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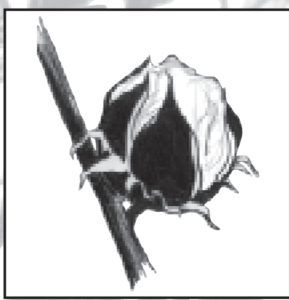

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Technical Change and New Directions for Cotton Production

Richard F. Kazmierczak, Jr. and Kenneth W. Paxton[1]

Introduction

The U.S. cotton production industry has undergone a half century of dynamic adjustment fueled by the forces of technical change. Approximately 13 million acres of cotton have been harvested in the U.S. in recent years, down more than 17 percent from average harvested acreage in the early 1960s. But over the same period, lint yields per acre have increased more than 39 percent, resulting in a total production increase of nearly 16 percent (Economic Research Service 1996). This increase in productivity can be largely attributed to the technologies embodied in new pesticide chemistries, novel pest management systems, efficient irrigation and cultivation, and improved cotton varieties (Fuglie and Day 1994). In fact, the acceleration of

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technical change has been the force powering sustained productivity increases throughout U.S. agriculture (Huffman and Evenson 1993).

Along with increases in productivity, the cotton production industry has experienced structural changes. The total number of cotton farms in the U.S. fell more than 10 percent over the last decade, with acreage per farm increasing by more than 23 percent (Glade, Meyer, and MacDonald 1995). Non-farm sectors of the cotton production industry also have experienced the forces of technical change. For example, 25 percent of the U.S. cotton gins have closed over a decade in which total production was increasing by more than five million bales (Bureau of the Census 1996).

Louisiana cotton producers also have been affected by the technical change influencing the national cotton production industry. Lint yields per harvested acre have increased approximately 43 percent since the early 1960s, to a recent five-year average of 730 pounds (Economic Research Service 1996). However, unlike national trends, total harvest acreage has increased in Louisiana over the last three decades. The early 1960s saw an average of 530,000 cotton acres harvested in Louisiana. By the first half of the 1990s, average harvested acreage had increased more than 60 percent to 848,000 acres, with over a million acres planted in 1995. This shift in national production toward Louisiana was made possible, at least in part, by the technical change embodied in sophisticated pest management systems, multirow mechanical harvesters, and module building and hauling equipment. These new technologies helped to remove biophysical production constraints facing Louisiana producers and may have increased Louisiana's comparative advantage in cotton production relative to other Southeastern states. Structural changes in Louisiana's cotton processing sector were slightly less dramatic than the national statistics, with the number of active cotton gins falling from 92 in 1983 to 77 in 1993, a 16 percent decline (Bureau of the Census 1996). With respect to technology, this decrease in gin numbers can be partly attributed to the increased ginning season made possible by module storage in gin yards.

Although cotton production technology has advanced tremendously in the last century, current and anticipated developments have the potential to increase the pace and importance of technical change. Instead of being driven solely by the search for increased output or net returns, much of this future technical change will be in response to a complex mix of political, regulatory, and economic pressures. A focus on conservation issues and fiscal restraint suggests the need for technologies that efficiently manage production resources in a way that is compatible with public desires for both environmental protection and federal budget reductions (Ruttan 1992). These new technologies will need to conserve resources and be adaptable to local production environments. However, this type of site-specific technical change is seldom neutral with respect to input mix, output mix, or regional competitiveness. As a result, the U.S. and Louisiana cotton industries face continuing dynamic changes in on-farm practices and regional production patterns. While the ultimate impacts of technical change are difficult to predict, prudence demands that current and anticipated technologies be examined for their potential impact on the structure and economic viability of the cotton industry.

Objectives and Information Sources

This report summarizes a year-long study of the current and future role of technology in the Mid-South, Southeast, and High Plains cotton production systems. Specific research objectives were to:

1) Identify the impacts of emerging technology on regional cotton production systems, including the implications of technology adoption on the economic and environmental stability of the system;
2) Examine the future direction of technical change in cotton production and its implications for the biological and economic structure of the cotton production system; and
3) Determine the potential role of future technologies on shifting regional competitiveness in cotton production.

Information used in the analysis was collected through a series of consultations with leading cotton research and extension personnel at regional research facilities and land grant universities. Given the verbal, descriptive nature of the information collected, the analysis represents the expert opinions of individuals working with and in the cotton production industry. In short, this report documents the combined vision of cotton production scientists and extension personnel with respect to the future of U.S. and regional cotton production. Necessary background information was obtained from published academic, industry, and government sources.

Participants in the consultations included agricultural economists, agronomists, entomologists, plant pathologists, and weed scientists from a variety of agricultural institutions (see Appendix A). In addition, a representative of the National Cotton Council attended each meeting. Consultations were conducted at three locations:

1) The annual Delta Farm Management Working Group Meeting held near Vicksburg, Mississippi (May 25, 1995). Those attending included eight research and extension specialists from Arkansas, Louisiana, and Mississippi;
2) Texas A&M University Agricultural Experiment Station in Lubbock, Texas (July 11, 1995). Participants included seven research and extension specialists from the High Plains region; and
3) The University of Georgia Coastal Plains Experiment Station in Tifton, Georgia (November 10, 1995), attended by seven research and extension specialists from Georgia.

The consultations were conducted in a "round-table," informal context that led to wide-ranging discussions covering the status and future impact of technical change on regional and national cotton production. In doing so, issues were discussed that covered production regions not directly represented by research and extension personnel (in particular, the Rio Grande region, North and South Carolina, and Florida). However, many of the participants in the consultations were knowledgeable about problems and opportunities in production regions adjoining their states. Detailed transcripts of the consultations were recorded and used in the analysis and synthesis provided in this report.

An Overview of the Report

Following a brief description of the historical and conceptual context for the role of technology and technical change, a focus will be placed on the main topics that arose during the consultations. Although the relative emphasis varied by group, participants concentrated on four broad areas in their discussions:

1) The current deficiencies in understanding how the cotton agroecosystem functions and the implications of these deficiencies for the future development and use of technology;

2) The need for continued technical change in insect management, particularly given regulatory reductions in chemical control alternatives and the repeated emergence of resistance;
3) The potential for biotechnology in cotton production, particularly in terms of developing insect- and herbicide-tolerant strains of cotton; and
4) The role of some sustainable technologies in cotton production and the reasons for their current and future adoption by producers.

Within each topic, discussions covered three levels of the cotton production industry that might be directly affected by technology. The first level was the agroecosystem, and discussions concentrated on the way current and potential technologies might alter the fundamental biological processes that occur in the field. The second level encompassed a producer's operations and the impact of technology and technical change on the ability of farmers to profitably manage cotton production. The last level concerned market structure and the potential for changes in the established relationships within the overall cotton production industry. Given that the consultations were held during informal and formal debate over the Federal Agricultural Improvement and Reform Act of 1996, effects of changes in federal cotton support programs and government regulatory activity also emerged as themes.

Following a topical discussion of consultation results, a synthesis of the information is presented. While this report attempts to integrate the information obtained in the consultations, important regional differences exist in the relationship between cotton production and technology. These differences are discussed where relevant. In addition, Figure 1 provides a summary of the main concerns expressed in each of the regional consultations.

