



THE ICAC RECORDER

International Cotton Advisory Committee

Technical Information Section

Discover natural fibres 2009

VOL. XXVII No. 4
DECEMBER 2009

Update on Cotton Production Research



Contents

Introduction

In the last 20 years, the share of plant protection chemicals (pesticides) measured by sales value used to grow cotton declined from 11% of all pesticide sales in 1988 to 6.8% in 2008, a decline of about one-third. Similarly, the share of insecticides formulated for use on cotton declined from 18.9% of all insecticides sold for use in agriculture in 2000 to 15.7% in 2008. In addition, ICAC Production Practices reports published every three years, and other reports, which are not necessarily focused on cotton production practices, generally indicate that the number of insecticide sprays per season is going down in most countries. The decline in the use of pesticides on cotton is very encouraging with respect to the environmental impact of cotton production.

Many factors are contributing to the reduced use of pesticides, including insecticides, in cotton production. Some of reasons for the decline are easily quantified, while others are more subjective and must be measured through surveys. This article does not report new survey results or studies of pesticide use. Instead, the article discusses in detail some factors responsible for the decline in the use of plant protection chemicals on cotton. The most important factors are the negative consequences of pesticide use, a better understanding of the consequences of pesticide use, the high cost of pesticides, the risks of insecticides on human health, a recognition that insecticides are not a long-term solution to insect control problems, and higher confidence in non-chemical control methods.

The second article is more specific to U.S. cotton production conditions where weeds have developed resistance to herbicides. Weeds can be removed manually with small implements, mechanically through cultivation practices, biologically by employing pathogens or chemically by applying herbicides. Manual weeding of fields or with the help of small implements is not feasible in large-scale production systems such as those used in the USA. Since the adoption of herbicide tolerant biotech cotton in the U.S., farmers have shifted almost entirely to the use of post emergence herbicides, specifically a herbicide sold under the trade name of Roundup. The commercial release of Roundup Ready Flex cotton allows farmers to spray Roundup on cotton until a week before picking. However, the repeated use of the same chemical on Roundup Ready® biotech cotton has given rise to weeds resistant to the herbicide Roundup, and those weeds are now difficult to control. U.S. cotton growers cannot go back to interculturing to remove weeds, so they are looking for newer technologies to tackle the weed resistance problem. LibertyLink® herbicide resistant biotech cotton is already commercialized. The U.S. Department of Agriculture approved the GlyTol™ glyphosate-tolerant technology for cotton in May 2009. Bayer CropScience reported at the 2009 Beltwide Cotton Conferences that they have developed a double gene herbicide resistant biotech cotton called GlyTol™ + LibertyLink®. If approved by the USDA, GlyTol™ + LibertyLink® will be the first stacked gene herbicide tolerant cotton. All these technologies, and the herbicide resistance problem, are discussed in detail in this article.

India is the only country where all the four cultivated species of cotton are grown commercially. In 1947/48, *G. hirsutum* varieties were planted on only 3% of the total cotton area—97% of Indian cotton area was planted to diploid species. India started growing hybrids on a commercial scale in the early 1970s, and it is estimated that 85% of the cotton area in 2009/10 was planted to inter and intra species of commercial cotton hybrids. Biotech cotton, which is also mostly F_1 hybrids, was planted on 80% of the cotton area in 2009/10. In India, research on cotton breeding is undertaken in the public sector, as well as in the private sector. In the public sector, the Central Institute for Cotton Research (CICR) of the Indian Council of Agricultural Research (ICAR) is the apex federal agency working on variety development. The Indian private sector is very active in developing new varieties and hybrids. Private seed companies supply most planting seed. The third article in this Recorder describes the variety development and seed production systems in India. Contributions to this article from Dr. Vinita Gotmare of the Central Institute for Cotton Research, Nagpur, India are appreciated.

The ICAC RECORDER (ISSN 1022-6303) is pulbished four times a year by the Secretariat of the International Cotton Advisory Committee, 1629 K Street, NW, Suite 702, Washington, DC 20006-1636, USA. Editor: M. Rafiq Chaudhry <rafiq@icac.org>. Subscription rate: $200.00 hard copy, $165.00 electronic version.

Award – ICAC Cotton Researcher of the Year

Last year, the ICAC decided to honor a distinguished cotton researcher each year beginning in 2009. An Award Panel, anonymous to the ICAC Secretariat, consisting of five recognized experts from at least four countries, was formed to select an outstanding cotton researcher of the year 2009.

The Award Panel is independent in its evaluation and decision. Applicants are required to submit information in a uniform format. Non-English speaking countries can send the same information translated into English and apply for the award. Researchers from all disciplines of production research are eligible for the award.

The first ICAC Cotton Researcher of the Year, Dr. Keshav Raj Kranthi of the Central Institute for Cotton Research, India, was honored at the 68th Plenary Meeting of the ICAC in Cape Town, South Africa. He received a shield, an honorarium of US$1,000 and the title "ICAC Cotton Researcher of the Year 2009."

The recognition of a distinguished cotton researcher will continue. Researchers from the ICAC member countries can apply for the award starting in February 1 until March 31, 2010. All information including how to apply and where to apply is available on the ICAC web page <http://www.icac.org/tis/researcher_of_the_year/english.html>. The winner will be announced on May 1, 2010 and he/she will be invited to attend the 69th Plenary Meeting of the ICAC to be held in Lubbock, Texas, USA where he/she will be awarded a shield, an honorarium and a certificate.

10th Meeting of the Southern and Eastern African Cotton Forum (SEACF)

Zambia will host the 10th Meeting of the Southern and Eastern African Cotton Forum (SEACF) in Lusaka from 9-11 March, 2010. The business meeting of SEACF will take place on March 9/10, and a workshop on "Soil Health in Cotton" on March 11, 2010. During the business meeting, country representatives will be asked to make 15-minute presentations on recent developments and changes in cotton production research in their respective countries. Information regarding the dates and venue will be available at a later stage. The agenda of the meeting will be circulated to all member countries via the ICAC's SEACF electronic mailing list, and information will be sent directly from the SEACF Secretariat to national contacts in countries of the region. All questions can be addressed to the Secretary of SEACF, Dr. Annette Swanepoel, at <aswanepoel@agri.ncape.gov.za> or the Chairman of SEACF, Dr. Graham Thompson, at <GThompson@arc.agric.za>. Representatives from outside the SEACF region are also welcome to attend the meeting.

11th Meeting of the Latin American Association for Cotton Research and Development (ALIDA)

The 11th Meeting of the Latin American Association for Cotton Research and Development (ALIDA) will be held in Resistencia, Chaco, Argentina from June 23-25, 2010. Preparations are underway, and all information will soon be posted on the ICAC web page at <http://www.alida-algodon.org/english.html>. Participation in ALIDA meetings is open to all countries; ALIDA meetings are conducted in Spanish. The ICAC is sponsoring the meeting and encourages researchers from the region to attend the meeting. The Government of Argentina has nominated Ing. Agr. Diana Piedra as the Coordinator of the meeting. She can be reached at the following address.

Ing. Agr. Diana Piedra
INTA
Centro Regional for Formosa, Chaco
Argentina
Email: dpiedra@correo.inta.gov.ar
Phone: (54-3722) 426-558/427471 Ext. 105

9th Joint International Conference CLOTECH' 2010

The 9th Joint International Conference CLOTECH'2010 on Innovative Materials and Technology in Made-up Textile Articles and Footwear will be held from May 27-28, 2010 at the Technical University of Radom, Poland. Registration is already open, and additional information can be obtained as follows:

Dr. Kazimierz Pulaski
Technical University of Radom
Faculty of Materials Science, Technology and Design
Department of Design, Footwear and Clothing Technology
26-600 Radom, Chrobrego 27
Poland
Fax (48-48) 361-7576
E-mail: i.stanik@pr.radom.pl
m.pazdzior@pr.radom.pl

Why Insecticide Use on Cotton is Declining!

Pesticides include insecticides, herbicides, fungicides, acaricides and other chemicals used to control insect pests and other pests. Insecticides for the control of arthropods and herbicides for the control of weeds are the two major groups of pesticides used in agriculture to control pests. No exact data are available to quantify the amounts of each insecticide or group of insecticides used on cotton versus other crops. This is the reason why different publications refer to different quantities, which in most cases range from too high to outright exaggeration. The other important factor that complicates the estimation of the quantity of insecticides sprayed per hectare to produce a kilogram of lint is the inability to pinpoint whether the author is referring to an active ingredient or to a formulated quantity of the insecticide. Sometimes, even the terms *insecticide* and *pesticide* are used interchangeably or insecticides+herbicides+ all other chemicals are lumped together as insecticides. These categories may be mixed up unintentionally, but the fact remains that the conclusions drawn from them confuse the public and unjustifiably stigmatize cotton as the top consumer of toxic chemicals in the world. Cotton is usually planted on about 33-34 million hectares, which is about 3% of the arable land in the world, but cotton's share of insecticides and pesticides used worldwide is about 16% and 7% respectively. There are other crops, such as vegetables and fruit that are planted on a much smaller area but are sprayed more often that cotton. Such high-value crops evoke no grave concerns because the area planted is so small that it is difficult to even ascertain the share of plant protection chemicals consumed by them. It should be born in mind that if the broader term *agrochemicals* is used, it would include fertilizers, which make up a much larger group of chemicals.

