NEW DEVELOPMENTS IN COTTON TECHNOLOGIES

Fred Bourland - University of Arkansas, USA

Several new developments are likely to occur in the cotton industry during the next decade. Obviously, the impacts of emerging technologies will vary among different regions of the world. However, any new development will likely impact most other cotton-growing areas. To gain a broader perspective, I have consulted experts in various disciplines for assistance. I will summarize my perspectives on new developments in five general areas: Genetics, Pest Control, Growth Management, Cotton Equipment, and Cotton Utilization.

Cotton Genetics

Transgenic cotton. Today, the term "cotton technologies" often refers to "gene technologies" and specifically to "transgenic technologies". Only a few years ago, transferring genes from other species into cotton was considered to be science fiction. Today, transgenic cotton is commonplace and is widely grown in many countries. In 1995, only a negligible amount of transgenic cotton was grown in my home state of Arkansas. By 2005, all except a small negligible amount was transgenic cotton. By expanding the gene pool to other species, transgenic technology has made it possible to acquire traits that were otherwise not available. Restrictions on the use of transgenic technology have provided seed companies an additional means to protect and regulate seed sales.

Transgenic cottons have had very positive effects on cotton production, and promise to continue to provide positive impacts. The major two transgenic types used today are the different forms of Bt genes for worm control and herbicide-resistance (e.g. glyphosate resistance commonly known as Round-up Ready®) genes to assist with weed control. Cottons possessing Bt genes were introduced in the mid 1990’s. These cottons immediately impacted insect control, and subsequently led to increased yields and reduced insect control costs. Glyphosate-resistant cottons, also introduced in the mid 1990’s, have profoundly affected cotton production systems in the U.S. Use of glyphosate for over-the-top weed control has simplified weed control, and decreased the time and effort needed to control weeds. Consequently, growers have been able to increase their farm size, while reducing their per unit production costs. Reducing the use of tillage and incorporated herbicides [herbicides blended into soil prior to planting] have allowed cotton plants to develop better root systems and incur less injury from tillage and incorporated herbicides.

Unfortunately, transgenic cottons have also had some negative effects:

- The regulations associated with transgenes often become cumbersome and can delay release and/or restrict distribution of improved varieties.
- Transgenes have sometimes exposed seed purity issues, and consequently have led to additional legal problems.
- Restrictions on genetic advance. Transgenic cultivars have primarily been developed using the backcross technique, which is a regression procedure that may restrict genetic advance of the basic germplasm. Time and expense is required to verify the presence/absence of transgenes. Progress is further restricted as the number of transgenes increase. Based on simple Mendelian inheritance, only 1 plant out of 16 in a segregating population will be homozygous for two transgenes, and only 1 out of 64 will be homozygous for three genes. Therefore, combining multiple transgenes with good agronomic genes becomes extremely challenging.
- Technology fees associated with transgenes have greatly increased the upfront investment, and subsequently some risks associated with a crop.
• Some pests are now building resistance to either the toxins or the herbicides associated with the transgenes. Most notable, wide-spread use and misuse of glyphosate in cotton and other crops has led to the development of weeds having resistance to glyphosate.

New transgenes are forthcoming that should counter some of these negative effects and/or add additional positive effects. Some of the most promising include:

• Stacking of herbicide resistance genes
• Resistance to other herbicides
• Additional constructs of Bt technology
• Lygus, or plant bug, resistance
• Drought tolerance gene for arid regions
• Reniform nematode resistance

Transgenes that might improve yield, lessen stress on plants, and improve fiber quality are being sought, but these genes will not likely be available in the near future. There is also interest in utilizing hybrid cottons a means of delivering transgenes. Hybrid cotton would provide inherent restriction on the use of transgenes, as well as, provide a nominal degree of hybrid vigor.

Cotton breeding. The development of successful transgenic cotton varieties ultimately requires an effective cotton breeding program. Since it requires about 10 years from making a cross until the release of a new variety, we can know what type of cotton varieties will be available in the next decade by simply examining cotton breeding nurseries. It is safe to assume that the basic germplasm of varieties will not change greatly in the next decade. However, genetic improvement is now being achieved with both transgenic and non-transgenic genes using novel selection procedures and tools.