Role of Technology and Technical Change

First studied by Schultz (1953) and Griliches (1958), there is now a large body of literature showing the critical role of technology in the development of U.S. agriculture over the past century. Although input use increased by only 15 percent between 1890 and 1990, real farm output increased more than 550 percent, leading to a 1.5 per-

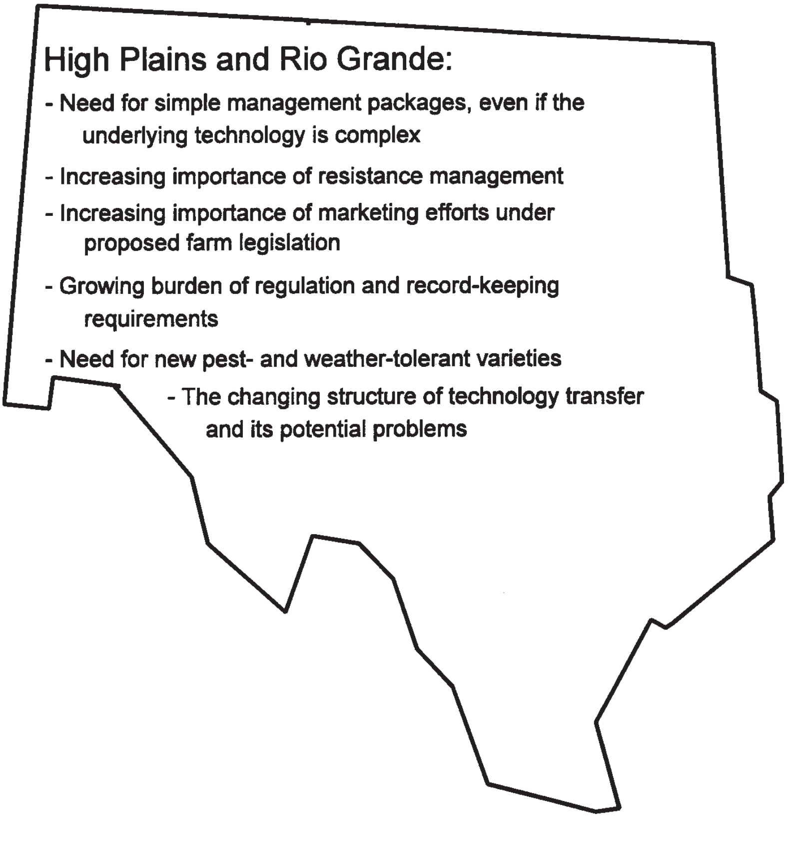
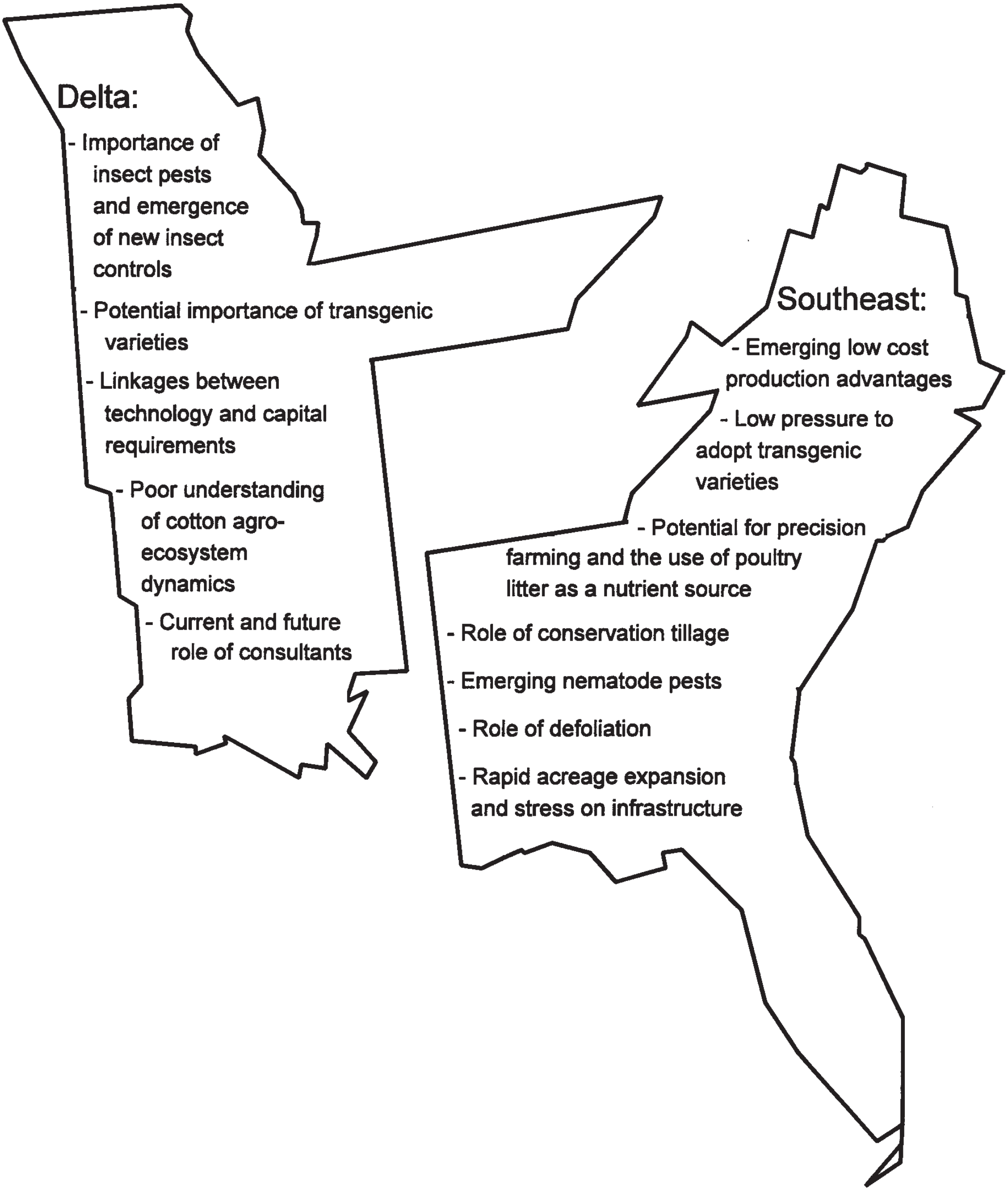


Figure 1. Major topics discussed by research and extension personnel in each regional consultation.


Delta:
- Importance of insect pests and emergence of new insect controls
- Potential importance of transgenic varieties
- Linkages between technology and capital requirements
- Poor understanding of cotton agro-ecosystem dynamics
- Current and future role of consultants
Southeast:
- Emerging low cost production advantages
- Low pressure to adopt transgenic varieties
- Potential for precision farming and the use of poultry litter as a nutrient source
- Role of conservation tillage
- Emerging nematode pests
- Role of defoliation
- Rapid acreage expansion and stress on infrastructure

cent average annual productivity increase (Huffman and Evenson 1993). Agriculture's growth in productivity has consistently exceeded the levels experienced in private non-farm economic sectors, where productivity has increased only 0.44 percent annually since 1947 (Jorgenson and Gollop 1992). Moreover, growth in productivity accounts for more than 80 percent of agriculture's overall postwar economic growth compared with less than 15 percent of the growth in the private non-farm economy. The vast majority of these increases in productivity can be traced to public and private investments in agricultural research, extension, and education programs (Huffman and Evenson 1993).