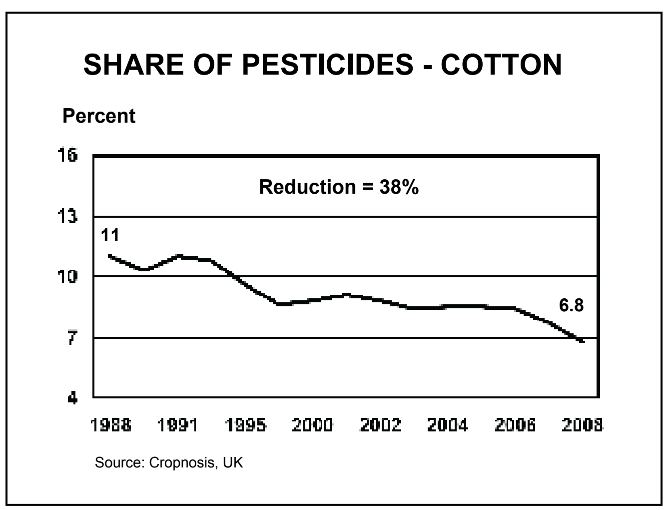
The Food and Agriculture Organization of the United Nations has defined the term *pesticide* as: *Any substance or mixture of substances intended for preventing, destroying or controlling any pest, including vectors of human or animal disease, unwanted species of plants or animals causing harm during or otherwise interfering with the production, processing, storage, transport or marketing of food, agricultural commodities, wood and wood products or animal feedstuffs, or substances which may be administered to animals for the control of insects, arachnids or other pests in or on their bodies. The term includes substances intended for use as a plant growth regulator, defoliant, desiccant or agent for thinning fruit or preventing the premature fall of fruit, and substances applied to crops either before or after harvest to protect the commodity from deterioration during storage and transport.*

Pesticide Use on Cotton by Value

In addition to herbicides and insecticides the third major plant protection chemical used in agriculture is fungicides. All other chemicals, including growth regulators, defoliants, desiccants, etc., make up less than 5% of the total consumption of plant protection chemicals. Cropnosis, a private company in the UK, maintains a long-term database on the dollar value of plant protection chemicals used to grow crops. The Cropnosis data show that plant protection chemicals worth US$44 billion were used in the world in 2008. Out of US$44 billion, plant protection chemicals worth only US$3 billion, or less than 7%, were used on cotton in 2008. The chart below shows that cotton's share of plant protection chemicals has declined by about 40% in 20 years, which is dramatic, and the trend is continuing. The low share of plant protection chemicals used on cotton could be due to either an increase in the amount of money spent on plant protection chemicals used on other crops, or to a decrease in the use of chemicals on cotton. Data on the consumption of pesticides on cotton show that in the eleven years since 1998, plant protection chemical use on cotton, by value and in real terms, increased by 17%, or 1.6% per year. While this increase could be due to increases in prices, during the same period, plant protection chemicals use on all crops including cotton increased by 50%, which shows that pesticide use on cotton, in terms of sale value, has in fact decreased since 1998.

Insecticide Use on Cotton by Value

Most countries started using insecticides during the 1970s, and the trend continued during the 1980s. Insecticide use on cotton, in general, reached its peak by 1990. As a region, Central America reached the 1990s stage earlier than most others. This was due to the widespread attack of the boll weevil (*Anthonomus grandis)* and the inability of the region as a whole to prevent the spread. Consequently, the boll weevil population density continued to grow, requiring more frequent sprays. Though individual countries adopted insecticides at different times, by the late 1980s insecticide use had become an integral component of cotton production systems. Those were the times when it was hard to believe that it might be possible



to produce a successful cotton crop without insecticides. The Cropnosis data show that herbicide use on crops other than cotton is even more extensive.

Data on the market value of plant protection chemicals show that almost double the amount of money is spent to buy herbicides compared to insecticides. Fungicide use, in terms of purchase price, has increased by over 80% in the last 10 years, reaching almost the same level as insecticides by 2008. Insecticide use on all crops in the period from 1998-2008 increased by 30%, while it increased by only 8% in cotton despite the fact that insecticide use is more widespread on cotton. Herbicide use on cotton equaled 31% of the value of pesticides in 2008. Fungicides amount to less that 4% of the plant protection chemicals used on cotton, but their share is on the increase. Defoliation is a pre-requisite for machine picking. Defoliants are covered under the category of *other chemicals* and that is why *other chemicals* account for almost 10% of all chemicals used on cotton. Among plant protection chemicals, *other chemicals* account for less than 5% of all chemical substances used on all crops.

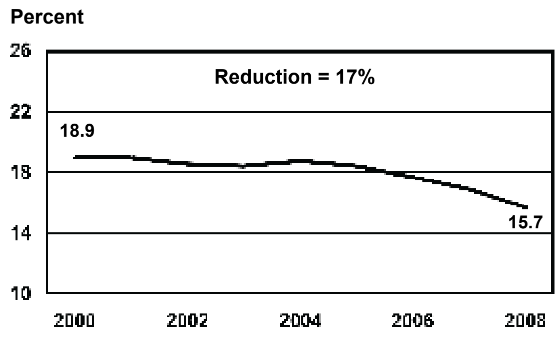
Cotton is often portrayed as the heaviest user of plant protection chemicals, particularly insecticides. Data on sales values from 1998 to 2008 show that insecticide use on cotton is also on the decline. In 11 years, cotton's share of insecticide use, in terms of purchase cost, decreased from 18.9% to 15.7%, or by 17%. Apart from insect resistant biotech cotton, which has directly contributed to the reduction of chemical control against bollworms, a number of other areas of research are being explored to minimize the use of insecticides.

Factors Responsible for Lower Use of Insecticides

Many factors have contributed to the reduced use of insecticides, some of them can be quantified while others cannot and must still be measured through surveys. This article does not contain any survey results or studies. It is rather an effort to encourage researchers to undertake studies on the factors discussed herein. The ICAC's Production Practices reports, published every three years, and other reports, which are not necessarily focused on this issue, generally indicate that the number of insecticide sprays per season is going down in most countries. The following factors may have contributed to the reduced use of insecticides:

- Countries have suffered negative consequences from pesticide use,
- Consequences are better understood,
- Chemicals are expensive - cost of production,
- Insecticides are dangerous,
- Insecticides are not a long-term solution,
- Confidence in non-chemical control has increased.

SHARE OF INSECTICIDES - COTTON



Source: Cropnosis, UK

Countries Have Suffered

Implementation of a successful insecticide use program in any country requires collaborative efforts by governments, researchers and farmers. All these segments of the industry, including extension services, public or private, used to work jointly to promote the use of insecticides. Some countries even fixed targets for the area to be sprayed with insecticides, and many governments actually subsidized insecticide use. Promotional campaigns to popularize insecticide use were undertaken by governments in consultation with researchers. In some cases, governments were directly involved in insecticide sales to growers, although this did not mean that governments were promoting insecticides for the sake of profit. Governments and researchers promoted the use of insecticides because the long-term consequences were not understood. With the extensive use of insecticides, countries started to see the development of resistance, the need to use them repeatedly, and change in the pest complex and resurgence of secondary pests. Australia is among the countries that suffered the most from bollworms that developed resistance to insecticides. Insecticide had a similar impact in West African countries. China, India and Pakistan, three countries that used insecticides extensively, also suffered because of the development of resistant bollworm populations.

As far as cotton production is concerned, Australia was among the first countries to implement a resistance management program. China also implemented a successful program when the adverse impact of insecticide use became apparent in the early 1990s. West African countries also realized the significance of the insecticide resistance problem. Owing to the similarity of production practices and pest complexes in the West African region, local cotton companies joined forces to tackle the problem collectively. Cotton companies assigned their researchers to a region-wide program that proved successful. Traore (2008) reported that the new calendar based program, known as the windows program, was designed and set in motion as a reaction to the appearance and expansion of the problem of resistance to pyrethroids. Later, two- and three-window programs were also implemented in the West

African countries. The window programs helped stop the problem of caterpillar resistance to pyrethroids. More details about window programs can be found in the paper by Traore (2008).

China implemented a successful integrated pest management program of its own that was subsequently made redundant by the introduction of insect resistant biotech cotton. If China had not commercialized biotech cotton, the performance of cotton yields in the country might have been very different. Planting cotton in conjunction with crops such as soybeans, which are also attacked by bollworms particularly in the Yellow and Yangtze River Valleys, would have complicated the successful implementation of window programs. In the beginning of the 1990s, cotton area in both valleys declined because of the resistance problem. India and Pakistan also faced a similar insecticide resistance problem, albeit less severe. With funding from the Common Fund for Commodities (CFC), ICAC implemented a project entitled "Sustainable Control of the Cotton Bollworm *Helicoverpa armigera* in Small-Scale Cotton Production Systems (CFC/ICAC14)" which ran from 2000 until recently. The project involved China, India, Pakistan and the Natural Resources Institute of the UK. Details about the project are available on the ICAC web page at http://www.icac.org/projects/CommonFund/BollWorm/english.html. Other countries, not mentioned here, also suffered from the insecticide resistance problem coupled with secondary pests and even new pests.

Consequences Are Better Understood

For a long time, both promoters and users of insecticides did not properly understand the long-term consequences of insecticide use. Researchers and growers came to recognize those consequences slowly during the process of adoption and popularization of insecticide use. Insecticides were used on other crops, but they were more extensively used on cotton. So, in this regard cotton proved to be the lead crop for a more judicious use of insecticides than other crops. Today we know that early use of pyrethroids can bring about a flare-up of mites at their maturity period; repeated use of pyrethroids develops resistance in caterpillars; doses that are lower or higher than recommended have negative impacts; mixing of insecticides may also be harmful, and the mechanisms are all better understood than before. Similarly, positive aspects of insect control, such as life cycle studies of target insects, determination of threshold levels, replacement of calendar based spraying with economic threshold spraying, use of proper spray machinery and other methods, are also better known now than at the time of the introduction of insecticides.