Genetic or DNA marker [recognizable genetic label occurring on chromosome near favorable gene] technology is perhaps the one tool that will make the most difference in the near future. As better DNA markers are identified, the breeder can greatly improve the odds of finding the favorable recombinants for traits that are quantitatively inherited such as lint yield and fiber quality. To effectively utilize DNA markers when addressing a problem, three hurdles must be overcome. First, the favorable gene must be identified and its function and possible interactions must be determined. Secondly, markers that are closely linked to the favorable gene must be identified. Thirdly, a method must be established to insure that the favorable gene is selected and is functioning when the marker is selected. In the next 10 years, I am confident that much progress will be achieved in the application of markers technology.

With or without DNA markers, breeding progress in many areas depends on the development of novel selection procedures. The development of novel selection procedures often requires advances in different basic sciences to better understand the problem and/or process. For example, the development of varieties with improved heat tolerance has long been a goal of many cotton breeders. At present, we still do not have a reliable, adequate measure of heat tolerance because we simply do not understand the basic science of the problem. However, we may be very near to having an instrument that can identify specific enzymes associated with heat tolerance of cotton lines in the field at first flower. If so, progress can be made to determine variation in heat tolerance among available cotton germplasm lines, and then select for higher tolerance.

Pest Control in Cotton

Insect control. Due to their sheer numbers and diversity, insect pests are dynamic and will often shift with different cropping systems, control tactics, and crop management strategies. Eliminating one pest species or neutralizing it with insecticides often leads to enhanced damage by another pest species. Recent changes in
cotton insect control in the U.S. illustrate this scenario. Over the past 15 years, boll weevils have been eradicated in most areas and heliothine species (worms) are become largely controlled with Bt cotton. The development of insects that are resistance to Bt toxins has been impeded by development of new constructs of Bt genes, yet there is a continuing concern for broad based resistance across the different toxins. The reduction of insecticide applications has had positive effects on the environment and on maintaining beneficial predators. Unfortunately, the elimination of insecticide applications for weevils and worms has frequently led to increased problems with plant bugs (Lygus spp.). Plant bug populations have documented resistance to organophosphate and pyrethroid insecticides. Neonicotinoid insecticides are applied as a seed treatment and as foliar treatments to combat plant bugs in cotton and are frequently used in other crops. With widespread and frequent use, plant bug resistance to this group of insecticides will likely evolve. Alternative control methods for plant bugs are currently being examined. Nectarless cottons [no glands on leaves or bolls that exude nectar, which attracts insects] are effective for lowering plant bug populations, and other sources of resistance to plant bugs are apparently present in our cotton varieties. New insecticide chemistry and perhaps transgenic control of plant bugs may soon be available.

As plant bugs are controlled, another species may become dominate if we follow the same path. The effectiveness of the control tactics may be sustained using area-wide approaches that consider multiple crop species and cotton plant development. Most parts of the cotton plant are essentially immune to most insect pests. Cotton management programs, particularly control of plant maturity, can often be tailored to lessen the vulnerability of susceptible plant parts, reduce insecticide applications, and sustain profitable production. Thus, successful insect management programs must be developed by multi-disciplinary teams that will seek to incorporate present and forthcoming knowledge bases and tools into integrated systems. For the most part, these knowledge bases and tools are currently present, but few integrated systems exist.

**Weed control.** The development of Roundup Ready® technology has impeded research and discovery of new chemistry for controlling weeds. Now at least 16 weed species world-wide have been confirmed to be resistant to glyphosate. Glyphosate-resistant Palmer amaranth (Amaranthus spp.) has become wide-spread in my home area, and is having negative effects on cotton acreage and production. Glyphosate resistance has accelerated interest in new herbicide chemistry, new transgenics, and the integrated use of some previously used weed control techniques. Biological [pathogenic or predatory] and allelopathic [one species exudes chemical that deters growth of another species] control methods provide some hope but are not likely to be soon available. The most likely near future approaches will include:

