THE ICAC RECORDER

International
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Committee

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- **Update on cotton production research**
- **Nouvelles recherches cotonnières**
- **Actualidad en la investigación de la producción algodonera**

Contents

Introduction

Bt cotton is grown on a commercial scale in only six countries but research is going on in many other countries all over the world. During 2000/01 transgenic crops were grown on over 44 million hectares, and transgenic cotton resistant to insects and herbicides was planted on over five million hectares in Argentina, Australia, China (Mainland), Mexico, South Africa and the USA. The most popular trait in the USA is resistance to herbicides, although in five other countries only Bt varieties resistant to insects have been planted on a commercial scale. It is expected that the Bt gene or insect resistance will continue to be the main reason for growing transgenic varieties outside the U.S. Since transgenic cotton varieties were introduced in Australia and the USA in 1996/97, there have been concerns that Bt cotton will develop resistance to the Bt toxin, and ultimately the Bt gene will become useless. However, researchers developed resistance management programs, and a component of the farmers technology package in the USA is the use of a refuge crop. It is expected that new genes will be identified and inserted into cotton varieties before bollworms develop resistance to the current Bt gene. The latest results show that a new Bt gene has been identified and inducted in cotton. The new gene, Cry2Ab called Bollgard® II, has been added to a DP 50 variety that already had the Cry1Ac gene. Bollgard® II has been tested in the USA in the field for two years against non-engineered DP 50 and a Cry1Ac variety called DP 50B, and may be available for commercial production in 2002/03. The new gene is more effective and compatible with existing transgenes in cotton. Monsanto has revised the refuge requirements from 2001/02 in the USA. Australia plans to adopt varieties with a herbicide resistant gene next year. More details on the new refuge requirements and limitations to the spread of technology are given in the first article.

The ICAC has published a number of articles on cotton yields in the world. The average yield in the world was the highest in 1991/92 and since then the world yield has not exceeded 598 kg/ha. There was an increasing trend in yields for almost half a century until the early 1990s, but there was no increase in the last 10 years. It is not known when the world yield will rise again. Yield is a complex character that is based on only a few parameters. But these parameters are so dependent on the environment and growing conditions that genetics seems to be helpless to express its potential. Since the invention and adoption of modern cotton production practices, cotton yields have increased significantly in the highest yielding countries of the world, while the lowest yielding countries have shown almost no increases in yield during the same time. The differences between high and low yields are commonly related to varietal differences, but that does not seem to be true. What determines yield in cotton and how it is controlled genetically is not properly understood yet. The second article identifies reasons for differences in yield among high and low yielding countries, emphasizing the need for better understanding of yield and its genetic control and suggests approaches to increases in yields.

Shorts Notes are included in this issue as usual.

ICAC has announced the World Cotton Research Conference-3 (WCRC-3), which at the invitation of the cotton industry of South Africa will be held in Cape Town, South Africa from March 9-13, 2003. At this time, only pre-registration forms are available. A complete registration package will be made available closer to the Conference. The pre-registration brochure is available from the ICAC Secretariat. On line registration is also available at <http://www.icac.org/icac/meetings/meetings.

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ICAC has seven ongoing projects funded by the Common Fund for Commodities. In the next few months two projects will conclude and final workshops are planned for the dissemination of results. The project on Integrated Pest Management of the Cotton Boll Weevil in Argentina, Brazil and Paraguay undertook extensive studies on various aspects of the pest including biological, ecological and chemical control, and devised an area-wide integrated management technological package for the region. In the second project, the Sudan Cotton Company in collaboration with CIRAD-CA, France, developed methods to isolate sticky from non-sticky cotton and spin sticky cotton in mixes with non-sticky cotton without any effect on processing and yarn quality. Researchers from all over the world are welcome to attend the workshops. Date, venue and contact details on the workshops are as follows:

Project: *Integrated Pest Management of the Cotton Boll Weevil in Argentina, Brazil and Paraguay*

Workshop dates: June 26-28, 2001
Venue: Fortaleza, Brazil
Contact: Dr. Teodoro Stadler
<picudo@redynet2.com.ar>

Project: *Improvement of the Marketability of Cotton Produced in Zones Affected by Stickiness*

Workshop dates: July 2-4, 2001
Venue: Lille, France
Contact: Dr. Abdin Mohamed Ali
<sccl@sudanmail.net>
Mr. Jean-Paul Gourlot <gourlot@cirad.fr>
Mr. Franck Clemmersseune <fclemmersseu@itf.fr>

Second Generation of Bt Cotton is Coming

Transgenic crops have been cultivated commercially for almost ten years now. China started commercial cultivation of transgenic crops by planting the first virus resistant tobacco and later tomatoes in the early 1990s. Commercial cultivation of genetically engineered crops started in the U.S. in 1994 with delayed ripening tomatoes. Commercial cultivation of transgenic cotton became a reality in 1996, when it was planted in the USA. An estimated 5.3 million hectares in the world were planted to transgenic cotton varieties in 2000/01. The U.S. is the largest producer of transgenic cotton. According to the International Service for the Acquisition of Agri-Biotech Application, 44.2 million hectares were planted to transgenic crops in the world in 2000/01. In 2000/01, transgenic cotton comprised 12% of the total transgenic crops area in the world compared to about 9% in 1998/99 and 1999/00, and 11% in 1997/98. Such a share in the overall transgenic area in the world indicates that transgenic cotton varieties are being adopted at about the same rate as other transgenic crops.

At the time commercial cultivation of genetically engineered cotton began in 1996, six countries had already started commercial production of other transgenic crops. The technology is expensive and many developing countries do not have ready access to it. The limited availability of genetic engineering technology is preventing the easy spread of transgenic cotton varieties, particularly to developing countries, and regulatory processes to start commercial production of transgenic varieties are not in place in many countries. Thus, transgenic crops were grown only in thirteen countries during 2000/01, compared to six in 1996/97, and almost 90% of the total transgenic area of 44.2 million hectares was in developed countries.

Transgenic Crops World Area

Year	All Crops (Ha)	Cotton (Ha)	Cotton %
1996/97	2.8	0.8	29
1997/98	12.8	1.3	11
1998/99	27.8	2.5	9
1999/00	39.9	3.7	9
2000/01	44.2	5.3	12

Commercial cultivation of transgenic cotton spread to Argentina, Australia, China (Mainland), South Africa and the USA almost three years ago; since then only Mexico has joined these countries. It is estimated that Mexico planted transgenic cotton in 2000/01 on about 25% of its total cotton area. There are many other cotton producing countries, both large and small that could grow transgenic Bt cotton successfully, and it could serve to reduce their heavy use of pesticides.

Transgenic Cotton Area in Various Countries–2000/01

Currently, only two types of transgenes are available for commercial production in cotton. There are two herbicide-tolerant genes and a gene offering resistance to bollworms. The two kinds of herbicide-tolerant genes, called BXN and Roundup Ready, are already being utilized. Each gene has been derived from soil bacterium. A cotton plant having either one of these two genes offers resistance to the broad leaf herbicide bromoxynil or glyphosate. More details about this can be found in the June 1998 issue of *THE ICAC RECORDER*.