Many factors converged to help educate researchers and cotton growers. Governments vigorously expanded their programs on entomological research, and in many countries entomological studies surpassed breeding research, which is usually considered to be the most intensely researched area in cotton. More funding for entomological research attracted more talent and more manpower, and while governments and researchers played their roles, pesticide companies also made heavy investments in education about the consequences of extensive use of insecticides. They hired talented young entomologists, provided attractive remuneration and tried their best to perfect the use of insecticides on a scientific footing. Companies teamed up with public sector researchers and liberally voiced their shared concerns about various products. Governments tightened their pesticide registration rules, and the pesticide companies collaborated with public sector researchers to test new products. Consequently, researchers knew a lot more about new products even before they were registered for commercial use and, more importantly, farmers in developing countries were no longer haunted by the spectrum of impending bollworm infestations that would otherwise cause severe crop damage thereby reducing their production (Kranthi, 2009).

Thus, as the problems/consequences of insecticide use became apparent, all segments of the pesticide chain got better connected to each other. However, while pesticide companies were targeting sustained used of insecticides, researchers were working to minimize their use. At one stage, pesticide companies realized that the long-term future for insecticide use in agriculture was diminishing and started curtailing their investments and manpower. Companies developed better products for use in agriculture in terms of target-specific soft chemicals that were less carcinogenic and had fewer unwanted effects.

Chemicals Are Expensive

When insecticides became an integral component of production systems, they increased the cost of production of cotton to uneconomical levels. The Central American countries suffered the highest insecticide costs, which ultimately led to abandonment of cotton production in the region. ICAC data on the cost of production of cotton (ICAC, 1992) show that insecticides accounted for 28% and 37% of the total cost of production in Guatemala and Nicaragua in 1990/91. A similar situation prevailed in El Salvador and Honduras. No country in the Central American region grows cotton any more. The same pest, the boll weevil *Anthonomus grandis* that created havoc in Central America has now moved south to Argentina, Brazil, Colombia and Paraguay. Bolivia also suffered from boll weevil infestation and no longer grows cotton.

Cost of Production in Central American Countries - 1990/91

Country	Total Cost of Production/ha	Insecticides	
	US$/ha	US$/ha	% of Total Cost
Guatemala	1,673	470	28%
Nicaragua	1,181	433	37%

Cost of Insecticides Used on Cotton in Selected Countries

Country/region	Cost of Insecticides+Seed as % of Total Cost 1994/95	2006/07
Argentina	2	4
Australia (Irrigated)	13	9
Brazil (Northeast)	13	10
Chad (Animal Traction)	12	NA
China (Mainland)	20	12
Colombia (Sinu)	21	9
Cote d'Ivoire	8	14
India (North)	14	4
Mexico	16	12
Pakistan (Punjab)	17	18
Sudan (Gezira, Acala)	19	20
Syria	1	< 1
Turkey (Cukurova)	19	8
Uganda	19	NA
USA (National)	12	11
Zimbabwe	9	NA

The ICAC data on cost of production (ICAC 1995; ICAC 2007) show that by 1995 insecticide costs had reached almost 20% of the total cost of production (under self-cultivated conditions) in many countries. This was the time when the rising cost of production, due mainly to insecticides, became a significant concern for the cotton community. Countries started designing ways to lower their cost of production, and insecticides were one of their first considerations. Farmers wanted to lower their cost of production, and also reduce other ill effects of insecticides on the community and their negative impact on natural biological control. Data comparing insecticide spending for 2006/07 as compared to 1994/95 (see table above) show that most countries lowered their insecticide outlays. Countries where insecticide costs did not decrease in 2006/07 compared to 1994/95 have either specific reasons or they have failed to take steps to lower the use of insecticides. Argentina is a special case where expenditures on insecticides are very low. In Pakistan, the number of sprays against the traditional bollworms certainly declined, but sprays against the leaf curl virus increased significantly. Moreover, it may safely be said that Sudan needs to take a serious look at its insecticide control system. In order to remove any doubts that the lower figures for 2006/07 in the table above might have been biased by the introduction of insect resistant biotech cotton, the cost of planting seed was factored into the cost of insecticides.

Insecticides Are Dangerous

Insecticides were a danger to humans before and they are a danger now, despite the fact that, over time, milder insecticides have been developed. However, awareness about toxicity and the consequences of inhalation have become better known and more widely recognized than they were before. Take the example of Dichlorodiphenyl-trichloroethane (DDT). DDT was discovered in 1939 and introduced for commercial use in the U.S. in 1947. Paul Hermann Müller was awarded the 1948 Nobel Prize in Physiology and Medicine for his work to develop DDT, and the product was used for decades in most countries of the world. However, DDT came under increasing suspicion of causing cancer and, in 1972, despite the lack of evidence of any fatal poisoning or other adverse effects on humans, it was banned in the U.S. The deleterious effects of DDT were later confirmed.

The pesticides that replaced DDT, such as dieldrin and aldrin, were far more toxic and have been responsible for many deaths. Because of the low cost of DDT and the absence of equally effective substitutes with low toxicity, it continued to be used for many years before it was actually banned. There are plenty of references confirming the detection of DDT in breast milk in areas where DDT was used to control malaria. Brunetto *et al.* (1996) studied levels of DDT residue in 145 breast milk samples 25 days postpartum from women living in various rural populations where DDT had been used in farming activities to interrupt malaria transmission. All participants showed quantifiable levels of DDT residue in the range from 5.1 to 68.3 µg/l and their levels significantly increased ($P < 0.05$) with maternal age. The determination of DDT residue (as DDE) in human milk was performed after a saponification process by gas chromatography with electron-capture detection. Confirmatory analysis was achieved using high-performance liquid chromatography with diode array detection. Detection of DDT in human milk, which was traced back to milk from cows fed on fodder sprayed with DDT was one of the factors responsible for the call to ban DDT.

Insecticide application requires sprayers creating an insecticide mist to cover all plant parts where insects may hide. Growers with smallholdings of a few acres cannot afford helicopters or tractor-mounted sprayers. They have to rely on small backpack sprayers that may be powered with a small engine or by a manually operated pump to build pressure. Mathews, (1992) has extensively discussed spray technology and appropriate nozzles for effective spraying in his book Pesticide Application Methods. He recommends optimum droplet size by insect type and says that if the target is a flying insect, a droplet size of 10-50 mµ in diameter is the most appropriate for good control. Foliage insects can best be controlled with 30-50 mµ diameter droplets, but if the objective is to cover the foliage properly, then the size of the droplets can be increased to a diameter of 40-100 mµ. To provide soil treatment while preventing mist drift, the recommended droplet size is > 200 mµ diameter. Thus, one may readily appreciate that the spraying operation itself is complex and entails risks.

Spray operators can inhale small particles, or they may drift to non-target crops (fruits or vegetables), and the risk of direct contact during dilution and pouring into spray tanks is always significant. Reports show that the number of incidents of insecticide inhalation reported at hospitals decreased significantly in China as a result of decreased exposure to insecticides in areas planted to insect resistant biotech cotton. Protection from inhalation or from any exposure to insecticides during spraying and handling requires protective uniforms for the spray operators. Farmers often fail to comply with the instructions provided by pesticide companies or experts. It is difficult to corroborate, but the media in India have carried many reports of people drinking insecticide to commit suicide. Awareness of the consequences of insecticide inhalation has grown with the use of insecticides.

Not a Long-term Solution

In the beginning, insecticides were presumed to be the absolute solution to insect problems and that was why governments subsidized and promoted insecticide use. There is no doubt that early on, insecticides provided good control, and they still do, if used and managed properly. Farmers were particularly impressed, as were researchers, to see insects dying right before their very eyes as they sprayed insecticides. Dramatic, or even complete elimination of heavy populations of insects in the field verified through pest surveys a few days after spraying insecticides, along with the subsequent impact on yields, convinced growers that they had found the right solution to their insect problem. Those conclusions were undoubtedly right, but after continuous use of insecticides over a period of at least a decade, they discovered that insecticides were not the long-term solution they had thought. Issues such as secondary pests, development of resistance, and so on, proved to be undermining the impact of insecticides convincing researchers and growers alike that insecticides were not the long term solution to the problem at all.

Confidence in Non-chemical Controls Increased

Prior to the development of insecticides during World War II and their introduction in agriculture as plant protection chemicals, insects were controlled through naturally occurring biological agents. Even agronomic measures, like uniform planting dates, similarly behaving varieties/zoning of varieties, removal of cotton stalks from cotton fields, elimination of pest-sharing intercropping production systems, use of shorter duration varieties, etc., were not popular. Agroecosystems had not been properly defined and sufficient knowledge about insect behavior was scarce. Host plant resistance programs like the one popular in the USA called "Multi Adversity Resistance" and integrated pest management were yet to be explored.

Countries employed a great many resources in learning the appropriate use of insecticides. Threshold levels for various insects were determined, significant progress was made in terms of spray machinery, detailed studies were undertaken on insect biology and ecology, bio insecticides/agents were developed, confusion or sex pheromone technology was invented, sterile moth technology was developed, artificial rearing of predators and parasites became commercial and now even biotech cottons are available. Unfortunately, none of those technologies alone could be considered or adopted as a substitute for insecticides. All insect control technologies, except for insect resistant biotechnology, were defeated in practical terms by insecticides, despite the fact that some of the technologies had great potential to be used successfully. Integrated pest control became recognized as a successful approach in the late 1950s and ultimately was developed by FAO into what became known as integrated pest management (IPM) in the early 1960s. IPM has been a catchword for almost half a century, but is not yet fully utilized. It is an effective and environmentally sensitive approach to pest management that relies on a combination of common-sense practices. IPM programs use the latest and most comprehensive information on the life cycles of pests and their interaction with the environment. This information, in combination with available pest control methods, is used to manage pest damage by the most economical means, and with the least possible hazard to people, property, and the environment.