- **Rotating technologies** – Weeds can be more easily controlled by rotating crops that use different weed control tactics and by alternating various biotech and conventional technologies.
- **Stacking gene technologies** - Varieties having both Roundup Ready and Liberty-Link will soon be available.
- **Reduction of weed seed bank** – Increased understanding of weed biology and population dynamics are leading to the development of management practices that will reduce the numbers of weed seed. Using global position guidance systems, tillage and disruption of soil, increased predation, and a more thorough understanding of weed seed production will reduce the seed bank.
- **Enhanced use of cover crops to maintain residue** – Cover crops can be used to improve soil texture, increase organic matter and nutrients, reduce wind and water erosion, and provide some weed control.
- **Improved spray technologies and formulations** – Work is being done to enhance the effectiveness of herbicide applications and to develop herbicide formations that are more easily activated.
- **Utilizing soil residual herbicides** – Maintaining an herbicide barrier to prevent seedling growth throughout the growing season can reduce weed numbers.
Areas where glyphosate resistance has not occurred can learn from the areas where resistant has occurred. Weed species can evolve and overcome any single new technology. Therefore, weed control should be approached from a system level rather than rely totally on one technology.

**Disease control.** Disease problems are often localized and generally cause less damage than insect pests. The most widespread cotton diseases include:

- **Seedling disease** – Most seedling disease problems can be effectively controlled with fungicides applied to seed and/or in-furrow at plantings.
- **Fusarium wilt** – Fusarium wilt is a world-wide problem. Most varieties exhibit some degree of tolerance to the disease.
- **Verticillium wilt** – Verticillium wilt tends to be localized in areas with specific soils and certain temperature regimes during boll development. Genetic tolerance to this disease exists, but the disease may be limit production even when obvious symptoms are not present.
- **Nematodes** – Incidence of cotton diseases caused by soil-borne nematodes has increased as other pest and nutrition problems have diminished. As problems with insects, weeds, water and nutrition are addressed, cotton diseases caused by soil-borne nematodes frequently become the limiting factor in production. Factors that favor crop development often will also favor nematode development. The most widespread occurring nematode problems are the root-knot and reniform (no visual symptom) nematodes. Columbian lance and the lesion nematode are important in some areas. Genetic resistance to root-knot nematode is presently available, but it has been difficult to combine resistance with good agronomic performance. Marker DNA technology should facilitate this. Since nematode problems are often localized in specific areas of fields, precision agriculture techniques provide much promise for assisting till better genetic resistance is available. There is evidence that hot areas of fields may be detectable via satellite – then treat as needed.

**Plant Growth Management**

Basic and applied studies in plant physiology provide the bases for understanding plant growth and development, which is applicable to all other disciplines. Over the past decades, a much greater understanding of basic principles associated with photosynthesis, nutrition, water use, rooting behavior, plant growth regulation, and yield components has been achieved. However, improvement is needed in the understanding of how these factors are affected by different soils, plant populations, and environments. Precise management depends on understanding these interactions within different cotton growing regions. Much advance is being realized in the areas of plant nutrition, plant growth regulators, and irrigation.

**Plant nutrition.** Increasing fertilizer-use efficiency and protecting environmental quality are two challenges facing cotton plant nutritionists. Traditional soil fertility research combined with new plant sensing techniques and precision application of plant nutrients are valuable tools to meet these challenges. Although the plant’s nutrition needs increase as yields increase, fertilization practices are frequently not adjusted to meet these increased needs. Traditional soil fertility research is needed to reexamine nutrient needs as yield potentials have increased and reduce potential environmental impacts. In addition, concerns with drinking water quality and hypoxia [deficiency of oxygen] in bodies of water are leading to increased environmental regulation, which will require fertility research to justify use of nutrients and to avoid mismanagement of nutrients. Research on application of organic amendments such as animal manure and municipal biosolids will provide an insight into how to improve soil quality. Since cotton must maintain a delicate balance of vegetative to fruiting development, precise nitrogen nutrition is important. Slow release of nitrogen by polymer-coated nitrogen fertilizer provides the opportunity to reduce environment concerns and to enhance nitrogen use efficiency in the plant. Precision of nitrogen nutrition may also be improved using new methods of assessing soil nitrogen availability and improved sensor-based nitrogen sensing techniques. Precision agriculture techniques can be used to identify variation in productivity of a
cotton field and then divide the field into management zones. Precise variable-rate technology can then be used to add nutrients as needed to different zones. These tools will allow us to reduce nitrogen use and protect environmental quality without reducing potential crop yield.