The influence of technical change on agricultural productivity also can be seen in the changing composition and quality of inputs. A century ago, more than 87 percent of farm inputs were supplied by producers, either in terms of family labor or intermediate products produced on the farm (Kendrick 1961). By 1990, less than 55 percent of inputs were supplied by producers. Between 1949 and 1988, productivity of all inputs to agricultural production grew 1.9 percent per year, compared with 1.7 percent for manufacturing (Fuglie and Day 1994). In particular, labor productivity in agriculture grew rapidly during this period, with output per agricultural worker expanding by 4.3 percent annually, compared with 2.6 percent annual increases for manufacturing labor. Partly as a result, total employment in agriculture steadily declined, and the average skill level of the remaining agricultural work force increased. Along with improved infrastructure and markets, productivity increases have helped to close the traditional gap between farm and non-farm income (Fuglie and Day 1994). Agriculture's productivity engine also shows little sign of slowing down. While a few studies suggest a decline in the rate of return to agricultural research (Lu, Cline, and Quance 1979), recent work overwhelmingly demonstrates continued research-led productivity gains in agriculture (Fuglie et al. 1996).

Although the history of agricultural technical change is impressive, future gains may be more difficult to achieve. Research aimed at increasing crop yields has encountered problems. For example, the incremental response of many crops to fertilizer use has declined, and research designed to prevent yields from declining in established varieties is rising as a share of total research effort (Ruttan 1992). In fact, some estimates suggest that around 30 percent of agricultural research expenditures go to maintaining current yield levels (Adusei and Norton

1990, Huffman and Evenson 1993). Many resources, such as land and water, also have become costly and subject to urban competition. While advances in microbiology and genetic engineering may help overcome some of these problems, the commercialization of this basic science into productive technology has occurred more slowly than expected (Caswell, Fuglie, and Klotz 1994). Unlike the past, these difficulties are occurring at a time when the ability of the research establishment to respond to agriculture's needs is limited by federal and state fiscal crises.

Understanding the potential impacts of technical change requires recognition that most agricultural technologies are, at some level, both geographically and temporally specific. Each location is characterized by soil, climate, economic, and managerial environments, with agricultural technologies usually being developed to address site-specific characteristics. Similarly, each time period will have its own unique biophysical, economic, and managerial problems that need to be addressed. Technology transfer among similar regions and periods may be possible, but a given technology typically has an absolute cost or profit advantage over alternative technologies only in a limited range of environments (Ruttan 1992).

Regional and temporal variation in technology can be illustrated by the segmentation that has occurred in U.S. cotton production. Viewed from both a varietal and end-use perspective, four cotton segments exist in the U.S. (Kidd 1994). The first segment is composed of the six million acres of picker cottons used in a wide array of textiles. The second segment encompasses the six-county, five-million acre area of stripper cotton around Lubbock, Texas. This low growing, leafy cotton is storm resistant but has shorter, coarser fibers when compared with picker cottons. As a result, they are primarily used for heavy fabrics that do not require surface dying or printing. The third segment is the million plus acres of Acala cotton in Arizona and the San Joaquin Valley of California. With irrigation and intensive management, Acala yields are three times the national average and highly sought after for producing quality textiles. Nevertheless, recent competition for water resources and the restricted availability of chemical inputs has led to a reduction in the acreage planted. The last segment belongs to Pima cotton, which has a fine, long, and strong fiber used in quality clothing. However, Pima cotton is very susceptible to growing conditions, including the impact of disease, insects, and damage during cultivation. This sensitivity tends to make Pima a poor yielding cotton in many areas of the country, and as a result Pima production is limited to a small percentage of the acreage planted in Arizona and California.

Given the importance of technology as a driving force in the development of U.S. agriculture, examining current and future paths of technical change is critical for the cotton industry. To analyze how technology and technical change might affect the structure and operation of cotton production, care must be taken to evaluate the source of the technical change, the reasons for its promotion, and the scope of its applicability. These factors will have implications for both the regional distribution of cotton production and the relative competitiveness of cotton producers in the U.S. But, most important, the long-term success of technical change depends on an understanding of the cotton agroecosystem.

Results of Consultations by Topic

Understanding the Cotton Agroecosystem

Cotton production occurs in one of the most artificial agroecosystems in the U.S., containing few plants and animals indigenous to the production regions. While these production systems were developed to control the productivity of the cotton plant and reduce pest populations, scientists involved in the consultations believed that there is a poor understanding of the complex and dynamic interactions that exist between cotton and its growing environment. Cotton physiology has been extensively studied, but there are fundamental knowledge gaps with respect to soil fertility, the fate of fertilizers, the appropriate use of irrigation, the management role of plant-growth regulators, and the production of early yielding cotton. The low percentage of the crop that is in peak condition at any given time (for example, 20-40 percent in the Mid-South) is evidence of both an information deficiency and a significant management problem in responding to field level productivity threats. In addition, an incomplete understanding of the cotton production system leads to ineffective implementation of technology, crisis-specific technology development, and a lack of confidence concerning the reliability of technology.

Ineffective Technology Implementation. One concern that surfaced during the consultations, particularly in the Mid-South region, was that uncertainty about the operation of the cotton agroecosystem may be leading to inefficient implementation of current production technologies. The source of this perception is the inability of scientists to foresee the many spill over effects of specific technologies over time. Although not unique to agriculture, this problem partly derives from the way many experiment station studies are designed, especially the tendency to examine a few interactions over a relatively short time period. Strictly controlled experiments allow scientists to isolate short-term cause and effect relationships imbedded in different technologies, but, in some situations, this limited data may not provide adequate information for the development of recommendations for commercial cropping systems.

There is a close linkage among the biophysical characteristics of a system, the characteristics of a technology, and the long-term response of the system to the use of the technology. However, the response of cotton agroecosystems to technology is not well understood, and the implementation of a technology over a wide range of environmental conditions by producers who have different management abilities increases the uncertainty. If ignored, this uncertainty can create significant disincentives for technology adoption and may create incentives to reverse adoption if a technology failure occurs. The boll weevil eradication program's problems with cost overruns, infestations by beet armyworm and tobacco budworm, and producer movements toward repeal of the program in some areas is an example of a technology that faced both problems at different stages in its life-cycle.

Although there may be significant gaps in knowledge concerning the biophysical cotton production system, scientists and extension personnel believed that incentives were increasing for the more multidisciplinary, long-term investigations needed to develop comprehensive cropping systems for producers. Much of this pressure originates with the regulatory requirements new technologies face, but significant motivation also was perceived as coming from producers. One theme that developed in the High Plains consultation was simplicity, or the notion that growers would increasingly demand technology packages that are easy to implement. Simplicity does not necessarily connote a lack of sophistication. Producers may be seeking technology that moves away from a crises-management framework to packaged systems that systematically address cotton production within a coherent, whole-farm context. In part, this approach may suggest a return to a prophylactic approach to managing problems such as pest infestations, but it will be developed within the new regulatory realities facing agriculture.