The bollworm-resistant gene has also been isolated from a soil bacterium, *Bacillus thuringiensis*, but it only provides resis-

Transgenic Cotton Area in Various Countries

Year	Area in 2000/01 (Mill. Ha)	Area in 2000/01 (%)	Estimate 2001/02 (%)
Argentina	0.03	5	5
Australia	0.15	30	30
China (Mainland)	1.00 *	15-20	25
Mexico	0.02	25	30
South Africa	0.04	40	40
USA	3.93	72	75

* Approximate area.

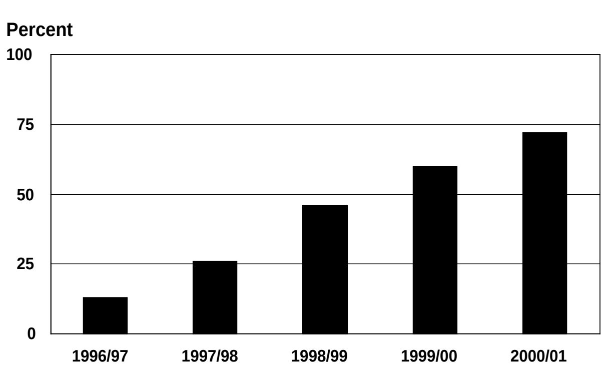
tance to a specific type of bollworms and not to sucking insects. Both herbicide-tolerant genes are compatible with the bollworm-resistant gene and can be put together in one genotype to make higher use of the technology. Such genotypes have been grown commercially in the USA since 1996. According to the Agricultural Marketing Service of the USDA, 72% of the total area grown under cotton in the USA during 2000/01 was planted to transgenic cotton varieties.

Transgenic cotton has become popular in the U.S. at a much faster rate than expected and transgenic area in the U.S. is equivalent to almost 15% of world area. Data from the USDA (2000) show that 20% of area was planted to the stacked gene varieties having herbicide-tolerance and bollworm-resistance genes during 2000/01.

Herbicide-resistant BXN and Roundup Ready cottons have been approved for growth on a commercial scale in the USA since the beginning of transgenic production. So far, Australia has grown Bt varieties only but will start growing the Roundup Ready varieties next year. It is assumed that most of the new varieties will be the stacked-gene type because Bt varieties have already met the target area permissible for transgenic varieties. It is estimated that in other countries most area is under Bt varieties, and that herbicide-resistant cotton is grown only on a small scale, if at all.

Although the Bt gene (Cry1Ac) derived from the soil bacterium *Bacillus thuringiensis* offers the greatest resistance to the tobacco budworm *Heliothis virescens*, it is also quite effective against the cotton bollworm *Helicoverpa armigera*. In the Yellow River Valley of China (Mainland), *Helicoverpa armigera* is a major cotton pest and the continued indiscriminate use of insecticides resulted in the development of resistance to a variety of insecticide groups. Not only did yields drop significantly, but cotton area also declined. China (Mainland) had to look for alternate means of controlling the cotton bollworm and found that Bt cotton is a good choice. China also claims to have developed its own transgenic cotton with a gene different from Cry1Ac. Estimates from China (Mainland) suggest that the area planted under transgenic varieties in 2000/01 increased by 200,000 hectares to a total of over one million hectares. The severity of the bollworm problem and its solution in the cultivation of transgenic bollworm-resistant cotton suggests that transgenic cotton might have been grown on a much larger area than reported in 2000/01. Personal communications indicate that most of the area in Hebei and Shandong provinces may already be under transgenic varieties or will be planted to such varieties in 2001/02. Some unconfirmed sources indicate that Bt cotton may have been planted on over one million hectares thus making 5.3 million hectares the world Bt cotton area. However, all countries except the USA will continue to grow bollworm-resistant varieties, and the demand for herbicide-tolerant varieties outside the USA will remain limited. The main reason for the low demand for the herbicide-tolerant gene is the availability of alternate means of controlling weeds and the low use of herbicides in most countries.

Transgenic Cotton Area in the USA
(Percentage of Total Area)



Environmental Safety

The Cry1Ac protein is a member of a large group of insecticidal proteins produced in nature by the bacteria *Bacillus thuringiensis*. Research conducted before the commercial application of the gene, and experience during the last five years, show that Cry1Ac binds to specific receptors in the mid-gut of sensitive insects, but does not affect mammals or insects that do not have the receptors. The presence of the specific receptors makes the Cry1Ac protein specifically toxic to a particular group of insects, affecting mainly the lepidopteran insects, and particularly the cotton bollworm *Heliothis virescens*. All other insects, fish, wildlife and beneficial insects in cotton fields are not affected. The insecticidal protein in the plant begins to break down immediately after the plant dies, thus it does not accumulate in the soil and it does not have the chance of leaching down in the soil and contaminating underground water.

Limitations to Technology Spread

The cotton bollworm is the most damaging cotton pest in the world. There are many countries confronted with the problem of bollworm control that have the potential to use transgenic varieties to reduce the use of pesticides. The increase in transgenic area in the USA from zero to 72% of total area in five years is testimony to the fact that transgenic varieties, including the variety resistant to bollworms, are more profitable than growing normal varieties and controlling bollworms with insecticides. Similarly, Australia reached the cotton area allowed by regulators in less than five years. Under the current resistance management program, Australian growers can plant only 30% of the cotton area to transgenic varieties and this target has already been reached. Transgenic cotton area is going to increase in China (Mainland). India conducted large-scale trials during 2000/01 and is close to commercial adoption of Bt cotton. Among the major cotton producing countries, Pakistan and Turkey are other potential users of Bt cotton but still probably many years away from commercial adoption. Two countries where Bt cotton does not seem to have a future in the short term are Greece and Spain because of public pressure against genetically engineered crops, including cotton.

Most of the countries that grow transgenic crops are industrialized. Adoption of genetic engineering technology outside the U.S. is comparatively slow, even though the benefits are substantial. Among all the crops with transgenic varieties for commercial cultivation, soybean and corn account for the most area, with 25.8 million soybean hectares and over 10 million corn hectares, compared to 5.3 million hectares of GE cotton. Soybean and corn are major crops in industrialized countries, unlike cotton that is produced mostly in developing countries. It is not the lack of desire to grow genetically engineered varieties that is limiting the spread of the technology, but it will be many years before the currently available Bt gene is utilized in most countries. Many other genes with different effects will slowly follow. The following are some of the reasons that hinder the easy spread of the latest production research technology to many countries.