**Plant growth regulators.** Since cotton is a perennial plant that grows in an indeterminate fashion, control of plant growth is an inherent physiological problem. To some extent, plant growth regulators (PGR’s) can assist with managing plant growth and development. Scores of PGR’s have been evaluated—most have some measurable effect on the plant, at least in some situations. Few have been found to have consistent effects, and only a very few of these have had positive economic effects. The most widely used PGR in cotton production is mepiquat chloride, which consistently will decrease plant height. Some promising new PGR’s appear to enhance fruit retention by reducing ethylene in the plant canopy, and thus lessen the adverse effects of certain stresses.

Increased fruit retention on the plant is the best PGR for controlling plant growth. As the plant accumulates fruit load, vegetative growth slows and finally ceases. An appropriate balance between vegetative and fruiting development is essential. Proper management of the vegetative:fruiting balance can provide both high yields and early maturity. We can now determine that balance by sequentially monitoring the progress of white flowers to the plant apex. New technology, such as remote sensing, that might be used to more quickly characterize this balance would be a great benefit.

**Irrigation.** Although cotton is more drought tolerant than many other species, maximum cotton yields usually require supplemental application of water. Optimum irrigation method (e.g. furrow, sprinkler, or drip) varies with different regions, water available, soils, etc.—and will not likely change drastically in the near future. Advances in techniques to improve the initiation, sequence, and termination of irrigation applications are being made. The relative progress of white flowers to the plant apex will respond to water relations in the plant by reflecting the vegetative:fruiting balance. This balance forms the basis for the COTMAN plant monitoring system which utilizes the chronological progression of the number of fruiting branches that have not yet produced a first-position flower. Resulting growth curves clearly show the delay in maturity associated with delayed initiation of irrigation. The curves also respond distinctly to deficient water, but this distinct response often occurs too late to avoid some degree of water stress. New technologies, such as improved soil probes, show promise for earlier detection of insufficient water—thus enabling more precise sequencing of irrigation.

**Cotton Equipment**

**Precision Equipment.** Yield monitors provide static and/or post-harvest measures of variability in fields and provide mountains of information on a cotton field. These data are often interesting from an academic standpoint, but are still not being used widely in crop management. Real-time sensing of plant development using satellite or field equipment mounted sensors will more likely provide tools to aid crop management. Global access to satellite technology may allow some forms of this technology to be universally available. These technologies may provide the opportunity to save input costs by only treating as needed, to maximize yields by treating areas that will respond best to treatments, and/or to enhance the timing of management decisions.

**Harvesting equipment.** Since about two-thirds of the world’s cotton is hand-picked, the primary advance in the next decade will likely be the adoption of present harvest technology. Technological advance beyond the 6-row picker equipped with an on-board module builder is not likely to occur in near future. Reducing modules to a size that might facilitate shipping and more central ginning may occur. Stripper harvesting is a lower-cost option for harvesting which works best with uniform, small plants in arid regions. Cotton harvested with strippers is typically a lower quality of cotton than that harvested by pickers.

One of the greatest advances that I have experienced in cotton research has been the development of cotton pickers equipped with electronic weigh systems. For cotton breeders, these improved pickers have made it
practical to determine yield of early generation progeny. In the past, we could only visually select progeny rows. In 2002, two of assistants and I visually rated the potential yield of 188 advanced progeny rows using of a scale of 0 (poor) to 9 (excellent). We then harvested the plots with a picker and determined actual yields. If a rating criterion of 6 or greater to retain were applied, then four (including the highest yielding progeny) of the highest 10% yielding progeny would have been discarded. All three of us gave the highest yield progeny row a rating of less than 6. Also, four of the lowest yielding lines would have been retained. These experiment data made me wonder how many great yielding lines I have discarded over the years. Expanded use of this technology in breeding programs around the world will assist in development of varieties that have higher yields combined with superior fiber quality.