According to the Food and Agriculture Organization (FAO) of the United Nations, IPM means *the careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and reduce or minimize risks to human health and the environment. IPM emphasizes the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms. FAO has organized many regional and crop specific workshops/meetings to promote IPM as the preferred approach to crop protection and IPM is regarded as a pillar of both sustainable intensification of crop production, and pesticide risk reduction. Even where IPM techniques have been implemented to their maximum, if not their fullest potential, chemical control has prevailed over all other choices because of its ability to provide a quick fix to insect problem. The trend is now reversing with researchers and growers placing greater confidence in non-chemical control measures in cotton.*

References

Brunetto, Rosario, Andrés León, J. L. Burguera and M. Burguera. 1996. Levels of DDT residues in human milk of Venezuelan women from various rural populations. *Science of The Total Environment*, Volume 186, Issue 3, 1996, Pages 203-207.

Cropnosis Agrochemical Service. Cropnosis Ltd, One St Colme Street, Edinburgh, EH3 6AA, UK, January 2009 (Also available on line by subscription at http://www.cropnosis.com/marketing/products).

Kranthi, Keshav R. 2009. Challenges and opportunities in cotton production research. *THE ICAC RECORDER*, Vol XXVII, No. 3, September 2009.

Mathews, G.A. 1992. *Pesticide Application Methods.* 2nd Edition. Longman Scientific & Technical, Longman Group UK Ltd., Longman House, Burnt Mill, Harlow, Essex CM20 2JE, England.

Technical Information Section. 1992. *Survey of the Cost of Production of Raw Cotton*. International Cotton Advisory Committee, Washington DC, USA, September 1992.

Technical Information Section. 2005. *Survey of the Cost of Production of Raw Cotton.* International Cotton Advisory Committee, Washington DC, USA, October 1995.

Technical Information Section. 2007. *The Cost of Production of Raw Cotton*. International Cotton Advisory Committee, Washington DC, USA, October 2007.

Technical Information Section. 2008. *Cotton Production Practices.* International Cotton Advisory Committee, Washington DC, USA, November 2008.

Traore, Ouola. 2008. Positive developments in integrated pest control for cotton in West Africa. In *Improving Sustainability of Cotton Production in Africa,* papers presented at the Technical Seminar at the 67th Plenary Meeting of the International Cotton Advisory Committee, Ouagadougou, Burkina Faso, November 2008.

Herbicide Tolerant Biotech Cotton: The Resistance Issue in the USA

Weeds may be annual or perennial, but they are always found in cotton fields everywhere unless proper control measures are taken. Early weed competition in the first few weeks after germination can cause significant yield losses. Weed infestation can deprive the cotton plant of proper growth, change its branching scheme, and change the overall shape of the plant. When cotton is in its flowering stage, weeds compete with the cotton plant for nutrients, and they also harbor pests. Furthermore, weeds growing outside the cotton crop serve as hosts for insects, mites and pathogens. When harvest time comes along, particularly if the cotton is machine picked, weeds interfere with defoliation. While defoliants will cause cotton leaves to dry and fall, weeds may not defoliate or be killed. Machine picking of weed-ridden fields will produce higher trash content in the cotton lint and result in stained cotton. Thus, a cotton field must be free of weeds from sowing until harvesting. Studies carried out in some countries have indicated that the optimum benefits of fertilizer and insecticide applications can only be achieved if there are no weeds in the field.

Weeds can be removed manually with small implements, mechanically through cultivation practices, biologically employing pathogens or chemically by applying herbicides. Manual weeding of fields or with the help of small implements is not feasible in large-scale production systems such as in the USA. The rising cost of labor is making this system expensive in many more countries. Mechanical control is feasible, but has its own limitations, such as the inability to remove weeds close to the plant, possible damage to the crop, soil compaction and the high cost of inter culturing. Biological weed control is the intentional manipulation of natural enemies for the purpose of controlling target weeds. There are three approaches to biological control: Conservation, augmentation and importation of natural enemy populations. Conservation is the preservation and maintenance of the natural enemies that occur in a given area, but it is rare indeed to achieve effective weed control exclusively through this method. Augmentation is the periodic release of microorganisms or agents that do not occur naturally in sufficient numbers to provide pest control. Augmentative releases may be designed to “seed” natural enemies in numbers large enough to overwhelm weed populations. Importation of natural enemies into areas where they do not occur is sometimes called classical biological control. Natural enemies from the native range of the pest are identified, collected, imported, reared and released. In a best-case scenario, the natural enemy will establish permanent populations and provide control of the pest without the need for further releases. Biological control is often the most environmentally friendly method, but unfortunately, without integrated control practices, it is not the most effective method.

The main drawbacks to biological weed control are: the high cost of the research, time and money needed to find suitable organisms, the time that biological agents take, so that when they finally do work the loss may have already occurred, biological agents must have a population of host plants to survive, so weeds cannot be completely eliminated, and finally, it might just be too expensive to produce and maintain bio agents. This is why biological weed control is not used in any country.

Chemical Control

Chemicals are the most effective and efficient way to control weeds. They may have their own consequences, but the weeds are killed in the minimum possible time. The discovery of 2,4-D and MCPA in 1944 marked the beginning of herbicide use in crops. Chlorpropham, dalapon, and diuron were developed between 1947 and 1954 and were among the first herbicides specifically labeled for use in cotton (Buchanan, 1992). Chemicals can be applied before planting (pre-emergence) so that the field is free of weeds during germination, and then applied again a few weeks after germination, or after planting (post-emergence), depending on the weed species found in the field. Growers are generally aware of their field conditions and have a good idea of the kind of weed that will appear. In addition to pre- and post-emergence applications of herbicides, chemicals may also be applied as lay-by applications if weeds tend to grow in patches in the field. Lay-by applications may also be used together with a mechanical method to control both the weeds growing close to the plant and the ones growing in the rows between plants. However, there is a limit to the time after emergence when post-emergence herbicides can be applied safely without affecting the cotton plant. Selective, post-emergence herbicides (sethoxydim and fluazifop) targeting grassy weeds were commercialized for use in cotton in the early 1980's. However, selective, post herbicides targeting broadleaf weed species were not introduced until 1996 (Wilcut *et al*., 1995). Pyrithiobac was registered for pre- and post-emergence application in cotton in 1996 and remains the only selective, post herbicide without a growth stage restriction for application.

Herbicide Resistant Biotech Cottons

BXN™ Biotech Cotton

The first herbicide tolerant biotech cotton was approved for commercial production in the USA as BXN™ in May of 1995. The BXN™ gene that conferred resistance to the herbicide Buctril (bromoxynil) was "nitrilase" from *Klebsiella pneumoniae* subsp. *ozaenae.* The development of herbicide tolerant biotech cotton revolutionized weed control in cotton. Buctril® 4EC (Bromoxynil) herbicide and the patented BXN™ cotton system allowed growers to effectively control commonly occurring broadleaf weeds in cotton from emergence until 75 days before harvest. Nitrilase gives cotton the ability to metabolize the bromoxynil herbicide, and the weeds will normally be killed in 2-3 days. BXN™ may be sprayed together with Buctril® compounds a maximum of three times from emergence up until 75 days before harvest. Glyphosate-tolerant herbicide-resistant biotech cotton (Roundup Ready®) was approved a few days later than BXN™ cotton. Because Buctril® was previously not registered for use on cotton, Buctril® received a three-year conditional registration, while Roundup Ready® was awarded unconditional approval. For various reasons, including its limited weed control spectrum, competition with the Roundup Ready® trait, and stacking of Roundup Ready® with Bollgard and the Bollgard II genes, BXN™ cotton is now obsolete. BXN™ varieties were last sold around 2004/05.

Roundup Ready® Biotech Cotton

Roundup Ready® biotech cotton was approved for commercial cultivation in the USA in the 1997/98 season. According to Stewart (1991), the mode of action of glyphosate lies in the inhibition of an enzyme 5-enolpyruvylshikimate-3phosphate (EPSP) synthase, which is a key catalyst in the production of aromatic amino acids. Since animals do not synthesize amino acids, glyphosate has low toxicity to birds, fish and mammals including humans, but ample toxicity to plants. Resistance to glyphosate has been accomplished by two different routes. In the first, a strong constitutive promoter was placed in front of a natural EPSP synthase gene so that the enzyme was over produced in the transformed plants. In the second, a mutated bacterial EPSP synthase gene that changed one amino acid in the enzyme protein resulted in the enzyme being insensitive to herbicide. With the appropriate promoter, plants transformed with this gene were resistant to glyphosate. The use of Roundup on Roundup Ready® cotton increased broad-spectrum weed control, minimized competition from hard-to-control annual and perennial weeds, and simplified weed management. Glyphosate has proven to be a reliable herbicide treatment for use on transgenic crops and has improved weed management in the short term. The adoption of herbicide-tolerant cotton, expressed in terms of percent of area planted, was approximately 20% in 1998, 68% in 2001, 73% in 2004, 81% in 2005, 85% in 2006 and over 85% since then. Roundup can be sprayed on cotton only up to the four-leaf stage. Weeds emerging thereafter have to be controlled manually, mechanically or with lay-by applications. Weed species shifts and selection for glyphosate-resistant weeds resulting from over use of glyphosate have been confirmed.

LibertyLink® Biotech Cotton

The Bayer CropScience company developed the LibertyLink® herbicide-tolerant cotton system. LibertyLink® cotton varieties were approved for commercial cultivation in 2004. LibertyLink® varieties were resistant to Ignite® herbicide also called Liberty®, Finale® and Rely®. The chemical name for Ignite® is glufosinate ammonium, so any chemical having glufosinate ammonium can be sprayed over the top of the cotton plant until 70 days prior to harvesting. In terms of growth, Ignite® may be sprayed over cotton until early bloom or, more technically, up to the 10-leaf stage. However, the total seasonal application rate should not exceed 1.9 kg a.i./ha (200 ounces/ha formulated) with no more than 0.7 kg a.i. (100 ounces/ha formulated) to be sprayed in one application. The herbicide application rate may be adjusted according to weed types, weed intensity and weed size. These criteria were, in fact, true for all over-the-top-applications of herbicides. Ignite® was most effective against broad leaf weeds, but grassy weeds can also be killed to some extent. Ignite® had no soil activity and translocation within the plant was minimal. Weeds will show chlorosis, and within 3-5 days weeds will show signs of wilting. LibertyLink® carried an enzyme that converted the herbicide into a non-phytotoxic compound. Liberty 200 herbicide is an inhibitor of glutamine synthetase. It is always better to kill weeds at an early stage, when they are only a few inches tall, but that will require successive applications of Ignite®. Ignite® is very effective against morning glory and cocklebur, while pigweed and nut grasses are not perfectly controlled, nor are grassy weeds. The LibertyLink® herbicide-tolerant cotton system is comparatively a new option for weed management.

