Chapter 15

WHAT IS IN THE FUTURE?

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INTRODUCTION

This chapter will explore the future of the control of weeds in cotton. Agronomic changes including reduced and no-tillage planting, management practices including the use of on-farm computers, advancements in science including biotechnology and biological weed control, and regulatory, environmental and commercial issues will be discussed. It is by intent that, in most of the discussions, the subject is not reduced to quantification of numbers. If the authors can give readers an insight and an awareness that allow them to anticipate and prepare more effectively for the future, then the objective will be reached. Ideas, concepts and extrapolations are of more value than tables and charts in this particular case.

The most significant factors that will shape the future of cotton weed control and weed control practices in general in the United States are non-technical in nature. These factors—which impact all industries from automotive and steel to agriculture—are regulation, public interest and concern about pesticides, farmer attitudes and the economic status of agriculture. This impact is obvious to those involved in the above industries. More restrictive and/or demanding regulations will delay or eliminate new herbicides or herbicide practices in terms of obtaining regulatory approval. Many current products or practices will be eliminated because registrations are cancelled, label restrictions prevent effective use of the product, or the costs of maintaining registration are excessive.

As public concern about the extent of pesticide use grows, local federal and state regulations will become more restrictive. Further, as urban sprawl moves farther out into agricultural areas, pressures to restrict the use of pesticides will increase.

Finally, poor economic conditions are driving the farmers into modifying all of their practices, including those of weed control. There is far more interest in low-cost weed control. When all of these factors plus others that are non-technical in nature are considered, the impact on weed control in cotton will be significant.

A difficulty in arranging the subject matter for this discussion is that the issues are interrelated to a significant degree. It is difficult to discuss environmental issues without discussing the parallel regulatory issues, or the impact on future farmer practices. Trends in the cotton acreage planted each year will impact weed problems. As planted acres increase, the new acres will have a different weed complex. The economic outlook for cotton also impacts the control practices used by the farmer. The acreage of cotton has varied from 14.5 million to 9.5 million during the last two decades. Barring political programs which override supply and demand forces, it will probably vary that much in the next two decades. In the early days of chemical weed control, the rate of change in practices depended primarily on how rapidly the technology could evolve. Performance in terms of weed control and crop safety were the two most important considerations as new molecular structures were developed. Methods of application received considerable attention. Those people concerned with weed control in cotton—or those who had an impact on weed control in cotton—were, for the most part, limited to farmers, researchers, extension staffs of academic institutions and USDA, and personnel from industry involved in the process. The use of herbicides in cotton was regulated by USDA and, when required, FDA. Subsequent changes in federal law during the early 1970s have positioned EPA as the lead agency in pesticide regulation. Today, effects upon man and the environment are given more consideration as selection criteria in evaluating new molecules.

The rate of change is accelerating in our society and weed control is no exception. As we consider the changes over the last three decades, the most fascinating of all are within the research process for discovering new compounds. Beginning with the synthesis of candidate molecules through the generation of data to support registration, the equipment, techniques and procedures have evolved at an astounding rate. Today, most synthesis efforts are computer assisted with literature reviews and patent searches also computer-based. Many procedures used in initial biological evaluations have changed from labor-intensive to automated. Examples are pot filling, seed counting, and even evaluation. Data are entered directly into a computer, with statistically analyzed results waiting for the scientist when he returns to his desk. Compared to the laborious and slower hand operations of 30 years ago, this is a remarkable change.

BIOTECHNOLOGY

The future of weed control in cotton will be strongly influenced by the emergence and commercialization of a new science—that of biotechnology. Biotechnology is usually defined as the science of genetic modification of organisms, primarily through recombinant DNA techniques, but is not limited to that approach.

The field of biotechnology is advancing so rapidly that scientific milestones which were expected to be reached in years are being achieved in months. It can now be stated with high probability that biotechnology will impact conventional weed control. Earlier estimates of practical applications available for field use have been advanced from the first decade of the next century to the decade of the 1990s. Perhaps a more accurate prediction of the future will be the emergence of biotechnology as a key element in the control of weeds in cotton through integration of the science of biotechnology with conventional weed science as practiced in the 1980s.