- There are two ways to acquire GE technology. Interested countries can either buy the technology from the existing owners or develop their own systems to convert their own varieties into transgenic varieties. Both options are expensive.
- There are scientific limitations to the utilization of this technology because only a specific gene expresses a particular toxin. Under currently applicable international patent laws, the gene cannot be inserted into local varieties without the permission of a company that owns this gene.
- It is critical to grow transgenic varieties on a large scale, particularly the Bt varieties. Large-scale production is impossible under the small scale farming systems unless every producer in the area commits to grow Bt varieties.
- Bollworm pressure varies from country to country and among regions within countries. The Bt gene varieties are not intended for all kinds of bollworms.
- There are countries that can grow, or have grown, only varieties of local origin. The Bt gene is available primarily in varieties of U.S. origin, and the U.S. varieties may not be suitable for all production conditions throughout the world. The Bt gene has to be transferred into local varieties, an additional step for most countries other than the U.S. There are other situations like India's, where millions of hectares are grown from the hybrid seed in the F_1 generation or, rarely, in the F_2 generation. Such conditions may also limit the use of transgenic varieties.
- Genetic engineering is a new technology still not completely understood. It is the responsibility of researchers to educate the public about benefits and potential risks of the technology. Any new developments have to be thoroughly tested before they are adopted in commercial production. Because the technology is expensive, countries are hesitant to develop something that may not be acceptable at the end use level.
- Some recent developments indicate that, unlike conventional breeding, the genetic engineering technology has the potential to be misused. Thus, some countries are highly cautious, probably more than required, to welcome the technology. Both developed and developing countries need assistance in the identification of biotech needs and priorities in addition to assessing potential socio-economic impacts.
- Experience from countries that have adopted this technology shows that there is a need to regulate its use. Many countries do not yet have such regulatory systems in place to make use of GE technology.
- Although some decisions remain with local governments, many countries need guidance to develop systems for genetically engineered crops. Transgenic cotton produced using recombinant DNA techniques has been available for five years, and new genes and new approaches are already being developed to make use of genetic engineering techniques. While the benefits of transgenics have been realized and no long-term effects have been detected to date, no doubt some possible environmental effects remain as areas of concern and there is a need to regulate biotechnology as a science. The technology is progressing and the sooner growers feel confident about adopting it, the better it will be for cotton.

Bollgard® II Gene

Biotechnology can be employed in many ways to improve plants and their products. Identifying not only the suitable genes, but also their functions and how they work, provides researchers with crucial knowledge to improve crop plants. One of the avenues could be "wide crosses" hybridization, in which genes are moved from one species or one genus to another to create a plant variety that does not and cannot exist in nature. But, because cotton is considered to be the highest insecticide-consuming crop, the major emphasis in cotton has been on agronomic traits particularly for savings on insecticide use. Communications from China (Mainland) show that they have developed a transgenic cotton having a different gene than Monsanto's Cry1Ac, but reports on the performance of this gene are not available because it has not been tried outside China (Mainland). However, it is expected to be as good as Cry1Ac, otherwise it will not gain acceptance against Bt. Egypt is also said to have developed a drought resistant transgenic cotton of its own. Many other countries are in the process of developing the capability to produce their own transgenics having a variety of characteristics.

Most researchers recognize that insects will develop resistance to the Bt toxin, and efforts are underway to avoid its development. Using refuge was always considered an interim solution. One of the strongest solutions proposed by supporters of the technology is to identify a second gene and insert it into cotton along with the Cry1Ac gene. With the advancement of knowledge about the technology during the last decade, researchers are convinced that such an option is possible and could be available soon.

Researchers have met the expectations of industry, and a stacked gene variety called Bollgard® II, with a new gene, Cry2Ab, is available. Cry2Ab has been added to the DP 50 variety, which already had the gene Cry1Ac. Bollgard® II has been tested in the field for two years against non-engineered DP 50 and the Cry1Ac variety DP50B. According to Voth (2001), a combination of the Cry2Ab and Cry1Ac genes shows promise for improved insect efficacy and an increased spectrum of control. Tobacco budworm, cotton bollworm and pink bollworm are more susceptible to the Cry1Ac protein than to Cry2Ab, whereas fall armyworm, beet armyworm, cabbage looper and soybean looper are more susceptible to Cry2Ab than to Cry1Ac. The level of the Cry2Ab expression measured in the ELISA is > 10 times the level of the Cry1Ac expression seen in Bollgard® II plants. This relationship is consistent and was seen for all sites, sampling times, and tissue types. The high plant expression of Cry2Ab contributed to higher efficacy against important lepidopteran insects in cotton.

Bollgard® II has been developed using the biolistic transformation technology. Trials conducted for two years in the USA during 1998/99 and 1999/00 show that the two genes in the Bollgard® II genotypes segregate independent of each other (Penn et al 2001). The two years of data also show that the expression of Cry2Ab did not comprise the expression of Cry1Ac in Bollgard® varieties. There were no differences in the lepidopteran activity level between the terminal shoot and squares. However, the lepidopteran activity level decreased in older leaves, which is also true in the case of Bollgard®. Analysis of samples at 2, 4, 6 and 8 week intervals shows a sharp decline in the lepidopteran activity in Bollgard® II compared to Bollgard® but even the lower activity in the larger leaves was still 2-3.5 times higher in Bollgard® II compared to Bollgard®. Cry1Ac expression in Bollgard® II by site, time and tissue type are all similar to Bollgard® Cry1Ac expression and there was no difference in the levels of activity of Bollgard® II at each individual field site.

According to a paper presented at the 2001 Beltwide Cotton Conferences (Voth, 2001), Monsanto is licensing the gene to seed companies liberally. At least six companies already have a license and thus the new gene is expected to be available in a number of new varieties developed by various companies at the same time. An efficacy profile is being defined and all regulatory requirements are being completed. It is expected that Bollgard® II varieties will be available for at least small commercial cultivation in 2002/03. In the meantime, studies will continue to redefine threshold for the stacked gene varieties, develop new scouting methods, and study economic benefits and any undesirable effects on the plant. Work will also continue to perfect refuge requirements for the stacked gene varieties. It is anticipated that once commercial production starts, Bollgard varieties will be replaced by Bollgard® II in about five years. Bollgard® II cotton varieties will also be available containing the Roundup Ready® gene.

New Refuge Requirements for 2001/02

Transgenic cotton has been strictly regulated in the USA. Concerns were expressed since the beginning of commercial cultivation of Bt cotton varieties, that if Bt cotton is planted year after year on a large area bollworms will develop resistance to the Bt toxin. The concern was taken seriously by the U.S. and Australian cotton industries. Australia put a ceiling on the maximum area to be planted to Bt cotton at each farm, while in the USA, a refuge crop system was adopted. Farmers were required to plant ten hectares of conventional cotton varieties for every 40 hectares of Bollgard cotton, and to treat conventional varieties with insecticides other than foliar Bt products. Farmers also had the option to plant 4% of their area to unsprayed normal varieties (4 hectares for every 100 hectares). The objective was to produce a hybrid generation of bollworms affected by the Bt toxin and delay the development of resistance for as long as possible. The approach seems to have worked well as no significant resistance has been reported so far.