Producers may be increasingly motivated by the desire to improve their quality of life, both in terms of reducing their decision-making burden and the actual labor requirement to produce cotton. However, this desire conflicts with the general trend toward more sophisticated technology packages and the need for higher levels of producer education and training, particularly in record keeping and computer use. Given the apparent conflicts between the desire for simplicity and the increasing complexity that characterizes most technical change, the adoption of management-intensive technologies like precision farming may not occur on a voluntary basis but only in response to direct regulatory pressure. On the other hand, sophisticated technologies that are easy to implement, such as the planting of transgenic cotton varieties, may be readily adopted if they are shown to contribute to farm profitability.

Crisis-Specific Technology Development. The uncertainty surrounding the biophysical functioning of the cotton agroecosystem has tended to preclude the development of holistic production technology packages. Instead, the agricultural research system has responded to individual problems as they appear, with priorities set by the extent of the economic, environmental, and political pressures that exist in the short-run. While this response is rational for technology inventors, it often does not address potentially important synergies that take place in the field. Instead of moving toward more integrated systems management approaches to cotton production, most research efforts continue to be directed at short-term technological solutions to individual problems even as the USDA struggles to implement the mandates of recent farm legislation to steer agriculture in a sustainable direction (Fuglie et al. 1996). Whether a result of the growing public-to-private shift in state agricultural experiment station funding sources or a new emphasis on value-added, product-oriented innovation, agricultural research oriented around short-term payoff objectives comes at a relatively high social cost. The question is whether short-term, crisis-oriented research is an appropriate approach to technology development or if this type of research response leads to problems with self-perpetuating technology-based production and environmental problems.

As an example of the difficulties that can develop from a short-term, problem-oriented view of technology development, scientists and extension personnel involved in the consultations pointed to the obstacles that hamper cotton pest management. Because cotton pest research and the resulting chemical pest management programs have evolved in response to the few economically important species in the agroecosystem, little is known about the role of secondary species. As a result, cotton entomologists cannot reliably predict the potential impacts of the reduced pesticide use that may occur due to regulatory pressure, resistance-induced loss of efficacy, or the use of transgenic, Lepidopteran-tolerant cotton varieties. One possibility would be the emergence of a major pest that is currently considered inconsequential because its potential effects are being suppressed by chemicals targeted against the bollworm, tobacco budworm, boll weevil, or other primary pests. The emergent pest, or its potential for causing economic damage, may even be currently unknown to exist in cotton fields.

Uncertainties associated with the cotton pest complex make it impossible to assess the long-term impacts of changes in pest management accurately and instead provide incentives for maintaining status quo chemical use until economic, biological, or regulatory realities force a change. As a result, comprehensive pest management programs are under-researched, even though history suggests that species-specific pest management technology (such as transgenic Bt cotton) will not be any more enduring than new technologies have been in the past. In addition, while the general biological mechanisms of insect resistance are well known, predicting the usable life-cycle of chemical controls with any accuracy is still difficult.

The lack of a unified body of knowledge concerning the operation of the cotton agroecosystem and the management problems this presents suggest the need for renewed emphasis on pretechnology research in cotton. In particular, scientists advocated the compiling and synthesizing of information concerning the functioning of large-scale, monocultural cotton production systems. This research requires the long-term funding support that has been declining in recent years due to federal and state fiscal problems. Private and public research partnerships have been advocated as a new funding mechanism, but this trend may alter the original rationale for public agricultural research institutions — the development of technology that is socially necessary but whose profit potential for the developer is limited (as in some resource-conserving technologies). The danger in relying too heavily on private / public partnerships is that research priorities could be driven by short-term solutions to production problems rather than the promotion of long-term production stability and profitability.

Confidence in Technology. Uncertainties about the functioning of the cotton agroecosystem create difficulties not only for researchers but also for producers looking to adopt new technologies. The reliability and profitability of a technology, always an issue in new technology adoption, has traditionally been addressed through demonstration projects and the goodwill, or confidence, that existed between producers and public agricultural research institutions. However, the scientists and extension personnel involved in some of the consultations expressed concern that post-experimental technology failure will increase with the complexity of technology. As a result, producers may be exposed to greater risk than historically associated with being an early adopter. The potential for technology failure after its commercial release also is increased by the rapid technology transfer that comes with the modern producer's aggressive approach to enterprise management. While aggressiveness may be an appropriate response to market forces, adoption can occur too quickly if producers bypass the normal technology validation / transfer channels. The natural consequence would be increased production failures, with a corresponding decrease in the confidence placed both in new technologies and the agricultural research system. This reduced confidence may be exacerbated as private and joint private / public research increases the perception that scientists are being motivated by short-term profit objectives.

Given the severe economic effects of production failure in a market driven agricultural economy, only a few well publicized problems with technology can quickly lead to a crisis of confidence. The reaction of cotton producers to recent production problems in the Rio Grande and Southeastern boll weevil eradication zones is an example of the potential damage that can be done to confidence when technologies appear to have unanticipated negative side effects. Though the problems may have been due to weather patterns, planting schedules, natural insect population cycles, and / or other environmental stresses on the crop, the lack of knowledge concerning agroecosystem dynamics directly contributed to efforts to repeal the boll weevil eradication program.

Technical Change and Insect Management

Without exception, the participants in each consultation focused on the problems producers have with insect management. The most threatening problems facing U.S. cotton producers are reduced efficacy of chemical controls due to target resistance and the outright loss of some insecticides from regulatory actions (Watkinson 1989). Given these problems, most research and extension personnel thought that both the short- and long-term future of cotton production was dependent on developing innovative solutions to pest control problems.

The Pest Resistance Problem. As an evolutionary phenomenon, insecticide resistance arises from genetic changes that occur in a pest population in response to the selection pressure generated by repeated control applications of a specific insecticide (Sawicki 1987). Resistance is possible with herbicides, fungicides, or insecticides, and the problem is increasing in most intensively cultivated areas around the world (Watkinson 1989). Theory suggests that optimal tradeoffs between economic yield and resistance development can only be accomplished by carefully controlling the intra- and interseasonal timing and dosages associated with specific chemicals in a production region (Mangel and Plant 1983). However, individual producers have no short-term economic incentive to incorporate resistance considerations into their private pest management decision making (Clark and Carlson 1990, Lazarus and Dixon 1984). As a result, some producers tend to engage in short-term, profit-oriented pest management that accelerates the depletion of susceptible populations and ultimately leads to a loss of efficacy in one or more control agents.