CONVENTIONAL SCREENING PROCESS

The conventional and proven method of bringing a new chemical herbicide to the marketplace usually involves a sequence of science and technology in the following order:

1. The selection of cotton as a target crop, which means that herbicide candidates will be evaluated early in the testing procedure to determine safety on cotton;
2. The identification and selection of appropriate weed species for the screening procedure;
3. The synthesis and evaluation of large numbers (several thousand) of new compounds as herbicide candidates;
4. The selection of promising candidates for more thorough examination;
5. Identification of the final candidate as a target for commercialization;
6. The initiation of a number of processes to generate the data required for regulatory approval including toxicology, detoxification, and safety to users and non-target life forms in the environment;
7. Determination of the commercial effectiveness of the compound; and,
8. Process studies to design and build facilities to produce, formulate and package the candidate. This process—from the initiation of screening to first farmer-use of a registered cotton herbicide in the United States—can take a minimum of six to eight years or as many as 15 to 20 years.

BIOTECHNOLOGY PROCESS

The procedure for a product of biotechnology research to be utilized in cotton is somewhat speculative and less precisely defined, but, nevertheless, is now underway.

The selection of cotton as a target crop and identification of weed species will parallel that of the conventional method. In both cases, key parameters must be considered. These include size of market, estimated length of time to success, technical and commercial probability of success, resources required to sustain a research and development program and a comparison with other opportunities competing for resources.

In the new situation, instead of screening new chemical candidates, the sequence is:

1. A search for a gene or gene sequence which confers herbicide tolerance;
2. Insertion into the genetic base of an individual cell of a cotton plant;
3. The cell regenerated to a new plant; and,
4. The desired traits demonstrated in that plant and in second-generation plants.

Once it is established that the new gene(s) is being expressed in the progeny, the utility of the gene must be demonstrated in field trials analogous to that of field-testing a new herbicide. The technology is at a stage where routine regeneration of cotton from cells and the insertion, transformation and expression of new genes in cotton will not be a barrier to using this new science for improved weed control in cotton. The most likely first product of biotechnology that will impact weed control in cotton will be the insertion of a gene that will confer resistance to glyphosate, N(phosphonomethyl)glycine (Roundup®), applied at commercial use rates. Glyphosate is a broad-spectrum, non-selective, post-emergence herbicide used for the control of many annual and perennial broadleaf and grass species (Baird *et al.*, 1971). It has minimal impact on the environment—*i. e.*, no soil residual, no bio-accumulation, and minimal leaching. (Rueppel *et al.*, 1977).

The insertion of the new gene will allow glyphosate to be sprayed over the top of cotton at rates which will control a wide range of weeds including johnsongrass, cocklebur, prickly sida, and crabgrass. This new development will give the cotton farmer a high degree of flexibility in his weed control program. Cotton resistance to other herbicides through biotechnology also is likely, and by the year 2000, the farmer should have a choice of several very effective herbicides which are currently phytotoxic to common varieties of cotton.

The availability of cotton with engineered herbicide tolerance will have a number of advantages for the cotton farmer. Most important would be immediate access to current herbicides which have met the regulatory requirements, and whose performance is comparatively well understood. The impact of soil type, moisture, rate, and susceptibility of weed species will have been observed under farmer-use conditions. This also may allow planting in fields infested with weeds which could not be controlled economically with conventional herbicides. No-tillage and reduced-tillage cotton planting also could expand in areas where selective herbicides were not available.

NEW ISSUES AND CONSIDERATIONS

Every new breakthrough in science brings a new set of issues. Biotechnology poses new issues to weed science in cotton. In addition, some current issues are involved. As herbicides are registered for new uses in crops as well as for new crops, regulatory requirements ranging from establishment of new tolerances to determination of impact on the acceptable daily intake (ADI) must be considered. For instance, an over-the-top application of a herbicide already registered for pre-plant application may change the residue levels on or in cotton seed and thus require establishment of a new regulatory tolerance.

New performance issues must be dealt with in the control of weeds in a genetically-modified, herbicide-tolerant crop. For instance, is the degree of resistance expressed as well under conditions of drought stress as under excessive moisture? What are the effects of colder than normal versus warmer than normal air and/or soil temperatures on the genetic expression of resistance? If the herbicide is postemergence active and its previous use was as a preplant treatment, as in the case with glyphosate, will the influence of the crop canopy on the control of small weeds require different nozzle arrangements? Will the spectrum of weeds and stages of weed growth present in cotton differ from those already labeled and require adjustment of the rate? Are there new problems of interaction with other pesticides that are analogous to the propanil-carbamate (*e.g.* herbicide [Stam®], insecticide [Sevin®]) interaction that causes severe injury to rice? These issues are not barriers to the genetic modification of crops to be resistant to herbicides; however, it is clear that the need for insightful, well-designed experiments in the area of applied weed science will be critical to the successful commercial introduction of this new, exciting science.