Bollgard® II varieties will be planted during 2002/03, and refuge requirements have been revised for 2001/02. According to Mullin (2001), the new refuge requirements are as follows:

20% Sprayed Option

This is an amendment to the existing 20% (or 10 hectares of non-Bollgard area for every 40 hectares of Bollgard area) option with the additional requirement that all Bollgard fields must be within 1.6 kilometers (preferably within 0.8 kilometers) of the associated refuge.

5% Unsprayed Option

The requirement for the unsprayed option has been increased from approximately 4% (or 4 hectares of non-Bollgard for every 100 hectares of Bollgard) to a true 5%, or 5 hectares of unsprayed non-Bollgard refuge for every 95 hectares of Bollgard. Additionally, the unsprayed refuge must be at least 45.75 meters wide (150 feet or approximately 48 rows in conventional row-width cotton) and all associated Bollgard fields must be within 0.8 kilometers of the unsprayed refuge. These requirements apply to all users of the 5% unsprayed option regardless of the percent of cotton area planted to Bollgard in a particular area/region. The treatment restrictions for the unsprayed option remain the same as those in place for the 4% unsprayed option in 2000.

5% Embedded Option

A third option has been added for 2001/02, which is the "embedded" option. Unlike the 5% Unsprayed Option, this option allows the refuge to be treated with any insecticide at the same time the Bollgard is treated, as long as the refuge is "embedded" in the field or the "field unit."

For large fields, 5% of the field would be planted to a non-Bollgard variety, the rest with Bollgard. If the Bollgard field needed treatment for bollworms (or any other pest), the entire field, including the refuge, could be sprayed with the same insecticide at the same time (i.e., within the same 24-hr. period). The refuge could not be treated with any insecticide labeled for lepidopteran control independently of the associated Bollgard field(s). For very large fields (more than 1.6 kilometers long or wide), multiple refuge blocks across the field should be used.

For smaller field situations, fields could be grouped into "field units" so that one of the smaller fields or a portion of one of the fields would serve as the "embedded" non-Bollgard refuge. Likewise, this embedded refuge could be treated with the same insecticide at the same time that all of the associated Bollgard fields were sprayed, but could not be treated with any insecticide labeled for lepidopteran control independently of the associated Bollgard fields. Any fields contained within a 1.6-kilometer square area (one mile by one mile) can be considered a "field unit."

As required for the 5% untreated option, the embedded refuge within a field or "field unit" must be at least 45.75 meters wide in all areas where the cotton bollworm or the tobacco budworm is a potential pest.

For areas where pink bollworm is the only pest of concern, growers are allowed to mix individual rows of non-Bollgard with Bollgard rows to embed their refuge, as long as the non-Bollgard rows represent at least 5% of the total Bollgard cotton. An example of how this "embedded" option would be planted is placing a non-Bollgard variety in one seed hopper and putting Bollgard seed in the remaining seed hoppers, resulting in interspersed rows of a non-Bollgard variety across a Bollgard field. Interspersing rows of non-Bollgard varieties and Bollgard varieties within a field is not allowed where cotton bollworms or tobacco budworm can be significant pests.

Community Refuge Plan

If farmers are small growers and are unable to meet the 45.75 meters requirement, multiple growers in an area can work together to ensure that the Bollgard cotton and refuge fields are appropriately sized and placed to provide optimum insect resistance management (IRM) value. The Community IRM plan must meet the requirements of either the 5% unsprayed option or the 20% sprayed option, or an appropriate combination of the two options. For 2001/02, growers will not be allowed to use the 5% embedded option within a community. 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 community refuge agreement among growers must require that an appropriate amount of refuge (depending on the option chosen) is associated with the total amount of Bollgard grown by the community and all distance requirements are met for all Bollgard fields included in the community. Each community must designate a coordinator for the total community refuge plan. This coordinator should be knowledgeable about all requirements of the community plan and agree to represent the group to explain the plan. The coordinator will act as a facilitator and/or spokesperson for the community refuge group.

Need for Education on Genetically Engineered Cotton

More than 40 transgenic crop varieties are available for cultivation with enhanced agronomic and/or nutritional characteristics or one or more features of pest protection (insect and viruses) and tolerance to herbicides. The most widely used transgenic pest-protected plants express insecticidal proteins derived from the bacterium *Bacillus thuringiensis* (Bt). The genetic engineering technology and its applications are spreading. The rate of acceptance is the highest among all research developments in the history of agriculture. But still, there is reluctance on the part of some researchers and countries to accept this technology. Rather, genetic engineering is seen as a short lived and disposable technology. It is assumed that this technology is highly risky and available for only a short period of time. While many concerns are valid, there are others that can be satisfied through scientific education. Genetic engineering technology is not completely understood yet, and the public needs to be educated about the usefulness as well as potential risks of this technology.

The International Cotton Advisory Committee realized the importance of public education on the subject and in January 2000 formed an expert panel comprised of nine international experts from eight countries. The expert panel noted that six national academies of science—Brazil, China (Mainland), Great Britain, India, Mexico and the USA—and the Third World Academy of Sciences issued a joint statement not only endorsing biotechnology but urging companies, governments and charities to extend it to the developing world. Most biotechnology research is in the private sector, and there is a need to ensure that the benefits of biotechnology are extended to developing countries at a reasonable cost. The seven academies say private companies must "share with the public sector more of their capacity for innovation" and that "care should be taken so that research is not inhibited by over-protection of intellectual property" (patents on genetic discoveries). The ICAC Expert Panel on Biotechnology in Cotton concluded that the technology can bring much good to cotton but should be used carefully. The Report of the Expert Panel is available online free of charge at:

<http://www.icac.org/icac/meetings/plenary/59cairns/documents/e_biotech.pdf>.

Hard copies can be requested from the ICAC Secretariat at publications@icac.org.

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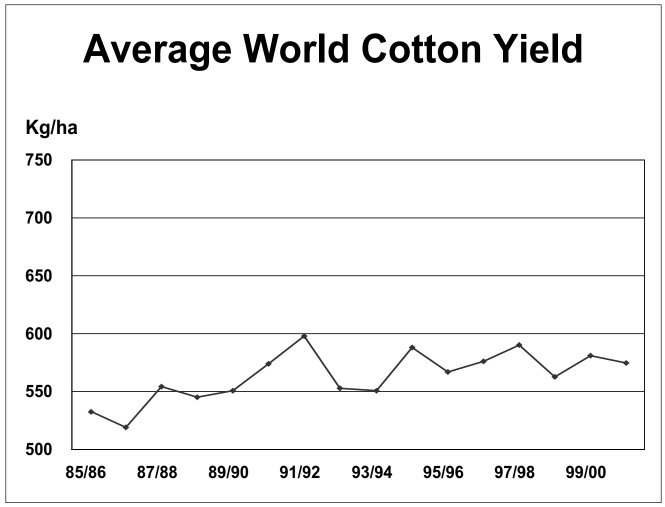
Why Yields Vary Among Countries?