Optimal insecticide use depends on a comprehensive knowledge of chemical efficiency over time, including consideration of application dosage and timing within and across seasons, but productivity cannot be assessed independent of the biological evolution of a production system. In addition, the potential for resistance development varies significantly by pest organism, type of chemical controls, and the way in which those chemical controls are used. Thus, it is entirely possible for susceptible populations to remain undepleted even when confronted by active chemical pest management (Hoy 1990). However, a small change in the way specific chemical controls are used, such as a shift in the timing of insecticide applications, can lead to the gradual rise of resistance in a previously stable susceptible population (Riley 1989).

One of the most widely reported and studied forms of resistance concerns cotton insect pests and the insecticides used for their control. In particular, cotton pest resistance to insecticides threatens the efficacy of many inexpensive, broad spectrum chemical controls that may not be replaced soon. The apparent decrease in the development and marketing of new insecticides in the U.S. can be traced to many factors, including the high cost of obtaining regulatory approval and public concern over the use of synthetic pesticides.

The High Plains production region is an example of the evolutionary development of pest management in cotton. In the last 20 years, High Plains cotton production has gone from being a system managed with relatively low pesticide use (primarily because damage was ignored) to one where pest management inputs are a focus of production decision making. Consequently, more problems are developing with resistance and secondary insect outbreaks, and this may continue to occur as elimination of the boll weevil allows pest species such as the beet armyworm and thrips to assume increased prominence. In addition, circumstantial evidence points to bollworm-targeted pyrethroid applications as responsible for the major aphid problems periodically experienced in the High Plains, perhaps due to an interaction between the pesticide and the aphid's reproductive physiology. But in this case, eliminating the bollworm through the use of Bt cottons could alleviate aphid problems by removing the need for pyrethroid applications. Of course, this assumes that the economics of Bt cotton make its production possible on the High Plains' variable dryland and irrigated acreage.

Part of the difficulty with pest and resistance management in the High Plains is that little work has been done to develop pest management schemes for dryland acreage. Growers typically use aldicarb (Temik®) on dryland acres to control sucking insects like aphids, but replantings and leaching rains may call for multiple applications at an expensive $9-10 per acre treatment. Even so, research and extension personnel felt that the potential impact of technical change in the region would be limited, with the adoption of any new practices being hampered by a severely depreciated producer capital stock. Producers do not have the financial resources to acquire new pest management technology and thus continue to use old technology and methods, thereby exacerbating problems with technology-induced problems like resistance. In fact, there is a perceived danger that, under the current economic structure of cotton production, resistance will eventually make cotton a largely unprofitable crop in the High Plains.

In contrast to the western side of the cotton belt, the successful boll weevil eradication in much of the Southeast has dramatically changed cotton production. Before eradication, producers were using 12-14 insecticide applications per year for a total cost of $80-$100 per acre. Post-eradication, the number of applications fell to 3-5 per year, for a total cost of approximately $35 per acre. Without the need for boll weevil controls, it might be expected that Southeastern growers could take full advantage of new technologies like Bt cotton in their pest and resistance management programs. However, the projected cost of the transgenic seed may exceed the current cost of insecticide applications for some growers. Thus, from an economic perspective, growers might use Bt cotton on a limited, insurance basis, especially in the short term and if secondary pest problems do not emerge. From a resistance management point of view, a geographically and temporally dispersed use of Bt cotton would be ideal for extending the life-span of the product. But, research personnel point out that one thing that could change this scenario would be the widespread development of resistance to pyrethroids. Under these conditions, growers may move rapidly into Bt cotton production if chemical alternatives are not available. The likelihood of this shift will be high if experiments show that the cotton plant does not suffer yield losses from the physiological demands of producing the Bt compounds.

Influence of Regulatory Activity. While resistance alone may lead to important losses in the economic benefits derived from a production system, additional losses may arise if regulatory actions change the size of the control technology set. For example, the withdrawal of a specific chemical control may force producers to rely to a greater extent on the remaining control agents. This situation can promote accelerated resistance development and resistance-induced declines in pesticide efficacy, even if the chemicals that remain post-regulation are used in an optimal manner (Kazmierczak et al. 1993, Knight and Norton 1989). This accelerated loss of economic benefits derived from a production system can be attributed to the interaction between resistance and regulation. However, it is only a partial measure of regulatory impacts because it assumes that the chemical withdrawal was undertaken with full knowledge of the potential dynamic impacts. Because legislative and administrative constraints foster static regulatory procedures based on partial budgeting analysis, the economic implication of resistance development is usually not included in quantitative benefit assessments.

Static regulatory decision making, in part the result of a lack of knowledge concerning the functional operation of the cotton agroecosystem, tends to promote an increase in resistance development and subsequent pest control failures. Thus, while resistance/regulation interactions may lead to economic losses, these losses can be inadvertently magnified if the regulatory decisions are not based on dynamic information about the affected system. Simultaneously, economic and regulatory pressures on the cost structure of chemical manufacturers promise to further diminish the size of the available pest-control technology set. In an active regulatory environment, cotton pest management systems that depend on specific and stable control chemistries may fail if an insecticide can no longer be used (Dover and Croft 1984, Mullins 1990). While research has attempted to provide approaches for incorporating resistance considerations into the regulatory process, the dimensionality and dynamic complexity of the problem require the use of comprehensive bioeconomic systems models to analyze the short- and long-term implications of insecticide withdrawals (Kazmierczak et al. 1993).

As an example of the complexity involved in analyzing the long-term implication of regulatory activity, research and extension personnel pointed to the pending emergence of nematodes as a major cotton pest in the Southeast. At the current time, more than 50 percent of the soil samples taken in some areas suggest that nematode populations are nearing economic threshold levels. But, because nematode-tolerant cotton varieties have not been developed for the area, producers must depend on a very limited number of chemical controls that are expensive compared with most pesticides. At the same time, these chemicals have been under EPA review several times in the past decade. The only current alternative for controlling nematodes on cotton acreage requires a rotational scheme with other crops that may be less profitable. Thus, while still in its infancy, regulatory and policy pressures may converge with the emerging nematode problem to make the current acreage of Southeastern cotton production the largest that the region will experience.

New Directions in Cotton Pest Management. From an entomologist's perspective, the dominant factor determining both short- and long-term cotton production viability is the successful development of environmentally safe and effective pest control methods. Three promising avenues of research and technical change that are already being explored are hormone mimics, biologicals, and genetically engineered products. The beet armyworm juvenile hormone is the mimic chemistry most fully developed at this time, but other compounds are not far from commercialization. Hormone mimics have the advantage of being pest specific, with little or no non-target effects on other species or the environment. Biologicals are produced from fungi or bacterial fermentation and rely on intensive screening of potentially usable compounds. In contrast, the development of both hormone mimics and genetically engineered products are accomplished by directed molecular manipulation that focuses on desired end-product traits. As a result, engineered products tend to be more profitable for private agribusiness. Bt cotton is the best known product of genetic engineering to date, but BXN cotton, glyphosate-tolerant cottons, and other products are rapidly approaching widespread commercialization.

Overall, the general tone of the consultations was that the technological base of pest control is not narrowing just because many traditional pesticide chemistries are being phased out. In fact, the base may be expanding because of the emerging directions of product development. Research and extension personnel believed that the development of single-product solutions to producer problems would be a serious threat to the stability of the cotton industry and contribute to the shortening of pest control product life-spans. They felt that producers need ongoing access to many alternative controls, especially if they are to avoid potential problems with high selection pressure and the rapid development of resistance.

