from the soil bacterium *Bacillus thuringiensis* (Bt), are Cry 1Ac and Cry 1F. Bollgard carries Cry 1Ac, while Bollgard II has Cry 2Ab in addition to Cry 1Ac. The addition of Cry 1F in WideStrike™ makes it different from the previously available Bt cottons and provides an additional tool for farmers and researchers to continue delaying the development of insects' resistance to toxins in transgenic varieties. Dow AgroSciences LLC, which developed WideStrike™, has announced that the novel insect-resistant genes will be available only in varieties developed by Phytogen in the United States. Only three such varieties will be available for commercial cultivation in 2005/06: PHY 440 W, PHY 470 WR, and

PHY 480 WR. The first variety has only WideStrike™ genes, while the other two also have the Roundup Ready herbicide-resistant gene.

Mode of Action

Cry 1Ac and Cry 1F bind to specific receptor molecules on the midgut epithelial cells of the target pests. Once bound, the receptor causes pores in the midgut cells, leading to lysis, cessation of feeding, and death. The overlap among receptors is incomplete. Cry 1Ac binds to at least three receptors, while Cry 1F binds to at least two receptors in the tobacco budworm. In the cotton bollworm, Cry 1Ac and Cry 1F each bind to at least four receptors, of which two are shared. Data submitted by Dow AgroSciences to the U.S. Environmental Protection Agency for approval of WideStrike reported that in the cotton bollworm approximately 60 percent of Cry 1Ac binding is to receptors that also bind Cry 1F, and the remaining 40 percent of Cry 1Ac binding is to receptors that do not bind Cry 1F. Incompletely shared binding is expected to delay cross-resistance when resistance is mediated by receptor changes.

Effect on Yield

Monsanto regulations prohibit direct comparisons among Bollgard, Bollgard II, and WideStrike™ varieties. Yield performance will also vary depending upon location, pest pressure, and pest complex, even if a WideStrike™ variety is grown under the same agronomic practices. Results from more than three years of field trials, including work conducted under EPA Experimental Use Permits (EUP) in 2003 and 2004, showed that WideStrike™ is effective and provides season-long control of target pests. Langston *et al.,* (2004) tested a WideStrike™ variety against a conventional variety grown under insecticide-treated and untreated conditions. Trials were conducted for three years, from 2001 to 2003, at various locations. They reported that the WideStrike™ variety PHY 440 gave the same yield under insecticide-treated as under unsprayed conditions. The conventional variety under sprayed (as needed) conditions also produced the same yield.

Seedcotton Yield (kg/ha) from 2001 to 2003

Variety	Treatment	Mean Yield of 13 Locations
PSC 355	Conventional, unsprayed	1,744
PHY 440W	WideStrike, unsprayed	2,397
PSC 355	Conventional, sprayed	2,412
PHY 440W	WideStrike, sprayed	2,493

Effect on Insects

Parker and Livingston (2004) compared the transgenic WideStrike™ and Roundup Ready variety PHY 470 WR with Roundup Ready PHY 410 R under dryland conditions. The treatments included insecticides applied to both varieties when bollworm numbers reached the treatment threshold in the non-Bt variety. The second set of treatments was the application of insecticides when caterpillar numbers reached a threshold level in WideStrike™ Bt cotton. Parker and Livingston (2004) observed that the latter threshold was never reached, due to the Bt genes, but they applied insecticide one time in any case. The trial had four replications. To assess the effects of WideStrike™ genes, data were recorded for 1) the number of Heliothine eggs, larvae, plant terminal damage, and damaged squares, 2) the number of larvae collected from the non-Bt and non-treated varieties in order to determine the percentage of bollworm and budworm larvae, 3) caterpillar damage on 25 bolls, 4) plant mapping to determine the location of bolls, and 5) yield assessment. The data showed that bollworm made up 96 percent, 29 percent, and 0.0 percent of the larval population compared to tobacco budworm on three different dates in the month of July. Heliothine larvae were always fewer on WideStrike™ except on one day, nine weeks after planting. Three applications of insecticides on non-Bt and WideStrike™ plots gave almost equal larval counts. The season average data showed that WideStrike™ had fewer damaged squares; the number of damaged squares was also significantly reduced in plots treated three times with insecticide. Boll damage was similar in both treatments. Yields achieved with WideStrike™ and cotton with three treatments of an insecticide, were not statistically different.