The average world cotton yield in 2000/01 is expected to be 575 kilograms per hectare. The average world yield the last 10 years ranged from 551 kg/ha in 1993/94 to 598 kg/ha in 1991/92. The maximum variation from one year to the next did not exceed 50 kg/ha or 9%, during the last 10 years. This shows that on the one hand there is reasonable consistency in the performance of world cotton production, on the other hand, the hopes for a significant increase in the world yield in a short period of time are limited. Significant increases could be expected only if some extraordinary technological developments are achieved and adopted in many countries at the same time, or at least in more than one major cotton producing country.

Average crop yields did not increase appreciably in any country until 1950. However, average cotton yields have varied significantly among countries even before the adoption of modern production practices—use of synthetic fertilizers and pesticides—including better agronomic management of the cotton plant. The upward revision in production practices widened the differences in average yields among countries. Fifty years ago, the lowest yields in countries growing at least 10,000 hectares were about 400-500 kg/ha below the countries with the highest yields, and the world average was 233 kg/ha in 1950/51. The table below shows that adoption of the current technology package in producing cotton, where fertilizers and pesticides have a major role, has benefited some countries more than others. This has happened in spite of the fact that there were no limitations, legal or technological, to the adoption of the technology applied in the highest yielding countries of the world.



Maximum and Minimum World Yields

Year	Range	
	Maximum	Minimum
1990/91	1,668	91
1991/92	1,781	55
1992/93	1,667	53
1993/94	1,723	65
1994/95	1,603	82
1995/96	1,779	87
1996/97	1,810	73
1997/98	1,845	105
1998/99	1,753	61
1999/00	1,665	108
2000/01	1,660	116

Yield and its Components in Cotton

Unlike many other agricultural crops, the yield in cotton is not determined only by the seed, and to some extent not even by seedcotton. If the seedcotton yield is high but most of it is seed itself rather than lint, high seedcotton yield may not be a desirable target to achieve. On average, 3% increase in seedcotton yield, which is the measure of yield in most countries where custom ginning is not done and farmers sell seedcotton, means only a 1% increase in lint yield. In countries where farmers arrange custom ginning and sell lint, farms are entirely interested in lint yield. In many species of cotton, particularly cultivated diploids and tetraploids, the seed coat may have two coats of fibers on it called fuzz and lint. Fuzz is a very small layer of non-spinable fibers, mostly comprised of cellulose, as is the case with lint. Still, fuzz is not considered yield. Thus, lint—a long unicellular outgrowth on the seed coat—forms the real yield in cotton and is correctly called “economic yield.” Without going into further details, it is important to clarify that yield in cotton may be seedcotton or lint so the most appropriate term for lint yield will be economic yield. Some other terms commonly used in reference to production are potential yield, theoretical yield and genetic yield. All these definitions refer to something, which is hypothetical or the highest possible limit, and is not possible to achieve, at least now. Only a part of potential yield is recovered. The word "yield" will be used in this article to refer to seedcotton yield and some times to lint yields actually achieved.

The most commonly used formula to estimate yield is number of plants per unit area x number of bolls per plant x boll weight x lint-to-seed ratio (ginning outturn or lint percentage). The number of plants could have a positive as well as a negative effect on the number of bolls per plant. If cotton is planted too close in row-to-row and plant-to-plant spacing, dense plant stands lower the number of bolls. As the distance among plants increase, the number of bolls starts to increase up to a certain limit. Too sparsely-located plants in a certain area may give a high number of bolls per plant, but the fewer number of bolls per unit area may lower yield per unit area. Thus, the number of plants per unit area and the number of bolls per plant can also be considered together as the number of bolls per unit area. Similarly, apart from the genotypic and atmospheric effects on boll size, under a particular set of environmental conditions, boll weight or lint production per boll is greatly influenced by the number of bolls on the plant. So, it can be concluded that yield estimation, taking into consideration the environmental and genotypic effects, is a simple arithmetic formula, provided boll condition (healthy or infected by a pest) is also known. The estimation of yield at various stages of development requires a lot more additional data to be collected and analyzed for its effects on boll formation and development.

Highest Yielding Region in the World

For the last two decades, cotton yields have been the highest in either in Australia or Israel. Current estimates suggest that the average yield will be the highest in Israel in 2000/01, but Australia will be replaced by Syria in second for the first time. During 2000/01, only seven countries will have an average yield of over one ton of lint per hectare and they are Australia, China (Mainland), Greece, Israel, Spain, Syria and Turkey. However, the average yield has been over one ton of lint per hectare continuously for five years only in Australia, Israel, Spain, Syria and Turkey. A contiguous block of three countries where cotton yields are exceptionally high includes Israel, Syria and Turkey. In Egypt, only *G. barbadense* is grown, which is lower yielding compared to upland varieties under most conditions. In Greece, the yield has been either one ton/hectare or short by only a few kilograms in three years out of the last five. Thus, a block of the five highest yielding neighboring countries in the world consists of Egypt, Greece, Israel, Syria and Turkey.

These five countries have good research facilities and good cotton production systems for achieving high yields. However, many other countries have similar and better facilities and production systems, and still their yields are lower than in these countries. The reasons for the high potential and its recovery in the five countries can be found in the best suitability of this part of the world for cotton production.

Role of Varieties in Improving Yields

The cotton plant has a complex morphology because it is a perennial tree but it is domesticated and grown as an annual plant. The cotton plant will never fruit to death if conditions remain favorable for growth. The main apex is typically indeterminate in nature even in the currently pseudo-annual behaving cotton plant. The main tip and also the dimorphic branches are indeterminate in habit. In the axil of every leaf on the sympodial branch, or main stem, a flower bud is formed which may or may not stay on the plant. At the end of the season, there may be only a few bolls on the plant, but the potential to form a huge number of bolls remains intact. The plant goes into dormancy during the off-season in winter, and as soon as conditions become favorable again, it starts its re-growth. The precocious fruit formation in various varieties is purely the result of adaptation/interaction with the environment.

This does not mean that varieties do not differ in their abilities to produce low or high yield. Breeders have always tried to improve yield and fiber quality. They have been successful in improving quality, but the only successful method of raising yields has been optimization in meeting nutrient needs of the plant and protecting it from pest attack. ICAC has published other articles on the issue, and more details can be found in the March 1998 issue of *THE ICAC RECORDER*.