Roundup Ready® Flex Biotech Cotton

The Roundup Ready® technology was limited by relatively poor expression of the gene in the reproductive parts of the plant, thus conditioning glyphosate applications exclusively to the period prior to the fruiting stage. The problem of poor gene expression was overcome in Roundup Ready® Flex. The

Roundup Ready® gene and the Roundup Ready® Flex gene use the same coding sequence of the EPSPS gene (enol-pyruvyl shikimate phosphate synthase) from Agrobacterium strain CP-4. The Flex gene is more constitutively expressed so that it is active in the fruiting structures. The Roundup Ready® Flex varieties have much higher levels of tolerance to glyphosate in the vegetative stage as well as the reproductive phase, with an extended over-the-top application window. Roundup Ready® Flex was approved for commercial use in the USA for the 2006/07-crop year. The Roundup Ready® Flex varieties used the same metabolic tolerance expressed in the Roundup Ready® trait. The difference between Roundup Ready® and Roundup Ready® Flex is that Flex varieties posses an improved promoter sequence that enables the plant to tolerate glyphosate herbicides in the vegetative as well as the reproductive stages. Glyphosate products may be sprayed on Roundup Ready® Flex varieties until a week before harvesting. The results of many years of experience shows that Roundup sprayed on Roundup Ready® Flex cotton varieties does not produce any damage on subsequent plant growth and development, yield or fiber quality. Different doses and times of application were tested with no negative impact on the cotton plant.

Glyphosate, being a post-emergence chemical herbicide, that is highly biodegradable controls only emerged weeds and does not keep new weeds from emerging. This means that multiple applications of chemicals are required to have season-long weed control. Roundup Ready® biotech cotton limited the use of glyphosate products to only the four-leaf stage, which meant that only a limited number of applications could be made in a single season. A much wider window, in the form of Roundup Ready® Flex, opened the door for multiple applications of glyphosate, which meant more frequent use of the same chemicals in a single season and the ensuing likelihood of faster development of resistance. Extended use of glyphosate could be intermingled with insecticide applications, and the limited studies conducted by Miller *et al*. (2009) showed that producers may be able to combine multiple pest and crop management strategies to reduce application costs with minimal effect on the crop. The negative effects evaluated in this study of co-applications on Roundup Ready® Flex cotton actively growing at the four- to five-leaf growth stage were limited to minor transient visual leaf vein chlorosis burn that lasted no longer than 21 days and did not result in reductions in crop height or yield. Miller *et al*. (2009) cautioned that if the co-applications evaluated in this research were applied to cotton in early growth stages, especially under less-than-optimal environmental conditions, or to cotton under stress, the potential for injury might increase. The studies are limited exclusively to specific insecticides and to early stage applications of herbicides. Different insecticides/micronutrients/plant growth regulators and herbicide co-applications should be tested independently to avoid losses. In 2008, Monsanto recommended the use of Roundup WeatherMAX® and Roundup Original MAX® on Roundup Ready® Flex cotton, thus confirming that even other glyphosate chemicals have to be used on Flex cotton carefully.

The option to use herbicides at any stage of crop development may result in the temptation to delay herbicide use during the early stages, which is not desirable. Early stage control of weeds is recommended even for Roundup Ready® Flex cotton, but this does not mean that non-chemical control measures should be abandoned. It is very important that an integrated approach continue to be followed with minimum reliance on herbicide use.

Effects of Herbicide Resistant Biotech Cottons

Herbicides provide more timely and targeted weed management with the ability to control weeds that emerge together with the crop or soon after. Herbicides, though expensive, provide efficient and complete control compared to other methods, but continuous herbicide use has its own consequences. The following are some of the consequences of heavy reliance on herbicide use, particularly with cottons that allow a longer window in which to use herbicides.

- Reduced use of inter-culturing and hoeing operations to remove weeds,
- Minimum use of pre-emergence herbicides – Pre-emergence herbicides are applied without knowing the kinds of weeds that will emerge nor their intensity after the cotton germinates. Post-emergence use of herbicides discourages the use of pre-emergence herbicides,
- Extensive use of herbicides,
- Heavy reliance on certain chemicals like Roundup and Ignite®,
- Emergence of resistant weed species - multiple applications of Roundup Ready® Flex over extended periods increases the likelihood of developing resistant weeds,
- Herbicide drift, particularly around irrigation structures, facilitates the development of resistant weeds,
- Volunteer herbicide resistant plants from other crops, such as herbicide resistant corn or soybeans, cannot be killed in cotton fields.

Herbicide Resistance and Its Management

The fact that weeds could develop resistance to herbicides was no surprise to researchers. Extensive use of a particular product, either insecticide or herbicide, enhances the ability and likelihood of the development of resistance to that product. The first report of herbicide resistance occurred in 1960 with the discovery of Trazine-resistant common groundsel (*Senecio vulgaris* L.) and since then many weeds have been found to be resistant to various chemicals.

According to the International Survey of Herbicide Resistant Weeds (http://www.weedscience.org/In.asp), 334 resistant biotypes, 190 Species (113 dicots and 77 monocots), have already developed resistance to herbicides. Herbicide resistance is the inherited ability of a plant to survive and reproduce following exposure to a dose of herbicide normally lethal to the wild type. Just as in insects, cross-resistance or multiple-resistance can also develop in weed biotypes. Characteristics, such as annual growth habit, high seed production, relatively rapid turnover of the seed bank due to high percentage of seed germination each year, (i.e., little seed dormancy), several reproductive generations per growing season, extreme susceptibility to a particular herbicide, resulting in over use of that chemical and high growth vigor of the resistant biotype are the factors that help weeds develop resistance to herbicides (Vargas and Wright, 2005). Herbicide characteristics that lead to rapid development of resistance include: action on a single site, broad-spectrum control and long residual activity in the soil. Some cultural practices can also lead to selective pressure for resistant populations.

Development of resistance to Roundup herbicide means development of resistance to all chemicals carrying glyphosate. However, a resistant biotype may be susceptible to other chemicals. MacRea *et al*. (2006) evaluated LibertyLink® cotton for the management of glyphosate resistant Palmer amarant (*Amaranthus palmeri*). They tried many combinations of pre- and post-applications including lay-by application on Palmer amaranth after it had emerged, and was 6, 12, or as much as 25 to 50 centimeters tall. They concluded that Ignite® 280 provided control of Palmer amaranth (resistant to glyphosate) when the herbicide was sprayed on weed plants 5 cm tall or shorter. Later applications reduced the effectiveness of Ignite® 280 to almost zero control on 50 cm tall weed plants.

Horseweed (*Conyza canadensis*) is a common weed in the mid-south region where most cotton is grown in the USA. Glyphosate-resistant horseweed began to appear within a few years after the widespread adoption of Roundup Ready® crops. Horseweed has the ability to produce from 50,000 to 250,000 seeds per plant (Hayes, and Steckel, 2005). The authors also advised in 2005 monitoring cotton areas for glyphosate resistance in common ragweed, goosegrass, nutsedges, tropical spiderwort, prickly sida, giant ragweed, and the pigweeds, especially Palmer amaranth. Palmer amaranth showed signs of resistance to glyphosate as early as 2004. During the next two years, Palmer amaranth, also known as pigweed or careless weed in the USA, developed significant resistance to glyphosate. Experiments conducted showed that in-field control of Palmer amaranth increased with different chemicals as the herbicide rate increased, but even the highest rates of Roundup WeatherMax® and Staple® LX applied singly and in combination were unable to affect more than 92% control (Sosnoskie *et al*., 2009). When resistance has developed, the target weed biotypes should not be allowed to reach the stage of reproductively mature seeds. No new generation of weed seeds can be allowed to issue from resistant populations of any biotype.

Horseweed in Tennessee and giant ragweed in Arkansas are also reported to have developed resistance to glyphosate. All efforts should be made to avoid development of resistance. Extensive use of a single group of chemicals should be avoided, otherwise resistance becomes extremely likely. Vargas and Wright (2005) suggested the following strategies to delay the development of resistance to a particular herbicide group.

- Alternate herbicides with different modes of action
- Use the minimum number of applications of any one herbicide per season
- Use tank mixes of different modes of action when possible
- Use short-residual herbicides
- Rotate crops with different seasons of growth
- Plant crops having different registered herbicides
- Do not entirely eliminate tillage from the production system
- Use hand weeding to remove escape weeds and prevent them from going to seed
- Prevent weed seed spread by using clean equipment
- Use certified planting seed

To control resistant species like Palmer amaranth, it is recommended to start with clean fields using a burndown herbicide program or tillage. Pre-emergence residual herbicides recommended particularly for the control of Palmer amaranth or other resistant weeds should be used. The philosophy is to ensure that the need for over-the-crop-use of glyphosate compounds is minimal.