Previous studies on Bollgard and Bollgard II cottons have shown that protein expression varies across parts of the plant and stages of crop development. A plant's ability to express Bt proteins varieties with type of plant structure (reproductive or foliage), age of leaves, and presence or absence of flower tissue attached at the tips of bolls. These differences affect lepidoptera mortality in the field. Gore *et al.,* (2002) concluded that bollworms are more likely to be found lower in the plant canopy on white flowers and bolls of Bollgard and Bollgard II plants than in terminals and squares of non-Bollgard plants. Earlier they also observed that larval survival is higher on white flower parts than on flower buds, squares, and bracts. Their conclusion is that bollworm survival is not related to the quantity of toxin, though larval mortality may be associated with the protein expression in plant parts.

Similar studies have been undertaken at the University of Louisiana by Tindall and her colleagues (2005) and presented at the 2005 Beltwide Cotton Conference held in New Orleans, Louisiana, from January 4 through 7, 2005. They evaluated the susceptibility of bollworm larvae fed on various plant parts of conventional cotton and WideStrike™ cotton. The one-day-old larvae were fed on white flowers, squares, and terminal leaves at two, four, and six weeks after flower initiation. The second-instar larvae were fed on leaf tissue (discs) from the fifth and eighth nodes below the plant terminal and quarter-size bolls. Mortality was assessed 48, 72, and 96 hours after larvae were placed on plant structures. Data were averaged over plant structure to determine if there were differences in mortality of one-day-old larvae over second-instar larvae. Mortality of larvae of the same age fed on different plant structures from conventional and WideStrike™ proved the effect of novel genes.

Mortality of One-Day Old and 2nd Instar Larvae on WideStrike and Conventional Varieties

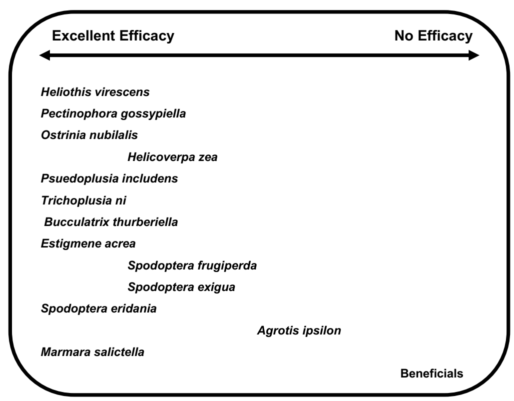
Treatment	% Mortality at 48 Hours	% Mortality at 72 Hours
WideStrike		
One-day old larvae	78.4	91.6
2nd instar larvae	30.1	67.9
Conventional Variety		
One-day old larvae	46.0	72.8
2nd instar larvae	9.2	23.5

The data from the average of all plant parts from WideStrike™ and a conventional variety showed that the mortality rate was higher in the one-day-old larvae than in the second-instar larvae for both types of feeding material. The data from 48 and 72 hours after feeding showed that the mortality increased as the larvae were allowed to continue feeding for another 24 hours. Mortality was significantly higher in WideStrike™ than in the conventional variety. Additional data showed that the mortality rate was almost the same in WideStrike™ if the larvae were fed on flowers, squares, or terminal leaves. Mortality no doubt increased with the feeding time, but mortality remained the same across feeding materials.