The seed industry will have a significant role to play as herbicide-resistant cotton varieties are brought to the marketplace. In the past, when a new cotton herbicide was commercialized, seed companies were involved to the extent that the herbicide had sufficient safety on the companies' varieties. Some soybean breeding programs have resulted in the selection of a variety with increased herbicide tolerance, *i. e.* 'Tracy M'. The use of a herbicide-resistant cotton variety will call for major technical input from the seed company over several years. This commitment of resources will not be made frequently. The practical implementation of biotechnology will depend upon the capability of the seed supplier to bring the engineered varieties to the cotton farmer.

Another requirement for the practical use of biotechnology in weed control in cotton is apparent and must be addressed. It is the need for collaboration and teamwork by scientists working in biotechnology with those in traditional weed control programs. The successful introduction of weed control practices and the rapid and widespread use of chemical weed control for cotton in the United States was due in no small part to the early and continuing cooperation by a wide range of scientific disciplines—the plant physiologist, taxonomist, chemist, biochemist, agricultural engineer, agronomist, horticulturist, forester and soil scientist. With few exceptions, there were no departments of weed science comparable to departments of entomology and plant pathology. The weed scientist, by necessity, was exposed to a broader array of scientific disciplines and weed science moved forward on a faster track.

Continued involvement by a wide range of disciplines will be necessary to capture the value of biotechnology for weed control in cotton. To be effective in bringing practical results to the farmer in a timely and efficient process, the cell biologist, the geneticist and the plant breeder—together with their related disciplines—must interact just as comfortably with those involved in weed science, as others did in the past.

BIOLOGICAL CONTROL

Insects, fungi, bacteria and viruses represent possible agents for weed control in cotton. Considerable attention has been given to this approach in the past. Commercialization has occurred in citrus, pasture and rangeland. The control of northern jointvetch was proven technically possible in rice, but was not commercially successful. This approach will accelerate in the future for several reasons. First, regulatory and public pressures are pushing this new approach. More resources are being invested in biological control as an alternative to chemical weed control. Government, academic and industrial scientists are proceeding in a cooperative manner to identify candidate organisms. Researchers now have the knowledge, skills and experience to obtain consistent, predictable and acceptable levels of weed control. Finally, the integration of biotechnology and biological weed control will substantially increase the number and quality of candidate organisms for this use.

As with any emerging technology, the use of biological weed control agents is confronted with several new issues, in addition to those encountered by conventional herbicides. These include: (a) new, different and increasing regulatory requirements; (b) the influence of environmental factors and climate upon effectiveness; (c) performance criteria; (d) possible escape of an introduced organism to non-target hosts; (e) market opportunity for the basic producer; (f) patent coverage considerations; (g) new delivery and application systems; and, (h) new educational and sales programs.

Regulatory history on the registration of biological weed control agents is limited. Only a few organisms have been successfully released within the last decade. Based upon events within the past two years, it appears that regulatory procedures and requirements will become more demanding, rigid and time-consuming. This will occur even where the biological agent is native to the environment. Public concern of the scientific community is high regarding the release of living life forms into a new area, particularly if they are microorganisms. The level of concern is even more acute for bioengineered organisms.

New regulatory demands will occur not only at the federal level, but also at the state and local levels as agencies respond to this new technology. While promulgated as being of assistance to the development of an emerging new technology, the regulations enacted, in fact, will be precautionary in nature. The real effect will be longer and more costly development programs and delayed availability to the cotton grower.

Based upon knowledge and experience gained so far, considerable improvement in results will be required for consistent performance in the field. Environmental factors including temperature, relative humidity, solar radiation and soil moisture must be better understood as to their effects upon a biological agent's ability to colonize and grow in the crop environment.