According to Constable (2000), 45% of the increase in yields in Australia in the last 20 years has come from the development of high yielding varieties, 25% from soil-nutrition-management, 20% from better insect control and 10% from better disease management practices. The 45% increase may be related to better varieties, but this does not mean that the ability of the plant to form more fruiting parts has been improved. What could have happened is that the genetic ability of new varieties to suit specific growing conditions has been improved, resulting in better adaptation and interaction between the genotypes and the conditions under which they are grown. Better interaction could include tolerance to high or low temperature, tolerance to water stress, tolerance to low fertilizer levels, improvement in the partition of the source to sink ratio, etc. As in Australia, breeders all over the world claim to have developed successively higher yielding varieties in their countries. Linking increases in yields to higher yielding varieties is very common. The 45% increase in yields in Australia might have come from better varieties, but the varieties need to be analyzed to determine the source of higher yields. Breeders have not affected the potential yield and neither can they. Such an observation is in agreement with Afzal (1990) who stated that yield expression is molded by diverse constrains which bring about a different degree of reduction in the potential yield. Thus, the removal of constraints is the right way to improve economic yield.

What Brings Differences in Yields?

The average yield in Israel in 2000/01 is estimated at 1,660 kg/ha. The range of yields may be from close to two tons to only one ton. This also includes *G. barbadense* area, which is usually 20-25% of the total cotton area in Israel. There are a number of countries in Africa where more than 50,000 hectares of cotton are planted every year, and the average yield is still less than 200 kg/ha of lint. There are at least five countries, Mozambique, Nigeria, Tanzania, Uganda and Zambia, where cotton is planted on over 200,000 hectares and the average yield remains less than 200 kg/ha. The average yield in the five highest yielding countries is eight fold more than the five lowest yielding countries planting at least 200,000 hectares every year. World yields in most crops, including cotton, started improving only after the Second World War. The historical data for the last 50 years shows that yields improved by 5-6 folds in the highest yielding countries in the last 50 years. Improvement was faster in the early years, which ultimately slowed to almost nothing in the last 10-15 years in most countries. In the last 50 years, there has been almost no increase in the average yield in the lowest yielding countries in the world.

The role of genotypes in producing a high number of bolls under specific growing conditions cannot be ignored rather and is the most important factor affecting yields. But, still the wide gap between the high yielding countries and the low yielding countries and others cannot be attributed to only varietal differences. It is quite possible that poor yielding countries have not been able to develop high yielding varieties for their growing conditions, and part of the variation may be due to poor varieties. No data are available to prove it but it is likely that the yield potential of varieties in low yielding and high yielding countries is not much different. This observation can easily be proved by testing varieties from low yielding countries in high yielding countries and vice versa. There seem to be other factors responsible for such drastic variations, and it is concluded that the following factors are responsible for differences in yields among countries.

- Feeding the cotton plant to meet its optimum nutrient needs as perfectly as possible is an assurance for better growth and fruit formation. However overdosing could result in negative impacts particularly in the case of nitrogenous fertilizers. Since the introduction of synthetic fertilizers, yields in some countries have increased at a faster rate compared to others because nutrient requirements are not met properly in poor yielding countries.
- Plant protection in the form of insect control has emerged as the most important component of production practices in cotton. Like fertilizers, insecticides used against pest attacks may not be as good in poor yielding countries as in high yielding countries. Depending on the type of insect and the stage of crop development, insect pressure could affect plant growth, fruit formation/shedding and boll health. Unhealthy plants produce fewer and smaller bolls, thus producing less cotton per boll.
- According to Clive James (2001), during the five years between 1996/97 to 2000/01, herbicide tolerance has consistently been the dominant trait in transgenic crops followed by insect resistance. It is estimated that 74% of the 44.2 million hectares planted to transgenic crops in 2000/01 had the herbicide resistant character. In the U.S., out of 72% of the total area under transgenic cotton in 2000/01, over 75% had genes resistant to herbicides (either alone or in combination with the insect resistant Bt gene) and less than 20% of area was planted to varieties resistant to insects alone. Experiments in many countries have shown that weed control is important to have a successful cotton crop.
- The third category of pests responsible for causing diseases may also be responsible for differences in yield among countries but seems to have little impact compared to the factors mentioned above.
- Though the issue here is high and low yield under irrigated conditions and similarly rainfed high versus rainfed low yields, the lack of irrigation water (rainfed cultivation) or a short supply of irrigation water has drastic effects on yields. Rainfed production always results in lower yield, compared to irrigated production under all other similar production conditions.
- Even if all inputs, the best varieties, pesticides and irrigation are available and production conditions are suitable, high yields cannot be achieved unless inputs are managed properly. It is very important to apply fertilizer at the right time and in the right doses. The same is true for other inputs. Moreover, it is not only the application of inputs but also the impact on the crop that needs to be watched, and further actions need to be taken accordingly. Thus, the ability of the farmer to grow cotton and to maximize the output-input ratio is the key factor in achieving high yields. The experience in many countries indicates that improvements in the awareness or the knowledge to grow cotton bring drastic improvements in yields. Farmers in high yielding and low yielding countries differ greatly in the knowledge and skills needed to grow cotton.
- There are some inherent and unavoidable factors that interact and are responsible for originating differences in yields. The most common example could be that Egypt is most suitable for *G. barbadense* cotton. Efforts have been made more than once to experiment and promote upland cotton to meet domestic spinning needs, but the results did not strongly support the recommendation to replace *G. barbadense* with upland cotton. Just as Egypt is best suited for *G. barbadense* production, some countries are simply more suited to produce high yields than others. The suitability of growing conditions, including soil and temperature, are factors that can be compromised to a lesser extent than most others. Extremely high temperatures, both minimum and maximum, induce sterility through incomplete fertilization. Countries have overcome this problem by developing heat tolerant varieties, but all natural ambient limitations to grow cotton

successfully cannot be eliminated or minimized, thus resulting in differences in yields.

Limitations to Improving Yield

The number of bolls per plant and boll size or boll weight are two of the most important yield components, and many references in the literature show that they are negatively correlated. If they are the most important and improvement in one will negatively affect the other, how can yield be improved. Genetic control of yield and its components has been studied extensively. Basu (1996), quoting references from many other authors, stated that yield in cotton is a recognized complex character which is mostly controlled by additive, dominant and epistatic gene action. He also quoted a number of references that found additive and non-additive gene effects important in the heritance of seedcotton yield and its components, in the number of bolls and in boll weight in upland cotton. The complex genetic control makes it extremely difficult to bring improvements in yield.

Cotton is ultimately used in spinning and weaving, dying and other operations even after the product is finished. Consequently, fiber quality is important. Breeders and other allied disciplines involved in the improvement of yield have a continuing challenge to improve fiber quality just as they have a challenge to improve yield. The need to improve quality, along with improvements in yields, makes the job more complex and slower.

Afzal stated in his various publications, particularly one of his last contributions published in 1990 and entirely devoted to the yield improvement issue, that yield improvement requires elimination of constrains. He suggested trying to eliminate constraints one by one. If his hypothesis on constrains is true, which proved to work in general all over the world with respect to the effect of fertilizers, pesticides and other specific conditions, working with yield improvement seems to be a two-fold issue: identification of a constraint and then finding a solution to eliminate or minimize the effect of this constraint. Finding a constraint on a scientific basis is even more challenging than finding a solution.