New Technologies

The U.S. Department of Agriculture approved the GlyTol™ glyphosate-tolerant technology for cotton in May 2009. Bayer CropScience developed the GlyTol™ cotton event GHB614 as an alternative herbicide tolerant cotton product. GlyTol™ gives cotton growers the flexibility to use glyphosate herbicides other than Roundup products. Flexibility to use different glyphosate products would delay the development of resistance by weeds. According to Bayer CropScience, the transformation event in GlyTol™ contains the stably integrated gene 2mepsps, which encodes the 2mEPSPS protein. The gene was introduced by Agrobacterium-mediated gene transfer. Southern blot analyses show that the GlyTol™ cotton event GHB614 contains one complete copy of the 2mepsps gene. The 2mepsps gene was generated by introducing mutations into the wild-type epsps (wt epsps) gene from maize, leading to a double mutant EPSPS protein with two amino acid substitutions (2mEPSPS). This modification confers to the protein a decreased binding affinity for glyphosate, allowing it to maintain sufficient enzymatic activity in the presence of the herbicide. Therefore, plants bearing this gene are tolerant to glyphosate herbicides (http://www.aphis.usda.gov/brs/aphisdocs/06_33201p.pdf).

GlyTol™ varieties will be commercially grown in the USA in 2010.

Researchers, particularly in the private sector, are working on a number of other herbicide resistance transgenes. Some of these new transgenes will be used to develop new multiple herbicide-resistant cottons that offer growers more herbicide options to meet their changing weed management needs and to help sustain the efficacy of glyphosate. Personal communications with Monsanto indicate that they are working on a triple gene herbicide resistant cotton. It may be available for commercial production in May of 2012, or perhaps later.

Dow AgroSciences has submitted an application to the USDA for a new family of herbicide resistant traits. The technology will be introduced in corn in 2012, soybeans in 2013 and cotton in 2015, and will cover the glyphosate and glufosinate chemical groups.

GlyTol™ + LibertyLink® Herbicide Resistant Biotech Cotton

Bayer CropScience reported at the 2009 Beltwide Cotton Conferences that they have developed a double gene herbicide resistant biotech cotton called GlyTol™ + LibertyLink®. The glyphosate tolerant technology in the form of GlyTol™ expressing the 2mepsps gene has been stacked with LibertyLink® cotton which is resistant to glufosinate ammonium (Ignite®). GlyTol™ + LibertyLink® is expected to be released for commercial use in 2011. If approved by the USDA, GlyTol™ + LibertyLink® will be the first stacked gene herbicide tolerant variety in cotton. Field-testing is still going on and will continue for the next few years, but the results achieved so far are encouraging. Rinehardt *et al*. (2009) reported results of three trials conducted in three different states in order to: 1) to determine if the herbicide tolerance to glyphosate and glufosinate in GlyTol™ + LibertyLink® cotton is affected when crop protection chemicals are tank-mixed, and 2) to determine if GlyTol™ + LibertyLink® cotton can tolerate glyphosate and glufosinate applications at rates that exceed full label rates. The results showed that the tank-mix treatment of glyphosate, glufosinate, and 2-pyridinesulfonamide at the 6-8-leaf cotton stage reduced plant height 10 days after application. However, plant heights for this treatment were not significantly different from those of the unsprayed as checked at harvest. Application of plant growth regulators tank-mixed with glyphosate and glufosinate did significantly reduce plant heights at harvest. Minor foliar phytotoxicity was also observed with tank-mixes of glyphosate, glufosinate and both 2-pyridinesulfonamide (5%) and Pyrithiobac (1%). However, none of these or any other tank-mixes, had any significant effects on lint yield.

The high herbicide rate trials used treatments with 2X rates of both, glyphosate and glufosinate, and 1X, 2X, 3X, and 4X tank -mixes of glyphosate and glufosinate. The results of these trials indicated that there was no significant effect on plant height regardless of rate or timing of application. A visual phytoxicity rating of 6% was observed with the 3X glyphosate + 3X glufosinate tank-mix applied at the 2-4 leaf growth stage. However, no damage was observed with later applications beyond the 2-4 leaf-stage, and there were no significant effects on lint yield.

In trials conducted in 2007 and 2008 across the cotton belt in the USA, Henniger, *et al*. (2009) also showed that GlyTol™ + LibertyLink® plants produced no adverse effects on plant establishment, maturity, vigor, yield and quality following multiple applications of commercial formulations of glyphosate. Multiple applications of glufosinate ammonium, alone or in combination with glyphosate at full rates, showed no effect on the agronomic or reproductive characteristics of GlyTol™ + LibertyLink® varieties.

References

Buchanan, G.A. 1992. Trends in weed control methods, In C G McWhorter and J R Abernathy, *Weeds of Cotton: Characterization and Control,* Memphis TN: National Cotton Council, 47-72.

Hayes, Robert M. and Larry E. Steckel. 2005. Glyphosate resistant weeds: Current problems, potential problems. Proceedings of 2005 Beltwide Cotton Conferences, National Cotton Council, Memphis, Tennessee, USA, pp. 3161-3162, 2005.

Henniger, G., S. Baker, R. Humphries, M. Rinehardt, L. Trolinder and J. Holloway. 2009. Performance of GlyTol™ + LibertyLink® Cotton technologies – A US cotton belt perspective. Proceedings of 2009 Beltwide Cotton Conferences, National Cotton Council, Memphis, Tennessee, USA, pp. 652, 2009.

MacRae, A.W., A.S. Culpepper, and J.M. Kichler 2006. Controlling Glyphosate-Resistant Palmer amaranth in LibertyLink® Cototn. Accesed on Nov. 26, 2009 at <http://commodities.caes.uga.edu/fieldcrops/cotton/rerpubs/2006/p82.pdf>.

Miller, Donnie K., David C. Blouin, Robert G. Downer, Ralph Bagwell, Eugene Burris, Ernest L. Clawson, B. Rogers Leonard and Alexander M. "Sandy" Stewart. 2009. Management Strategies for Roundup Ready® Flex Cotton. Louisiana Agriculture, Winter 2009 at http://www.louisianafoodandhealth.org/en/communications/publications/agmag/Archive/2009/winter.

Rinehardt, Mark, L. Trolinder, S. Baker, G. Henniger, R. Humphries, and J. Holloway. 2009. Effect of high herbicide rates and tank mix applications on GlyTol™ + LibertyLink® cotton. Proceedings of 2009 Beltwide Cotton Conferences, National Cotton Council, Memphis, Tennessee, USA, pp. 651, 2009.

Sosnoskie, L.M., J.M. Kichler, R. Wallace and A.S. Culpepepr. 2009. Proceedings of 2009 Beltwide Cotton Conferences, National Cotton Council, Memphis, Tennessee, USA, pp. 1351-1352, 2009.

Stewart, J.McD. 1991. *Biotechnology of Cotton*, ICAC Review Articles on Cotton Production Research No. 3., CABI, UK.

Vargas, Ron and Steve Wright. 2005. Principlals of weed resistance management. Proceedings of 2005 Beltwide Cotton Conferences, National Cotton Council, Memphis, Tennessee, USA, pp. 3157-3159, 2005.

Wilcut, J.W., A.C. York, and D.L. Jordan, 1995. Weed management systems for oil seed crops, In A E Smith, *Handbook of Weed Management Systems,* New York: Marcel-Dekker, 343-400.

Cotton Breeding and Seed Production in India

Vinita Gotmare, Central Institute for Cotton Research, India, and M. Rafiq Chaudhry, ICAC

India is the only country in the world where all four cultivated species of cotton are grown on a commercial scale. During 2009/10 about 85% of the cotton area was planted to inter and intra species Bt hybrids, also known as commercial cotton hybrids. India developed the first commercial cotton hybrid in 1970. Dr. C. T. Patel, who is usually considered to be the father of the commercial cotton hybrid program in India, developed the first hybrid, H4 (intra hirsutum) in Surat, Gujarat. In the four decades since then, more than 200 hybrids have been developed. Another important aspect of the history of cotton in India was the development and release of native *G. arboreum x G. arboreum* hybrids. The first intra-arboreum hybrid LDH 11 was developed at the Cotton Research Station of the Punjab Agricultural University, Ludhiana, Punjab (Singh, 1999) in 1994.

Species Composition in India

Prior to the introduction of tetraploid species in the Indian subcontinent, diploid cottons were grown on a large scale. Initially, tetraploid species did not do well, but it ultimately established itself and started taking over area from diploid cotton also known as "Desi" cotton or indigenous cotton in the subcontinent. The 4F variety and LSS (Labh Singh Selection) are among the earliest and most successful upland varieties and they have been grown in India and Pakistan for a long time. The table below shows that of all the arable lands that fell to India in 1947/48 at the time of partition (independence from Great Britain), only 3% of the total cotton area was planted to *G. hirsutum*; conversely, *G. hirsutum* varieties covered the greater part of the cotton area that came to be part of Pakistan. The table below, which is an updated version of the Basu (1995) data, shows that in 1993/94, 2.7 million hectares, which was 36% of the cotton area in India, was planted to hybrids

Cotton Area by Species in India

Species/Hybrids	Cotton Area in Million Ha				
	1947/48	1965/66	1993/94	2008/09	2009/10
G. hirsutum	0.14	3.21	2.68	-	-
	(3)	(41)	(36)	-	-
G. barbadense	-	0.08	0.01		
	-	(< 1)	(< 1)	(< 1)	(< 1)
G. arboreum	2.79	2.84	1.29	1.32	1.01
	(65)	(36)	(17)	(14)	(10)
G. herbaceum	1.39	1.78	0.88	0.38	0.41
	(32)	(23)	(12)	(4)	(4)
Hybrids	-	-	2.64	7.71	8.6
	-	-	(36)	(82)	(85)
G. hirsutum x G. hirsutum	-	-	2.13	6.77	7.59
	-	-	(29)	(72)	(75)
G. hirsutum x G. barbadense	-	-	0.44	0.94	1.01
	-	-	(6)	(10)	(10)
G. arboreum x G. arboreum	-	-	0.07	-	-
	-	-	(1)	-	-

Source: Basu (1995), updated by Vinita Gotmare, CICR, India
( ) = Area in percent