WideStrike™ Activity against Non-Heliothines

WideStrike™ is most effective against three key pests: tobacco budworm *Heliothis virescens*, pink bollworm *Pectinophora gossypiella,* and cotton bollworm *Helicoverpa zea.* In addition, WideStrike™ controls several other lepidopteran pests. WideStrike™ is effective against Heliothine lepidopterans, as it has Cry 1Ac, which has already proved effective in the form of Bollgard cotton. Haile *et al.,* (2004) studied the effect of Cry 1Ac and Cry 1F proteins again non-Heliothine insects and concluded that WideStrike™ is quite effective against many Heliothines. Studies have compared populations of non-Heliothines on a WideStrike™ variety versus a conventional variety. The target insects in the studies were released into the field if the insect population was not large enough. Field and bioassay studies for three years, from 2001 to 2003, showed that WideStrike™ has excellent efficacy against pink bollworm, cabbage looper, soybean looper, saltmarsh caterpillar, and European corn borer and good efficacy against Spodopterans, including beet armyworm, fall armyworm, and southern armyworm. WideStrike™ also provided moderate control of black cutworm almost equivalent to conventional insecticide control. WideStrike™ activity against Heliothine and non-Heliothines can be seen below.

WideStrike™ Efficacy Against Lepidopterans



Refuge Requirements

The advantages of planting refuge crops along with transgenic varieties are widely acknowledged in the United States. Refuge requirements have been followed in the United States, but not by 100 percent of growers. An internal survey conducted by the U.S. Environmental Protection Agency (EPA) indicated that only 77 percent of cotton farmers were in compliance with the refuge requirements for cotton in 2002. Bollgard registration was due to expire at the end of 2004 after a one-year extension. The refuge requirements were one of the issues seriously reconsidered by U.S. EPA before they extended registration of Bollgard cotton. Refuge requirements are a complicated issue. After months of debate, the EPA granted an extended registration for Monsanto's Bollgard cotton gene for another five years with no significant changes in the amount of land growers must plant to non-transgenic cotton. Australia restricted the use of Bollgard (called Ingard in Australia) cotton to a maximum of 30 percent of area until 2005, and thus automatically employed refuge requirements. These area restrictions were lifted only after Bollgard II was approved in Australia. The South African Cotton Industry has tried to get rid of refuge requirements, claiming that alternate host crops for the most important target insects are grown in close proximity to Bt cotton; hence there is no need for unsprayed or conventional cotton. It is argued that alternate host crops produce enough bollworms to hybridize with the population, if any, surviving on Bt cotton. However, refuge restrictions have still not been lifted. Transgenic cotton area is increasing in China (Mainland) and it is quite difficult for farmers to meet refuge requirements. However, soybeans and corn often planted in adjoining plots, particularly in the Yellow River Valley and Yangtze River Valley, provide ample bollworm populations for hybridization. In Argentina, India, Colombia, and Mexico a lot of cotton that is not transgenic is still grown next to Bt fields. Refuge requirements are a condition in all these countries.

The EPA requires that commercial cultivation of WideStrike™ follow the same refuge requirements that are followed for the Bollgard and Bollgard II varieties. The objective is to maintain consistency in the field and help extend the durability of Bt genes against target pests. The resistance management practices saw a major change in 2001 when Bollgard cotton registration was renewed for the second time. Current options available for refuge crop are as follows:

5 percent Unsprayed Option

The primary requirement for this option includes 2 hectares of unsprayed non-Bt cotton for every 40 hectares of Bt cotton. In addition, all Bollgard/Bollgard II/WideStrike™ cotton fields must be within 2.5 kilometers of the refuge, and the refuge must be at least 40 meters wide, but preferably 80 meters wide. It is required that whenever the biotech variety is sprayed with any insecticide, the embedded refuge must also be sprayed with the same insecticide at the same rate and within 24 hours. The insecticide may also be a pyrethroid application to a Bt variety to control escaped target insects. However, the embedded 5 percent refuge cannot be treated with any lepidoptera-active products unless the Bt field is treated with any of these products, nor can it be treated with foliar Bt. Fields bigger than 1.6 kilometers must have more than one embedded refuge plot. In Arizona, California, and New Mexico, where pink bollworm is a major pest, growers are allowed to plant refuge crop within the Bt field. However, one row of refuge crop must be planted for every six to ten rows of Bt cotton. The refuge may be treated with sterile insects, any insecticide (excluding foliar Bt products), or pheromones labeled for the control of pink bollworm, whenever the entire field is treated. The in-field refuge rows may not be treated independently of the surrounding Bt cotton field in which they are embedded. Agronomic management should be exactly the same for the refuge crop as for the Bt variety. The in-field refuge rows or area, no matter how large, cannot be treated as refuge crop for any other adjoining area (Denney, 2004). Smaller fields may be grouped together to have an embedded 5 percent unsprayed refuge.