When two inbred lines are crossed and the hybrid outyields its parents the result is an interesting phenomenon to study with respect to yield improvement. In India, over four million hectares are grown under hybrids and they must be better yielding than other varieties. Usually, dominance and over-dominance theories are considered to be the scientific basis for outperformance of hybrids over their parents or even the control. But, which parents will produce a hybrid that will transgress its parents or the control (in case of commercial cotton hybrids) is not known. The issue also remains unexplained why some countries get a sufficient heterotic effect in cotton while others do not. The hybridization process goes on as an effort to create variation, of course for better selection, but the biological bases of heterosis remain unknown (Roupakias 1998). If the bases for the heterotic effect are not known, the ability to bring improvement is undermined and remains underutilized.

The environmental impact on the cotton plant is so pronounced that many times it suppresses the ability of genes to express their effects. Genotype-environment interaction is extremely high for yield thereby indicating that the high yielding varieties under one set of growing conditions may not be high yielding under another set of conditions. The impact of environment is not only prominent among varieties, but it has also been noted in hybrids. Hybrids performing better at one location may not give the same yield at other locations. Similarly the yield level may not be the same during different years at the same location. The sensitivity of the plant to environmental conditions, or the high response to growing conditions, can no doubt be used as a plus factor, but most of the time it is a limitation to improved yields.

The cotton plant starts with monopodial branches, also called vegetative branches, that give rise to fruiting branches. There may be real monopodial branches if not shed at an early stage and there may be only nodes indicating that vegetative branches were shed at an early stage. But, whatever the case, once a sympodial branch appears on the main stem, the plant has the genetic ability only to form fruiting branches. Thus, the cotton plant always has a fruiting branch on the top close to the terminal. Any increase in the terminal will give rise to additional branches and additional branches mean additional fruit. Additional branches also mean an increase in height, and height has a strong correlation with maturity. A correlation can be calculated showing how many centimeters increase in height results in how many days delay in maturity. Maturity and increase in height also affect boll retention. Some countries have already done studies, but specific effects under specific conditions can be determined. This and similar other negative correlations, genetical, physiological, etc., cap yield improvements beyond certain limits.

How to Improve Yields?

The current trend in yields in many countries suggests a new technique to bring an improvement. If current techniques were working, yield increases would not have stopped. The momentum should have continued but it has not. Thus, there is a need for a change in the approaches adopted to improve yields.

The fundamentals of breeding can be divided into two parts; 1) create variability and 2) make selections based on the targets to be achieved. Hybridization is a conventional and popular means of creating variability though natural variation, and irradiation and other means, including chemical mutagenesis, could also be utilized. Hybridization has its own limitations, and characters that do not exist in either parent cannot be expected in the offspring. There is no controlling which parent will contribute a character unless the character is controlled by simple qualitative genes. But, because other reliable choices are not available, conventional hybridization continues to be the main source of creating variability.

The hybrid may or may not be better performing than parents but the need to create variability in the population exists and probably will continue to be the primary focus until directed breeding becomes practical. Directed breeding means an insertion or deletion of certain specific characteristics through recombinant DNA technology, or any other technology not yet known in biotechnology. New means of creating variability, which provide more control on inheritance of characters in the form of what to include and what not, could contribute towards yield improvement.

In order to bring improvement in yields the foremost issue is a better understanding of the genetic control of yield. Until the knowledge about the inheritance of yield components, particularly boll number and boll weight, is perfected, efforts to make significant progress are handicapped.

While efforts are underway to better understand the genetics of yield, and significant progress has already been made in DNA technology in the last decade, it remains important to identify constraints and to try to eliminate each one by one.

The average yield in various countries of the world and the opportunities to improve it indicates that countries can be divided into three categories: low yielding, medium yielding and high yielding countries. The low yielding countries have better chances to improve yields, as they have yet not reached their peak. Medium yielding countries have lesser chances to improve yields compared to low yielding countries. The highest yielding countries have the minimum chances to improve yields in the near future.

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Short Notes

• National Organic Standards Established in the U.S.

Organic cotton is generally considered to be elimination of synthetic chemicals used to grow cotton, including chemical insecticides, fertilizers, defoliants, growth regulators, boll openers and other chemicals applied either through soil application or by air. The U.S. government has been working for almost ten years to establish national organic standards. In April 1995, the U.S. National Organic Standards Board defined “organic agriculture as an ecological production management system that promotes and enhances biodiversity, biological cycles and soil biological activity.” The system was based on minimal use of off-farm inputs and on management practices that restore, maintain and enhance ecological harmony. “Organic” was considered to be a labeling term that denoted products produced under the authority of the Organic Foods Production Act.

On December 21, 2000, the National Organic Program was announced establishing the national organic standards under the direction of the Agricultural Marketing Service (AMS), an arm of the United States Department of Agriculture (USDA). This program establishes national standards for the production and handling of organically produced products, including a national list of substances approved for and prohibited from use in organic production and handling. The new organic standards prohibit the use of genetic engineering, irradiation or sewage sludge as well as toxic and persistent synthetic pesticides and synthetic fertilizers in organic agriculture and processing. Under the program, companies/agents will certify production and handling operations in compliance with the requirements of this regulation and initiate compliance actions to enforce program requirements. All agricultural products labeled organic must originate from farms or handling operations certified by a state or private agency accredited by the USDA. Farms and handling operations that sell less than $5,000 per year of organic agricultural products are exempt from certification.

In order to promote organic agriculture, the U.S. government has decided to provide financial assistance to farmers in 15 states to help pay their costs for organic certification, but none of the cotton producing states is included on the list. In order to be certified organic, crops must be grown on land which has been free of prohibited substances for three years prior to harvest. Crops grown on land in transition to organic (during the first three years after switching from conventional farming to organic) cannot be labeled organic. More information on the organic standards, along with detailed fact sheets and other background information, is available on line at <http://www.ams.usda.gov/nop>.

It is estimated that about 14,000 tons of organic cotton were produced in the world during 1999/00. Turkey was the largest producer of organic cotton, followed by the U.S. and India. ICAC published a table on organic cotton production in the December 2000 issue of the *ICAC RECORDER*. Greece has corrected the production data to 267 tons in 1998/99 and 234 tons in 1999/00.