Public Sector Cotton Breeding Program

In India, research on cotton breeding is undertaken by both public and private sectors. In the public sector, the Central Institute for Cotton Research (CICR) of the Indian Council of Agricultural Research (ICAR) is the only federal agency working on variety development. CICR has two regional research centers one each at Coimbatore, Tamil Nadu and Sirsa, Haryana to cater to the needs of cotton growers in the south and north regions respectively. While CICR headquarters in Nagpur is a multidisciplinary research institute with fundamental as well as applied research programs, the two regional research centers are more focused on applied research. The Regional Research Station in Coimbatore is also responsible for executing the All India Coordinated Cotton Improvement Project (AICCIP) at the national level. ICAR's second mono-crop research institute on cotton, the Central Institute for Research on Cotton Technology (CIRCOT), Mumbai is entirely focused on fiber quality, spinning and cotton by-products research. In addition to the two federal institutes, Cotton Research Stations of the State Agricultural Universities also undertake a substantial amount of research on cotton. There are 14 such research stations located at Ludhiana, Hisar, Sirsa, Srinagar, New Delhi, Khandwa, Akola, Surat, Nagpur, Dharwad, Guntur, Coimbatore, Nanded and Parbhani

Private Sector Cotton Breeding Program

The private sector undertakes most research on hybrid cotton and biotech varieties. There are about 30 private seed companies that are directly engaged in the development of high yielding and superior quality hybrids and production and supply of planting seed. Most of the non-intraspecific hybrids were developed by conventional method, i.e., by the hand emasculation and pollination method, and very few were evolved through the use of male sterility systems. So far one *G. hirsutum* hybrid has been developed through the use of genetic male sterility (Suguna) and three hybrids through the use of the cytoplasmic male sterility system (PKVHy 3, PKVHy 4 and MECH 4).

National Cotton Germplasm Bank

Indian germplasm collection consists of seeds of germplasm accessions (more than 10,000) of cultivated and wild cotton. Germplasm collections are grown for rejuvenation and seed multiplication. One third of the core collection is grown every year. Seeds of germplasm lines are stored in medium term storage (MTS at 4 ºC) and long term storage (LTS at -40ºC). MTS is available at the Central Institute for Cotton Research, Nagpur, while for LTS the seed samples have to be sent to the National Bureau for Plant Genetic Resources (NBPGR), New Delhi. Maintenance and seed increase is done by growing and selfing.

Germplasm seed requests are made through the National Bureau for Plant Genetic Resources to the donor countries. A prescribed application form is duly filled for procurement of exotic germplasm through the National Bureau for Plant Genetic Resources. The National Bureau for Plant Genetic Resources then finds out whether a Material Transfer Agreement (MTA) is already available with the said country from which the seed material is to be procured and makes necessary correspondences. The seed material is received through the National Bureau for Plant Genetic Resources. Seed disbursement is on the basis of the request of the indentor [public sector institution, private research organization/seed company and state agricutural universities (SAUs)] through the National Bureau for Plant Genetic Resources and the Central Institute for Cotton Research. The Indian Council of Agricutural Research provides full funding for the germplasm collection program. New additions to the acessions are made through collections on the basis of national exploration, expedition and receipt of new germplasm from abroad.

Seed Supply

The All India Coordinated Cotton Improvement Project (AICCIP) plays a major role for the evaluation of candidate varieties developed by public and private sector breeders. The variety evaluation process is long and carried out by the All India Coordinated Cotton Improvement Project and SAUs. Initially the cultures/genotypes are screened at the institutional level and the best entries are sponsored for trials under the All India Coordinated Cotton Improvement Project for national trials. The best entries are promoted for zonal trials to be carried out at each of the research centers of the 9-10 cotton growing states of the country. The best entries are further confirmed through multi-location trials before the varietal release committee considers candidate varieties for approval. The Central Varietal Release Committee and the State Varietal Release committees then notify the varieties/hybrids found to be performing superior over currently cultivated varieties/hybrids.

The Genetic Engineering Approval Committee (GEAC) of the Ministry of Environment approves biotech varieties and biotech hybrids for commercial cultivation. The Review Committee for Genetically Modified Organisms (RCGM) considers multi-location performance data from various locations of cotton growing states as per the guidelines set by the government. The stipulated biosafety tests data also completed before a biotech variety or hybrid is approved by the Genetic Engineering Approval Committee for commercial release.

Varieties and hybrids planting seed is produced according to standard protocols and guidelines stipulated for seed production. Nucleus seed and breeder's seed are produced by notified institutions and agencies. Foundation seed is made available to seed producers, state seed corporations and agencies for the production of certified seed. Commercial varieties and hybrids that have not received notification from the government are sold as truthfully labeled seed. Planting seed is made available to farmers through seed dealers appointed by seed companies. At present about 85% of planting seed is made available by private companies and 15% by the public sector. Some of the leading private seed companies include Maharashtra Hybrid Seed Company Ltd. (Mahyco), Nath Seeds Ltd., Navbharat Seeds Private Ltd., Nuziveedu Seeds Private Ltd., Raasi Seeds Private Ltd., Novartis India (Seeds Division), Advanta India Limited (formerly ITC Zeneca Ltd.), JK Agri Genetics, Krishidhan, Bioseeds Research, Prabhat Agribiotec, Ankur Seeds, Ajit Seeds, Nandi Seeds, Vibha Agrotech, Ganga Kaveri, Pravardhan, Tulsi, Pro-Agro, Bayer Biosciences, Emergent Genetics, Pioneer, Syngenta, Hindustan Lever, and Nagarjunua Agri Research and Development Institute (NARDI).

The wide spread use of hybrid seed involving hand emasculation and pollination encouraged the establishment of private seed companies particularly dealing with cotton planting seed. The National Seeds Corporation Limited established in 1963 is an undertaking of the Ministry of Agriculture with its headquarters in New Delhi. The National Seeds Corporation Limited mainly deals with cereals, pulses, oilseeds, fodder and vegetable seeds.

Plant Variety Protection

India signed the Intellectual Property Rights Agreement (TRIPs) in 1994 but did not have its own intellectual property rights protocol. The Intellectual Property Rights Agreement covers four broad areas viz (i) how basic principles of the trading systems and other international intellectual property agreements should be applied, (ii) how to give adequate protection to intellectual property rights, (iii) how countries should enforce those rights adequately in their own territories, and (iv) how to settle disputes on intellectual property. More specifically, article 27.3 9(b) of the agreement requires member nations to provide for protection of plant varieties either by a patent or by effective legislation. In 2001, India made significant development for protecting the rights of the breeders, farmers and local communities. The Government of India passed an act called the "Protection of Plant Varieties and Farmers' Rights Act" in 2004 (Brahami *et al.*, 2004). The main objectives of the Act are to establish an effective system for protection of plant varieties, provide rights to the breeders and farmers, stimulate investment on research and development for the growth of the seed industry, and ensure availability of high quality planting seed to farmers.

Salient features of the Act are as below:

- *Authority* – The Government of India will establish an authority called the Protection of Plant Varieties and Farmers' Rights Authority. (The Authority was established soon after the Act, http://www.plantauthority.gov.in/)
- *Eligibility* – A candidate variety must conform to the criteria of novelty, distinctiveness, uniformity and stability. While distinctiveness, uniformity and stability explain themselves, novelty means that the candidate variety is new in India and outside India.
- *Application form* – The applicant has to provide all possible details about the new material. The most important requirement is the affidavit sworn by the applicant that the new variety does not contain any gene or gene sequence involving terminator technology.
- *Period of Protection* – Crop varieties plant protection certificate will be usually valid for six years, and extendable to 15 years.
- *Breeder's Rights* – The breeder or his successor or agent of a candidate variety has the exclusive rights to produce, sell, market, distribute and export the approved variety. Researchers have free access to the variety for research purposes. The breeder of a derived variety will have the same rights as the original breeder.
- *Farmers' Rights* – Farmers Rights refers to the legal rights provided farmers to save, use, sow, replant, exchange, share or sell their farm produce including seed of a variety protected under the Protection of Plant Varieties and Farmers' Right Act.
- *Benefit Sharing* - The Protection of Plant Varieties and Farmers' Rights Authority has the power to decide/settle benefit-sharing claims.
- *National Gene Fund and Appellate Tribunal* – The National Gene Fund and Plant Variety Protection Appellate Tribunal had to be established under the Act. The National Gene Fund is supposed to be utilized for supporting conservation and sustainable use of genetic resources.

Cotton Breeding Procedures in India

Cotton varieties can be developed by direct introduction from other countries, hybridization, mutation breeding and selection from within existing varieties. Introduction is the least expensive and easiest way to adopt and commercialize varieties in any country. However, high sensitivity/response of cotton to growing conditions limits wide spread adoption of introductions. Additionally, limited flow of varieties across countries and now more recognition of intellectual property rights prohibit the use of varieties across national borders. Introductions have become legally out of bound with gene patents in the biotech varieties. Varieties have been transported illegally across countries and regions and continue to be physically carried to other countries without quarantine checks, which is not desirable. As more and more patented genes are inserted in biotech varieties, germplasm exchanges will become smaller. Introductions as a breeding method or a way of commercializing new varieties have a bleak future. New genes for germplasm development will be less available and the genetic base of breeding programs is going to get narrower.

India, like most other countries has made a limited use of introductions because of the apparent reasons mentioned above. Singh and Narayanan (1999) have discussed the cotton improvement procedures followed in India. They have stated that American nectariless and the former Soviet Union *G. barbadense* varieties have been used to develop commercial varieties in India. Varieties may have been developed using foreign germplasm in India but the proportion of such varieties compared to the total number of varieties is definitely smaller.