20 percent Sprayed Option

This option requires that 8 hectares of sprayed refuge crop should be planted with every 32 hectares of Bt cotton. The refuge crop can be treated with any insecticides (except foliar Bt products) and it is not required that Bt cotton be treated with that insecticide as is the case with the 5 percent unsprayed option. The EPA requires that the Bt field must be within 1.6 kilometers of the refuge crop. It is even better if the field-border-to-field-border-distance is maintained closer to 2.4 kilometers.

Community Refuge Option

It is very difficult for small growers in other countries to adhere to refuge requirements developed for large growers in the United States. The minimum distance and 40-meter refuge plots' width, announced in EPA's 2001 revisions to the refuge requirements, are difficult for small growers to meet. A variety of field configurations could also make it difficult for large growers to follow either of the two options above. A group of farmers may have a community refuge plan that qualifies as a resistance management strategy. Additionally, there is merit to the concept of multiple growers in an area working together to ensure that the Bt cotton and refuge fields are appropriately sized and placed to provide optimum insect resistance management value, while providing for more flexibility in refuge field placement than can be achieved by an individual grower working alone. There are no limits on the number of growers or the area that can be covered in a community refuge plan. The community refuge plan must meet the requirements of either the 20 percent sprayed option or the 5 percent unsprayed option, or an appropriate combination of the two options. The larger area bounding the entire group of farms would form a geographic "community," and the refuge requirements would apply to the community of growers and the geographic community exactly as they apply to a single grower. The 5-percent embedded refuge option is not allowed for use by a community group.

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The Performance of Bt Cotton Hybrids in India

Palanisamy Ramasundaram, Central Institute for Cotton Research, Nagpur, India

The development of Bt cotton represents a technical change in cotton production. This technological breakthrough has the potential to expand the production frontier of cotton and improve producer welfare (Edge *et al*., 2001). In India, commercial cultivation of Bt hybrids was provisionally approved in March 2002 for the southern and central states for three years, subject to review of its performance. In 2004/05, Mahyco-Monsanto sold 700,000 packets of MECH Bt cotton hybrids, and Rasi Seeds sold another 400,000 packets of RCH-2 Bt hybrid. Each packet contains enough seeds to plant 0.4 hectare (one acre).

A survey of Bt cotton cultivators was conducted in 2002/03 and 2003/04 to investigate the performance and constraints in harnessing this new technology. The survey was conducted in two phases – one during the season and the other after the crop harvest (March-April). The 2002/03 survey covered 56 Bt cotton producers who had planted MECH 162 and MECH 184 Bt hybrids and Ankur 651 and NHH 44 conventional hybrids. As the repeat adoption was less than 40% during the second year, the second year's sample included additional cultivators, besides the repeat adopters. During the initial visits the observations on source and cost of seed, acreage, awareness of cultivation practices, and expected yield, price, and reduction in plant protection expenses were recorded. During the post-harvest visits details on actual costs and returns and constraints were recorded. Only one visit was made in 2004/05, after sowing, to determine the adoption or discontinuation pattern.

The average holding of Bt cotton cultivators was 6.3 hectares (ha) during the year of introduction. The average number of years of schooling of the cultivators was 9.5. All producers had provisions for protective irrigation for the crop. During the second year, the irrigation status remained the same, while the average size of holding and literacy level of adopters went down substantially.