• Ultra Narrow Row Effects on Cotton Quality

Cotton must be planted in rows for easy intercultural operations, uniform plant population distribution throughout the field, uniform application of fertilizers and other inputs, uniform crop maturity and quality, in addition to a number of other advantages related to agronomic as well as technological characteristics. Row-to-row spacing is important. In most countries, cotton is planted either in 30-inch (76 cm) or 40-inch (101 cm) row spacing. In some countries, both 30-inch and 40-inch row spacing are popular and in others the same variety may be planted at 30-inch and 40-inch rows in the same region. The cotton plant has high compensation ability, and thus yields may not be affected at either row spacing. But, ultra-narrow row creates extremely high populations that could have effects on yield and quality. Planting cotton at 25.4 cm (10 inches) or under would require different production practices that could affect fiber quality. The main benefits of growing cotton at close row-to-row distances are early crop maturity, a shortened growing season and lower cost of production. A shorter growing season means formation of bolls in the shortest possible time, which leads to higher uniformity in the fiber produced. Early maturity and higher uniformity in fiber quality are desirable characters, but ultra-narrow row planting may not be suitable for all growing conditions. It is usually recommended not to adopt ultra-narrow row planting if the soil is highly fertile or land is traditionally known to have severe weed problems.

Ultra-narrow row (UNR) has been tried in the U.S. for many years but it is still not adopted on a significant area. 35% of the total area is estimated to be grown under 30-inch row spacing, and almost 60% is planted at 40-inch row spacing. USDA and Cotton Incorporated undertook a joint study during 1998/99 and 1999/00 to evaluate UNR with conventional row spacing. The same variety was grown at nine locations in 1998/99 and six locations in 1999/00 under farmer field conditions. UNR was stripped while 30- and 40-inch row cotton was spindle picked. The data recorded during both years is presented in the table below.

UNR cotton had significantly higher trash content compared to wider spacing because of different picking equipment used in UNR. Trash had to be removed either before ginning or after ginning which lowered the lint percentage. As a result of pre- or post-cleaner operations, color grade was not affected. UNR cotton also showed lower micronaire values but differences were not significant. Fiber length, strength, uniformity index and color +b were not affected by row spacing. Short fiber content and neps were the worst affected in UNR spacing. The cotton produced in conventional spacing and UNR was also tested for spinning performance. The results revealed that yarn strength or evenness between conventional and UNR cotton were the same.

Comparison of Ultra Narrow Row and Conventional Cotton

Fiber Property	1998/99		1999/00	
	Conventional	UNR	Conventional	UNR
Initial Trash (%)	7.80	20.90	7.70	19.70
Lint percentage	34.90	29.80	34.80	30.70
Micronaire	4.50	4.30	4.40	4.00
Strength (g/tex)	28.90	28.90	29.60	29.90
UHML (mm)	27.40	27.20	27.20	27.20
Uniformity Index	81.60	81.00	82.20	81.80
Color: Rd	73.40	74.90	75.80	76.80
Color: +b	8.70	8.80	8.80	8.80
Trash (% area)	0.27	0.25	0.28	0.39
Leaf Grade	2.90	2,8	3.10	3.10
Bark (Bales)	0.00	1.00	0.00	3.00
Short Fiber Content (% AFIS)	8.60	9.40	6.40	7.90
Neps (per gram AFIS)	268.00	373.00 *	275.00	338.00 *

* Significant difference at 95 percent confidence level within years.
Source: Ultra Narrow Row Cotton Ginning and Textile Performance Results, Cotton Incorporated, 6399 Weston Parkway, Cary, NC 27513, USA.

• Transgenic Cotton in Regard to Cottonseed Oil

The US National Cottonseed Products Association has stated that the oil refined from the genetically engineered cotton seed varieties does not carry any risks for consumers. The refined cottonseed oil can be safely consumed because no DNA content nor any protein content resulting from DNA, native or otherwise, was detected in the oil. The primary function of refineries is the elimination of all but the lipid (fat) from the oil. If even a small amount of protein is left in the oil, it will cloud and be easily seen. If there was any DNA residue in the oil it would be found along with protein. Non-detection of genetically altered DNA and residues of proteins in refined cottonseed oil does not negate the fact that the genetically altered DNA is carried to the seed from the plant. The level of non-native DNA in the seed is very low, below measurable threshold levels when oil is cleaned. Thus, refined cottonseed oil does not carry any concerns with regard to the biotech varieties used in oil extraction. (*The Cotton Gin and Oil Mill Press*, Vol. 102, No. 1, January 13, 2001)

• Automatic Classing System

High volume instrument (HVI) grading of cotton was introduced in the U.S. in 1976 but the first classing office went 100% HVI classing in 1980. USDA first offered services to producers on a voluntary basis as the HVI technology continued to improve. Now, 240 HVI stations are used at 12 classing offices throughout the cotton belt, and USDA implemented 100% HVI testing as the official grades for upland cotton for length, length uniformity and strength in 1991. HVI grading spread throughout the cotton industry because of demand for instrument measurement of fiber quality. Through the 1990s, the Cotton Program of the USDA measured length, length uniformity, strength and micronaire on HVI at all classification offices while still maintaining manual classification to determine the official grades for color, leaf and extraneous matter. In 2000, the USDA Cotton Program adopted HVI color as the official U.S. color grade. Leaf and extraneous matter still remain manual measurements.

During the process of HVI classification, improvements have been made in the machines. In the 1980s, each HVI station required three operators to keep the station running. However, by the mid-1990s the number of operators was reduced to only one per station, thus minimizing the chances of errors arising from manual operation and sample feeding. Additional benefits included efficiency in terms of space and labor utilization. Developments in the HVI systems have continued and now Zellweger Uster—the largest HVI manufacturing company in the world—has developed the Automatic Classing System concept. The Automatic Classing System does not involve even a single operator.

The Automatic Classing System (ACS) has been installed in the Memphis, Tennessee classing office of USDA. It comprises ten HVI stations, six loading stations, one system controller, one unloading station and peripheral equipment. The whole system is interconnected by an integrated conveyor system that moves cotton samples automatically. The human classers who will continue to measure leaf grade and extraneous matter will perform an additional function as operators at loading stations. Classers will load samples into a loading chamber and push the button to activate the loading station. Once activated, the loader will automatically load the sample in specially designed plastic cassettes for transport throughout the rest of the classification system. The system also provides for retesting of samples if required and holding of samples for specific purposes. Once the sample has passed through the whole system, and data has been recorded for all required parameters, the sample is automatically disposed of. The main system controller, called SYSCON, controls and monitors all operations within the ACS and alerts the personnel in the event of trouble or malfunction. ACS automatically submits data to the central data system of the USDA Cotton Program.

The new HVIs used in the ACS measure fiber length, length uniformity, strength, micronaire, color reflectance of cotton fibers (Rd), yellowness (+b), trash, short fiber content and elongation. The new machines are also capable of measuring moisture content and a new trash measurement enabling separation of leaf from extraneous matter has been added. The cassette containing a sample pauses at four different points along the HVI system, allowing it to take different readings. First the sample passes through a bar code scanner that transmits the sample identity to the HVI. The HVI records the data and allows the sample to pass to the next data recording. The ACS is going through extensive testing and is not yet accepted for commercial classification. The three main areas of interest under investigation by the USDA are reliability of the data produced, accuracy of measurements and labor savings. (*The Cotton Gin and Oil Mill Press*, Vol. 102, No. 2, January 17, 2001)

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