Hybridization is the most common breeding method wherein breeders can combine two or more characters found in two or more genotypes. Heritability estimates have been calculated for important characters but it is usually not easy to transfer only the desired genes carrying desired characters into the new genotypes. Genetic linkages and quantitative control/expression of characters controlled by multiple genes make difficult to get desired results as planned. Once a cross has been made between the two parents, different approaches can be followed starting from the F_2 generation to select a desired genotype. The pure line selection method has been extensively used in India and many varieties using this method have been released for commercial adoption (Singh and Narayanan, 1999). Pure lines can be developed from natural mutations, natural selection or induced mutations, but in hybridization desired plants are selected from a heterogeneous population. Selected plants are tested for fiber quality and carried forward for further testing and evaluation until a homozygous line or lines with desired features is achieved.

In the case of the pedigree method, single plant selections are made from the segregation population preferably at F_2 generation. Single lines are grown from selected plants. Better performing lines and better performing plants within those lines are selected for next generation testing. The selection process continues until a selected line or lines becomes uniform (homozygous for specific traits). It usually takes 7-8 generations to purify a selected plant/line using the pedigree method. Performance of a selected line can be traced back to its previous generations. A single plant selected in the F_2 generation at the end (after F_7 or F_8) becomes a variety. The pedigree method has been commonly used in India.

The F_2 selection can be delayed for F_7 or F_8 generations until plants become more or less homozygous for specific traits. Selection could be delayed for lesser generations and pure line selection method could be started earlier. If the selection process is delayed for the 7th or 8th generation, better-looking plants could be selected in each generation and bulked. A bulk population is grown each year without any testing for fiber quality. In such a method, breeders run the risk of selecting, testing and maintaining plants of poor quality fiber characteristics. Singh and Narayanan (1999) stated that success in a mass selection method depends on variability in the base population, mode of inheritance of a character to be improved and heritability of the character to be improved. Singh and Narayanan (1999) claimed that, due to high heritability, mass selection could be more effective in oligogenic characters compared to polygenic characters. Mass selection varieties have been released in India both in upland and *G. arboreum* but it is not popularly used in India any more.

One other method used in selecting plants from a segregating heterogeneous population is the bulk method. The Bulk selection method takes longer to develop a variety because a portion of the seed from one generation without selection is planted in the next generation. During the long bulk production procedure, gene frequencies for desirable genes may decline in the population thus requiring more time to get homozygous plants. Similar behaving plants bulked to develop a variety have a higher adaptability. Bulk selection has rarely been used in India.

The back cross method was not common in cotton breeding until the introduction of biotech cotton. Currently, almost all biotech cotton varieties are developed through back crossing. The donor parent (biotech variety) is crossed with the recipient parent (candidate conventional variety), and F_1 is backcrossed with the recipient parent for 3-4 times until a biotech variety with morphological and quality characters similar to the receipt parent is attained. In India, four *G. herbaceum* varieties were released using back cross method even prior to the introduction of biotech cotton.

Mutation breeding was once commonly used in the world to create variability and then following one of the methods discussed above to make the plant homozygous before putting the genotype into testing. The Central Asian Republics of the former Soviet Union were leaders in developing mutant lines. Gamma rays, X-rays, thermal neutrons and chemical mutagens like diethyl sulphonate, ethyl methane, sulphonate, colchicine, gebberalic acid, etc., have been used to create variability or get fertile seeds. Mutation breeding is not pursued anymore because of high probabilities to end up with undesirable features compared to desirables most of the time. Mutation breeding can create non-existing features but most prove to be deleterious. In India three varieties of *G. hirsutum* and one each of *G. arboreum* and *G. herbaceum* have been developed and commercialized using induced mutagenesis (Singh and Narayanan, 1999).

Commercial Cotton Hybrids

Commercial cotton hybrids of the F_1 generation have been grown in India for the last four decades. The first intra-hirsutum hybrid H4 was released for commercial cultivation in 1970. H4 is considered to be the worlds' first commercial cotton hybrid and is also famous for its "telephonic production system." H4 is a huge plant that when full of bolls require a support named a telephonic system. Most intraspecific hybrids in India involved only *G. hirsutum* x *G. hirsutum* and *G. arboreum* x *G. arboreum*. All the hybrids used in India are single cross hybrids. Varalaxmi is the first interspecific (*G. hirsutum* x *G. barbadense*) tetraploid hybrid released for commercial production in 1972. The Cotton Research Station, Dharwad, University of Agricultural Sciences, Bangalore, developed Varalaxmi. In diploid cotton, the first interspecific hybrid was released in 1983. Since then many hybrids including diploid, tetraploid, intraspecific and interspecific have been released for commercial production. Four diploid interspecific hybrids, DH 7, DH 9, DDH 2 and Pha 46 were developed as superior medium to long staple category. DH 9 and Pha 46 have staple lengths of 26-28 mm and can spin up to 40 counts. In the beginning hand emasculation and hand pollination were used. Later, when cytoplasmic and genetic male sterility systems became available in the 1980s, stringent efforts were made to use sterility systems for the sake of reducing the cost of hybrid seed production. Sterility systems are still used but on a much smaller scale, for reasons of lack of good fertility restorers in the case of cytoplasmic sterility, and the need to eliminate 50% of the population in the case of genetic sterility system. Lack of natural cross pollination (in the absence of insect pollinators) and lower seed setting efficiency has always been the issues. Reports show that diploid interspecific hybrids provide lower seed setting compared to interspecific hybrids of tetraploids.

Area Under Commercial Cotton Hybrids in India

Year	Area in % of Total Cotton Area
1975/76	<1
1980/81	11
1985/86	26
1990/91	36
1995/96	44
2000/01	45
2005/06	55 (including 14% under Bt hybrids)
2009/10	85 (all Bt hybrids)

Biotech Cotton Area in India

Year	Area in % of Total Cotton Area
2002/03	< 1
2003/04	1
2004/05	6
2005/06	14
2006/07	42
2007/08	66
2008/09	82
2009/10	85

Similarly, the male sterility systems are said to set less seeds compared to conventional hybrids (hand emasculation and pollination) involving the same parents.

Role of the Genetic Engineering Approval Committee

The GEAC is the apex body constituted by the Ministry of Environment and Forests under Rules for Manufacture, Use, Import, Export and Storage of Hazardous Microorganisms/ Genetically Engineered Organisms or Cells 1989, under the Environment Protection Act, 1986. The Rules of 1989 also define five competent authorities, i.e., the Institutional Biosafety Committees (IBSC), Review Committee of Genetic Manipulation (RCGM), Genetic Engineering Approval Committee (GEAC), State Biotechnology Coordination Committee (SBCC) and District Level Committee (DLC) for handling of various aspects of the rules.

References

Basu, A.K. 1995. Current Genetic Research in India. *Genetica*, 97:279-290.

Bhale, N.J. 1999. Heterosis Breeding in Cotton. *Handbook of COTTON IN INDIA*, Editors: V. Sundaram, A.K. Basu, K.R. Krishna Iyer, S.S. Narayanan and T.P Rajendran. Indian Society for Cotton Improvement, Mumbai, India.

Brahmi, Pratibha, Sanjeev Saxena and B.S. Dhillon. 2004. The Protection of Plant Varieties and Farmers' Rights Act of India. *Current Science*, Vol. 86, N0. 3, 10 February 2004. Also available at http://www.ias.ac.in/currsci/feb102004/392.pdf

FAO. 2001. The International Treaty on Plant Genetic Resources for Food and Agriculture, adopted by the 31st Session of the Conference of the Food and Agricultural Organization of the United Nations, Rome, 3 November 2001, p. 45.

Singh, Phundan and S.S. Narayanan. 1999. Cotton Improvement Procedures. *Handbook of COTTON IN INDIA*, Editors: V. Sundaram, A.K. Basu, K.R. Krishna Iyer, S.S. Narayanan and T.P Rajendran. Indian Society for Cotton Improvement, Mumbai, India.

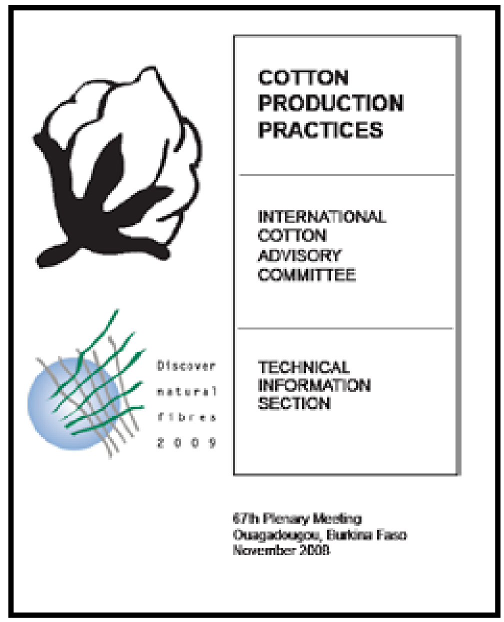
Singh Phundan and Singh Sanjeev (1999) Heterosis Breeding in Cotton, Kalyani Publishers, New Delhi, India.

COTTON PRODUCTION PRACTICES




EDITION - 2008

The report contains data from 34 countries on varieties and their fiber characteristics, insects, diseases, weeds and methods used to control them, use of fertilizers, farm size, rotations, harvesting and ginning of cotton.



US$155 - *Internet access*

US$205- *Hard copy*
(shipping included)

Order Form

☐ **By Internet : 155 US$**   ☐ **Hard Copy : 205 US$**

Find enclosed a check of US$________

Find enclosed my credit card details:

☐ American Express ☐ Master Card ☐ Visa Card

Card Number: ______________________________ Expiration Date: ______________________________

Billing/Shipping Address:

Name (please print)____

Address ____

City and zip code ______________________State ________________ Country__________

Email: ____

Return your order form by mail, email or fax at:

ICAC Subscription Services
1629 K Street, Suite 702 - Washington, DC 20006 - USA
Email: publications@icac.org --- **Fax**: (1) 202-463-6950 --- **Phone**: (1) 202-463-6660 Ext. 111
You may also order online at **http://www.icac.org**