Driven by the desire to find long-term solutions to pest and resistance management problems, there has been an escalating interest in the use of biologically based pest control products. As a rule, these products are easier to register and tend to be environmentally benign. The oldest and most widely used of these products are based on the naturally occurring insect pathogen *Bacillus thuringiensis* (Bt) and are targeted at various Lepidopteran pests. Bts have been known to exist since the early 1900s, but it was not until the mid-1960s that they were commercially produced for pest control. As evidence of their increasing popularity, biological pesticides (including Bts) have grown in use by as much as 30 percent per year in the last decade compared with only 1-2 percent annual growth for traditional chemical pesticides (Marrone 1991). While Bt insecticides are more selective than broad-spectrum chemicals, their most useful attribute has been the ability to be effective at controlling insects that show high levels of resistance to traditional chemical insecticides. As a result, Bts have been used in resistance management programs to control early season outbreaks of bollworm / tobacco budworm. Although some evidence exists for the development of Bt resistance, it has been used successfully for many years in Australia's intensive resistance management program and has been credited with increasing the commercial lifespan of a wide range of other chemical control products (Watkinson 1992).

Despite their apparent advantages, the lack of contact activity in many biological pesticides means that coverage and timing of application are more critical than with most traditional chemical insecticides. For cotton pest control, there has been skepticism that the common biotype of Bt could provide commercial control of tobacco budworm, thus requiring the identification of different strains of Bt with higher unit activity against tobacco budworm and armyworms. In addition, companies have continued to develop new formulations that improve efficacy and residual activity, including formulations containing feeding stimulants, UV inhibitors, and rain-fast polymers. Tank mixing of Bts with other chemical insecticides also may improve efficacy while reducing the total chemical amount applied to the cotton fields (Marrone 1991).

While hormone mimics and biological pesticides promise significant changes in the way cotton pest management will be conducted in the future, there are other agricultural practices that can be combined with pesticides to form reduced-chemical pest control technology packages. Technologies to reduce insecticide use include scouting or monitoring pest population to decide when to treat, destruction of stalks harboring insects, uniform planting dates, crop rotations, water and fertilizer management, and alternative tillage practices. As an example of the effectiveness of these new technology packages, their use in the High Plains has decreased insecticide use by more than 90 percent since the mid-1960s, a decline enhanced by a switch from organophosphate insecticides to pyrethroid compounds. This move to pyrethroids itself has been credited with decreasing total insecticide applications from 6 pounds to less than 2 pounds per acre, although the environmental dosage and costs associated with the materials have not necessarily decreased proportionally.

An even larger opportunity to reduce insecticide use on cotton requires increased attention to how chemicals are applied. In fact, the scientists participating in the consultations believed that future cotton producers face more restrictions on the application of pesticides. These restrictions may force producers to continue to hire pest management services due to the potential complexity of application technology, reporting and record keeping requirements, and perhaps bonding requirements against potential environmental damage. Nonetheless, substituting improved ground sprayers for aerial application could increase the insecticide reaching the target area. In this respect, covered, ground-based spray booms can more accurately direct insecticide applications and thus reduce spray drift and the inefficiencies that accompany it. Thus, improved management and technology, and the additional effort and investment required to implement them, can be economically beneficial to producers if they ultimately decrease the use of costly pesticide materials (Kidd 1994).

Biotechnology in Cotton Production

The commercial introduction of genetically engineered cotton varieties has been eagerly anticipated by the cotton industry for many years. With the potential for solving the problems of high insecticide costs, herbicide scheduling difficulties, and the impact of variable weather conditions, the significance of cotton biotechnology has been compared with the development of fuel-powered agricultural machinery. However, as with all technical change, the widespread use of biotechnology products will have implications for the way in which agricultural enterprises are structured and operated. In addition, the trend toward privatization of biotechnology research has serious implications for the potential adoption and spread of technology, particularly with respect to the viability of small producers.

Promising Innovations. Biotechnology research in cotton production has occurred in both public agricultural research institutions and private agribusiness, with much of the work to date concentrating on developing the methods for transfer of genetic material between organisms. Some significant progress has been made in developing applied technology, but only a few products are close to commercialization. In addition, the direction of technology development in the future is not known with certainty because of continuing progress made at the basic science level. Because of this high degree of uncertainty, research and extension personnel involved in the consultations focused on two technologies that are close to widespread commercialization — Bt and BXN cotton.

The cotton biotechnology products with the largest current potential for boosting productivity are related to the breeding of insect resistance into the cotton plant. Of these products, Bt cotton is well developed and currently being commercially distributed on a wide scale. Given that there is little known physiological cost to the plant for producing Bts, using Bt cotton varieties in commercial production is equivalent to purchasing an integrated technology package that combines the output product, or cotton, with an important production input, or pest control. While Bt cotton is not resistant to all insect pests, with boll weevils, plant bugs, aphids, whiteflies, and thrips being the most important exceptions, it can resist in varying degrees the attacks of several Lepidopteran species.

As with other approaches to the pest problem, there are questions concerning how best to manage the development of resistance to genetically engineered products. Part of the grower registration package for Bt cotton may require limits on the acreage that can be planted with the genetically transformed varieties. To maintain control of Bt varietal use, penalties for breaking the registration agreement are expected to be severe. However, enforcement costs will be high, and it remains to be seen how well producers will abide to the requirements. In many areas that do not have high pest control costs, these restrictions and the cost of using transformed varieties (estimated to be $6 per bag premium for seed, along with a $30 per acre licensing fee) may limit adoption. The high forecasted costs of using genetically transformed varieties is due to the attempt by companies not only to recover product development costs but also to capture the potential savings that growers might experience from reduced pesticide use. The unknown useful life-span of genetically transformed varieties also may prompt companies to accelerate cost recovery.

A herbicide-tolerant cotton, or BXN, is another biotechnology product that research and extension personnel believed to be important to the future of the cotton industry. Widespread field testing of BXN cotton will occur in 1996 on approximately 200,000 acres belt wide. Although there are two potential varieties, their economic viability is still in question due to some disappointing yield trials. Overall, herbicide-tolerant cottons have done poorly under stressful environmental growing conditions, and even under ideal conditions have yet to generate expected yields. In addition, these particular herbicide-tolerant cottons will not solve all weed control problems and may raise new problems if they lead to the development of herbicide-tolerant weeds. Other types of varietal biotechnology, such as the development of nitrogen-fixing capabilities, also are unlikely to achieve rapid commercialization because significant genetic changes need to be made, and there are large physiology costs to the plant to accomplish a process like nitrogen fixation. On the other hand, these potential hurdles to biotechnology product development also were forecasted, but rapidly overcome, in the development of Bt cotton.