Ginning equipment. Combining ginning on the mechanical harvester has been a dream of some individuals. Such a machine was examined about 40 years ago, but it is not being actively pursued now. Like harvesting, ginning equipment has made much advance in recent years. A new ginning technology that is now showing promise is the high speed roller gin. By adding a cooling system to the roller, feed rate can be increased drastically, comparable to saw ginning rates. Also, the ginning efficiency (adhesion of fiber to seed) of varieties is being examined with the goal of identifying ones that would gin more easily on a roller gin. In addition, a new technique, which uses cylinder pins (like ones used in textile mills) instead of saws, is being developed to clean cotton lint. Both the high-speed roller gin and cylinder pin lint cleaners would have positive effects on fiber quality – particularly fiber length.

Cotton Utilization

Fiber Quality. Since cotton fibers were once living seed coat epidermal cells, physical properties of cotton fibers in a sample and even on a single seed vary greatly. There has always been a challenge to characterize and to improve fiber properties. New fiber testing technology is focusing on nep [small entanglements of fibers], maturity, short fiber content and trash identification. Improved characterization of fibers may enhance improvement and utilization of cotton.

Fiber characteristics of most cottons fall within relatively narrow ranges. Generally, varieties that have better fiber quality tend to be late maturing, and subsequently relatively low yields in many environments. Development and use of a selection index for fiber quality appears to be assisting to break this negative relationship. We are using an index called “quality score” to assimilate up to six fiber parameters into one measurement. By applying strong selection pressure using this quality score index in early generations, then selecting for high yields in subsequent generations, we are developing lines with both superior fiber quality and high yields. Improvement of fiber length by 2-3 mm, length uniformity index by 2 points, and strength by 3-4 g/tex may have significant positive effects on the utilization of cotton fibers.

Fabric finishes. To compete in the world fiber market, we must recognize who is the competition. According to ICAC, chemical (i.e. synthetic) fibers accounted for 62% of all fiber use in 2009. Therefore, the primary competitor for cotton producers is synthetic fiber producers rather than cotton producers in other countries. Increased and enhanced utilization of cotton fibers is essential for sustaining the cotton industry and making cotton more competitive. During the last three years, Finishing Research division at Cotton Incorporated has brought to market different types of “value added” finishes for cotton fabrics. In order to get quicker implementation of these concepts, they were branded with the cotton logo. Among these innovations are WICKING WINDOWS™, TOUGH COTTON™, STORM DENIM™, and endure™. This broadening of cotton fiber utilization will strengthen competitiveness of cotton and increase demand for cotton.

Cotton byproducts. Cottonseeds were once considered as a byproduct of cotton fiber production. Now, cottonseeds are important sources of oil and protein. However, utilization of cottonseed has been hindered by the present of gossypol, which renders the seed inedible by non-ruminant animals. Considerable work in the 1970's
led to the development of glandless cottons. These glandless cottons did not accumulate gossypol in glands that are associated with most plant parts. However, the removal of these gossypol glands made the plant vulnerable to a wide array of insects and pests that feed on leaves and stems. Using biotechnology, Texas A&M University has now developed cotton lines that produce glandless seed on glanded plants. This technology may further increase the value of cottonseed and help to address the protein needs of millions of hungry people now and in the future.

Gin trash was also once considered as a byproduct of cotton production and was usually burned. New technology is now being developed to greatly expand the use to gin trash. These include:

- Recycling back into the soil as a mulch on fields/gardens or as mushroom compost
- Mixed with water and grass seed and sprayed on the sides of roads to control erosion
- Pressed into briquettes to be burned as fuel
- Slathered on walls for noise control
- Mixed with construction materials and used to make decking for homes
- Used for the inner lining of bathtubs and other containers.

Conclusions

As I visited with specialists in these various disciplines, I was impressed with their perspectives and their optimism. As we consider the adoption of available technology and advent of new technology, there is certainly room for optimism. However, new technology is not free, and in some cases it is very costly. One specialist posed the question of whether the industry can afford the addition of certain new technologies. Perhaps, a more important question is whether our industry can afford to not adopt many of these technologies. Certainly, not all new technologies should or will be adopted in every country. But each country needs to be receptive to the technologies that will advance the profitability and sustainability of their cotton production.