The differences in the cost of planting seed, sowing, and plant protection were obvious and considerable. The cost of Bt planting seed was US$100 per ha, compared with US$34 per ha for conventional hybrids. Plant protection costs in Bt hybrids dropped by half to US$24 against US$49 in conventional hybrids. The reduction in plant protection cost was attributed to the reduced number of sprays, particularly against bollworms. Overall, the pest situation in the study area during the periods of reference was not alarming. The favorable pest situation lessened the advantage of the technology in reducing the cost of plant protection. The results showed that the gross and net returns per ha were higher for Bt (US$542 and US$262 respectively) than for conventional hybrids (US$438 and US$206 respectively), but the benefit-to-cost ratio was slightly less (2.07 for Bt against 2.17 for conventional hybrids), reflecting the high cost of seed. Many producers contended that the added picking cost was due not merely to additional yield, but also to the relatively small boll size of Bt hybrids (particularly in MECH 162), necessitating more labor (Ramasundaram, 2004). The discontinuance rate was high, mainly because of the less-than-expected performance, even though the returns were positive. Most discontinuation was motivated by disenchantment. Non-repetition of Bt hybrids was related to the previous year's experience. It was observed that non-adopting farmers were much better informed about Bt performance than were their counterparts who had never used the technology (Qaim and de Janvry, 2002).

The second-year crop performance was better than 2002/03 in general, supplemented by better prices. Further, the level of expectation had gone down, and there was a higher level of awareness about the technology (that it is specific to target pests and not a "no spray" cotton remedy for all pest maladies in cotton) as had been believed the previous year, with farmers freely using terminology like Bt, non-Bt, and refuge. The total cost of Bt as well as conventional hybrid cotton cultivation increased slightly, to US$289/ha and US$238/ha respectively. The average seedcotton yield was 1,248 kg/ha in Bt against 963 kg/ha in conventional hybrids. The gross and net returns from Bt cotton were US$624/ha and US$335/ha, against US$476/ha and US$238/ha from conventional hybrids.

The two-year average showed that Bt hybrids gave higher seedcotton yields than conventional hybrids (1,210 kg/ha against 969 kg/ha), with corresponding additional returns. Partial budgeting showed additional returns of US$142/ha in savings in plant protection (US$28/ha) and higher yield or savings in yield loss (@201 kg/ha worth US$114) and added costs of US$83/ha with higher seed cost (US$64/ha) and picking expenses (US$11). The net benefit was on the order of US$62/ha.

Respondents endowed with higher irrigation and cropping intensities appreciated the early crop termination in Bt hybrids. Early termination encouraged growers to use refuge seed for gap filling in Bt cotton.

The major constraints identified among Bt cotton producers were the high price of seed, the crop's continued vulnerability to sucking pests, the absence of refuge (used in-lieu for gap filling), the small boll size (particularly for MECH 162), incidences of wilt, high rates of discontinuance, and weak education and poor monitoring. During the 2003/04 survey, discontinuance because of disenchantment was witnessed. However, the follow-up surveys in 2004/05 revealed that 55% of the respondents of the previous year had already exhibited discontinuance of a replacement nature, shifting to just-released RCH-2 Bt. It will be pertinent to point out here that Bunny, Ankur 651, NHH 44, and PKV Hy-2 are the ruling hybrids (and RCH-2 was a popular hybrid until recently) in the region, accounting for more 75% of the crop area, while MECH non-Bt did not figure in the sample farms, barring the refugia supplied along with Bt. Hence, a Bt version of any of these ruling hybrids has powerful replacement potential.

Conclusion

The yield increase (in the case of MECH 184) and reduction in plant protection expenditure have been significant, but lower than expected from the technology, particularly for early adopters. However, even this performance arouses hopes of better returns in case of severe incidences of target pests. But with prevailing planting seed prices, the net benefit from the adoption of Bt technology does not unambiguously favor adoption of Bt cotton. The poor refuge practices call for serious attention with the expanding area of Bt cotton (Jayaraman *et.al*, 2005).

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