Potential Problems with Biotechnology. One potential major problem facing growers concerning the increasing agribusiness emphasis on biotechnology solutions is that new product introductions are going to be patented or licensed. Companies also are going to require producers to sign contracts that restrict the use of the products and their distribution. This will effectively provide monopoly protection to companies to recover their product development costs. What happens after harvest will be of particular interest to the companies. Companies are currently working to develop contracts and pricing schemes that provide for cost recovery with respect to the seed itself, guarantee that producers do not save and / or share seed with others, and allow for pricing variability among regions. The ability to price differently across the cotton belt will be important to fostering widespread adoption of the technology. As noted earlier, adoption of Bt cotton on anything other than an insurance basis in places with low pest control costs will depend on low direct and indirect seed prices. These difficulties may cause reduced adoption early in the product life-cycle, but the regulatory pressures associated with chemical pest controls may eventually force adoption by most producers if the genetically engineered products continue to pose minimal threats to the environment.

Another looming problem with biotechnology in cotton production, and in agriculture overall, is that proprietary concerns may exclude public breeders from much of the ongoing research activity. Important cotton genetics projects currently involve both coalitions and blockers (Kidd 1994). As an example, in 1989, Agracetus (now a division of W.R. Grace) used *Agrobacterium* to transform cotton by incorporation of a *Bacillus thuringiensis (Bt)* endotoxin gene licensed from the University of Washington. Following successful field trials, Agracetus filed patent claims to all transformed cottons and was eventually awarded blocking patents. A coalition of Monsanto and Delta & Pine Land has licensed Agracetus' technology for the development of commercial cotton varieties featuring certain agronomic traits. In 1992, Monsanto and Delta & Pine Land agreed to the commercial introduction of *Bt*-transformed cottons, and they are currently extending their cooperation to cottons transformed for tolerance to Monsanto's glyphosate herbicide products. Thus, even if the developing companies do eventually make the relevant genes available to public breeders, it will almost certainly be with the stipulation that they be paid royalties on any subsequently developed commercial varieties. Combined with the fact that there is a fair amount of consolidation occurring in the agricultural biotechnology industry, this control of the genes and the royalties derived from them raises the potential for market domination and monopoly pricing power.

Sustainable Technologies in Cotton Production

The idea of sustainable technology runs the gamut from old techniques used in new, resource-conserving ways, to genuinely new technology that was purposefully designed for minimal use of resources. Currently, there may not be any truly sustainable cotton production technology from a system-wide perspective. Instead, individual problems are addressed, usually in response to declining resource availability, increasing resource price, and / or the pressures that develop from a conservation feature of a regulatory program. However, not all, or perhaps any, of the sustainable technologies are easier to use, and they generally reverse the historical trend of substituting capital for labor in agriculture. For example, in the High Plains, there has been a movement away from center pivot irrigation to row watering. Initially, growers thought that row watering would be an easier technology to implement, primarily because of the reduced maintenance that it would take to keep the system running. But the actual use of row watering increased the number of decisions a grower had to make, especially in terms of when to water particular areas. LEPA (low energy precision application) irrigation systems also are becoming much more important in the High Plains than they have been, although the technology is not yet perfected, nor is the producer's ability to implement it. But the renewed interest in irrigation technology has demonstrated a marked divergence in the yields experienced by dryland and irrigated cotton. This is in contrast to the historical tendency of yields to track each other closely when irrigation water was excessively applied as supplemental rainfall.

Precision farming is a sustainable, systems-oriented concept that has gained much attention in recent years, although its widespread commercial adoption may still be many years away. Many input suppliers, most especially fertilizer companies, have embraced the idea because they expect to sell more specialized products and / or services under this kind of technology regime. Environmentalists, on the other hand, have expressed concern that precision farming will result in a net increase in fertilizer and other chemical use. In particular, fertilizer use could increase dramatically on leachable, sandy soils. This possibility will require that precision technology packages be examined carefully not only for their economic potential but also for any potential environmental spill overs. Like many sustainable technologies, precision technologies will probably need to be evaluated annually given their intimate linkage with soil type and condition.

Synthesis

The U.S. cotton production industry is regionally segmented based on economic structure and operation, a fact that is not surprising given that agricultural technologies are, at some level, geographically specific. However, the research and extension personnel participating in the consultations shared many common observations about, and concerns for, the future of U.S. cotton production. Perhaps the most ubiquitous concerns were generated from the assumed challenges producers would face in managing insect and other pest populations.

The Southeastern U.S. has a long history of cotton production, but its cotton industry was in serious decline because of severe pest infestations. In recent years, however, production area and yields have expanded tremendously, with the primary credit given to the elimination of the boll weevil as a major pest in many areas. Even so, research and extension personnel were not entirely sanguine about the future because other pests may be emerging as serious threats to cotton production. In particular, nematodes are becoming an increasingly serious problem. In fact, concern was expressed for the emerging negative synergies among nematode populations, chemical regulatory pressure, and farm policy shifts. The fear is that, having gone a long way toward eliminating the boll weevil as a production constraint, the region may now be faced with an even more difficult problem in controlling nematodes. The potential damage of severe infestations, and the limited controls available for management, lead some research and extension personnel to suggest that the renaissance in Southeastern U.S. cotton production may have already reached its peak.

Other areas of the cotton belt also were concerned with insects and related pest problems. Research and extension personnel in the Mid-South viewed insects as the single most important current and future problem for cotton producers. The bollworm / tobacco budworm complex is generally viewed as the most important pest species in the region, with the boll weevil considered a secondary pest despite high damage estimates generated by some entomologists. The boll weevil's perceived minor role probably accounts for at least part of the difficulty of passing boll weevil eradication referendums in states like Louisiana. On the other hand, while Rio Grande producers traditionally considered the boll weevil an important pest, the recent emergence of severe secondary pest outbreaks following implementation of their boll weevil eradication program has led to successful efforts to repeal the program. Environmental factors like rainfall, temperature, and wind are important in the High Plains region, but insects also can cause substantial problems in cotton production. In fact, a string of recent mild winters has reportedly increased boll weevil numbers in some areas near the High Plains.

Because of the widespread concern about the future of insect control, there has been considerable interest in the transgenic Bt cottons and their ability to control some Lepidopteran pest species. Superficially, Bt cottons would appear to have the highest probability of adoption in the Southeastern U.S. production region because the bollworm / tobacco budworm complex is generally considered to be the major insect pest after boll weevil eradication. However, the fact that proposed Bt cotton costs are equal to or greater than current control costs may limit long-term adoption by producers. As a result, sustained use of Bt cotton may occur on a limited, insurance basis. This potential scattered use of Bt cotton should serve to enhance resistance management efforts and thus extend the marketable life-span of the Bt varieties.

Besides the recent emergence of transgenic Bt cotton, there has been a decade-long increase in the popularity of biological pesticides, though the lack of contact activity in many biological pesticides means that application coverage and timing issues are more critical than with most traditional chemical insecticides. The use of biological pesticides, especially Bt-based control materials, has grown by as much as 30 percent per year in the last decade, compared with only 1-2 percent annual growth for traditional chemical pesticides. However, resistance is also a major concern with the biologicals, with the fear being that cotton pest management systems that depend on them will be subject to collapse if material efficacy rapidly decreases. The potential for a rapid decrease in efficacy is made even more probable by using transgenic Bt cottons, primarily because the target pests will be constantly exposed to the control agent. Add in the potential for outright loss of traditional chemical controls through regulatory action, and what emerges is a pest management system whose stability can be seriously questioned.

Although many problems and concerns exist with respect to pest management in cotton, overall the consultation participants believed that the technological base for pest control was not narrowing just because many traditional pesticide chemistries were being phased out. In fact, some participants believed that the technological base may be expanding because of the different emerging directions of product development. But research and extension personnel did feel that the development of single product solutions to pest management problems would be a serious threat to the stability of the cotton industry and contribute to the shortening of pest-control product life-cycles.

Besides a universal focus on pest management, concerns were expressed in all areas of the cotton belt for the level of scientific knowledge about the cotton production system. Scientists participating in the consultations believed there is a poor understanding of the complex and dynamic interactions that exist between cotton and its growing environment. Uncertainty about the operation of the cotton agroecosystem may be leading to inefficient implementation of current production technologies. The source of this perception is the inability of scientists to foresee the spill over effects of specific technologies. For example, scientists questioned whether the adoption of transgenic cotton varieties might be the first step in reducing the variability of the cotton gene pool, with the subsequent problems that might occur if growing conditions change in the future. Adoption of the genetically altered cottons also could cause new pest species to emerge, as has been predicted for some areas of the Mid-South where widespread use of Bt cotton to control bollworm / tobacco budworm could lead to the emergence of the boll weevil as a major pest. Similar concerns were voiced across the belt regarding herbicide-resistant cottons. A major fear with this technology is the creation of weed gene pools that are tolerant of herbicides. Thus, the increasing role of biotechnology in cotton production makes it important to develop a better understanding of cotton physiology and how it responds to the growing environment.

The uncertainties associated with cotton agroecosystems, and especially the dynamic function of pest complexes, make it impossible to assess the long-term impacts of changes in pest management accurately. This lack of knowledge appears to provide incentives for maintaining the status quo chemical use. The lack of a unified body of knowledge concerning the operation of the cotton agroecosystem, and the management problems this presents, suggest the need for renewed emphasis on pretechnology research in cotton. Scientists and extension personnel participating in the consultations believed that incentives were increasing for more systematic, long-term investigations on the management of cotton production. Much of this pressure originates with the regulatory requirements new technologies face, but significant motivation also was perceived as coming from producers. In short, producers may be seeking technology that moves away from a crises-management framework to packaged systems that systematically address cotton production within a coherent, whole-farm context.

Historically, the introduction and adoption of new technology have required increases in management ability. This is true with the new Bt cottons because use of these transgenic varieties demands extensive knowledge of the insect population dynamics in the field so that control measures can be instituted at the appropriate time and place. The implementation of a technology over a wide range of environmental conditions by producers who have different levels of management skill only increases the uncertainty. If ignored, this uncertainty can create significant disincentives for technology adoption and may actually create incentives for reverse adoption if a technology failure occurs.

Across the belt, concern was expressed about new technology and how it might fit into existing production systems. In the High Plains region, concern focused on the state of capital equipment and the financial condition of producers. Research and extension personnel participating in the consultations raised serious questions about the willingness or ability of producers to adopt new technology. In essence, they believed that producers do not have the financial resources to acquire new pest management technology and thus continue to use old technology and methods. In doing so, producers may exacerbate problems with technology-induced problems like resistance. Furthermore, the stated desire of producers for additional leisure time and/or reduced management requirements also may serve to limit adoption of technologies in this region. Given the apparent conflicts between the desire for simplicity and the increasing complexity that characterizes most technical change, the adoption of management intensive technologies like precision farming may not occur voluntarily but only in response to direct regulatory pressure. On the other hand, sophisticated technologies that are easy to implement, such as the planting of transgenic cotton varieties, may be readily adopted if they are shown to contribute to farm profitability. The management requirements of new technology were not perceived as adoption constraints in the other production regions but were supplanted by concerns that new technologies always seem to be accompanied by a set of unforeseen, but potentially serious, production problems.

Researchers and extension personnel across the cotton belt also expressed concern for the potential changes that will occur in the overall cotton industry as a result of technological changes. These concerns range from stress on the infrastructure to concerns about monopolistic tendencies in the input markets for genetically altered cotton varieties. The expansion in cotton acreage in the Southeast has occurred more rapidly than storage/processing facilities for cotton seed. This has led to price distortions for cottonseed produced in this area, a problem that will only be resolved if new processing facilities begin operation as scheduled. New technology in variety development has decreased the life of a given variety, so that producers are faced with decisions regarding variety selection more frequently than in the past.

While concern has developed about the structure of the overall cotton industry, questions also are being raised about the future of cotton production management and the freedom allowed for individual decision making. The future appears to hold increasing restrictions on the way cotton producers will be allowed to apply pesticides. Cultural practices that are combined with pesticides to form technology packages should substantially reduce producer reliance on pest control applications. However, the coming restrictions on chemical use may force producers to hire pest management services due to the potential complexity of application technology, reporting and record keeping requirements, and perhaps bonding requirements against potential environmental damage.

A related issue discussed by participants in the consultations was the environmental impact of cotton production. These concerns covered a wide range of topics, from the availability of water for irrigation in the High Plains region to ground water contamination in the Mid-South and Southeastern regions. Producers in the Southeast and Mid-South areas are coming under increasing pressure to reduce runoff from cotton fields. Not only does runoff have the potential to degrade surface waters, it represents a loss of nutrients or other inputs into the production process. These losses reduce yields and increase production costs per unit of output. There is some general concern that widespread adoption of herbicide-resistant cottons could increase the use of herbicides because growers would not need to worry as much about post-emergent applications and their effect on cotton growth. While experience with new technologies and continuing advances in microbiology and genetic engineering may help overcome some of these problems, the commercialization of this basic science into productive technology has occurred more slowly than expected.

There are many reasons for the apparent difficulties encountered in developing solutions to some of the more complex economic and environmental problems facing cotton producers. Unlike the past, these difficulties are occurring at a time when the ability of the research establishment to respond to agriculture's needs is limited by federal and state fiscal crises. One proposed solution to this constraint is the widespread use of private / public research partnership in agriculture. However, the danger in relying on private / public partnerships is that research priorities will become progressively influenced by short-term rent-seeking behavior, not the promotion of the long-term production stability and profitability. Scientists and extension personnel expressed concern that this short-term outlook may lead to post-experimental technology failure, thereby exposing producers to greater risk than historically associated with being an early adopter and potentially threatening the credibility of the agricultural research establishment.

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Appendix A: Participants in the Consultation Groups

Delta Farm Management Working Group Meeting (Vicksburg, Mississippi):

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Mark Cochran	Agricultural Economics	University of Arkansas
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Frank A. Harris	Entomology	Delta Research and Extension Center, Mississippi State University, Stoneville
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Kater Hake	Extension Specialist	Texas A&M Research and Extension Center, Lubbock

James F. Leser	Extension Entomology	Texas A&M Research and Extension Center, Lubbock
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Eduardro Segarra	Agricultural Economics	Texas A&M Research and Extension Center, Lubbock
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Technical Change and New Directions for Cotton Production

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