Acceptance of new performance criteria by growers who successfully use biological agents will sometimes be required. Growers accustomed to observing necrosis on treated weeds within days or hours after application of a herbicide will be concerned with slower symptom development from a biological agent and the continued growth of weeds for perhaps days after treatment. Related questions are posed. If the biological agent fails, will retreatment at a later stage of weed development be effective? If the biological agent is narrowly host-specific, will control of the host weed result in death of the biological agent for lack of a food supply, thereby necessitating a second application for newly emerged weeds?

New economic thresholds for weed control may be required with some biological agents. This will be true particularly for cotton growers, who generally have exceptionally high performance standards versus those for soybeans. This is due largely to the use of mechanical harvesters and loss in grade due to grass or stain in the gin sample. A weed which has been successfully colonized by a pathogen or insect may be rendered essentially noncompetitive with the crop even though it remains alive. Cooperative studies by traditional weed scientists and biological control scientists will be necessary to determine the correct population and timing thresholds for most profitable use by growers.

Delivery or application systems must be developed for effective use of biological agents. Traditional herbicides are formulated for application by granular units or hydraulic sprayers. These have been effective with some plant pathogens, but modifications will be in order for others. For instance, a pathogen which requires abrasion of the leaf surface for successful inoculation might be significantly more virulent if minute, sharp particles were included in the formulation or added to the air or liquid carrier. This would require the use of components in the applicator which would be largely unaffected by the particles. Time of application will need to be determined. For instance, fungal organisms used for weed control generally have higher survival rates when moisture is maintained on the infection court during inoculation—in practical use, this means that success is highest when the application is made to wet foliage under humid conditions maintained for the number of hours required for infection of the weed.

Adequate market size is important to a potential producer of a new product. Just as a young man contemplating farming as a career cannot economically justify a 20-acre cotton operation, a potential producer of a new biological herbicide must consider the market size. Since it can be anticipated that biological weed control agents will be weed-specific, the market potential for any given product will be comparatively small. The cost of registration is essentially the same regardless of the size of the market, so it will not be economically feasible to commercialize small market products. This specificity is well demonstrated by a product trade-named Collego® which was based upon the microorganism *Colletotrichum gloeosporiodes*. This organism is pathogenic to northern jointvetch and does not injure rice. It was developed and registered for use in rice and was successful on the target weed. It was not well accepted by rice growers, however, due to its lack of activity on Indian jointvetch, a related species which inhabits rice. Thus a scientific success following many years of research and development culminated in commercial failure due to weed specificity.

Another example of a technical success in the control of a weed with a biological agent is that of the control of stranglervine in Florida citrus with a species of *Phytophora*. A product based upon the organism was so effective on stranglervine, a major problem weed, that future sales will be limited to scattered small infestations. Such narrow specificity is desirable in that it allows use on a target weed without injury to non-target species. Yet, that very characteristic makes it financially unattractive to the product manufacturer.

The biological control of weeds in cotton is in the early stages of development, with no current farmer use. Yet progress is predicted and, in fact, is inevitable. One only has to observe insects selectively feeding on horsenettle in the field or see morningglory diseased with a naturally-occurring pathogen to be optimistic. The rate of advancement is increasing both in the public and private sectors. The most significant advancements will probably be based upon genetically altered organisms and research programs where scientists in biotechnology and traditional weed control work together.

HERBICIDE RESISTANCE AND ENHANCED DEGRADATION

Two major areas of investigation during the next two decades will be genetic resistance in weeds to herbicides and the buildup in the soil of microorganisms which detoxify the herbicide to prevent acceptable weed control.

Tolerance is perhaps a better term than resistance in that the latter implies an absolute condition. Populations of weed species in the field are heterogeneous and several generations of seed are likely present. Thus the genetic diversity which helps ensure survival of the species can result in lines or varieties of a species in which a genetic character for tolerance to a particular herbicide is repeated in succeeding generations. With repeated use or exposure to the same herbicide over a period of years, the percentage of the native population of that weed species carrying the resistant trait is increased. With sufficient repeated use and production of viable seed, the resistance-bearing strain may repopulate to the point that it predominates. This is particularly true where control of the susceptible species is maintained at a high level over a period of years where crop rotation and herbicide rotation are not exercised.

The development of herbicide-resistant strains of weed species has been anticipated, based upon the history of insect resistance to individual insecticides and then to classes of insecticides. It was found that repeated use and dependence upon a single insecticide, such as DDT, resulted in the selection of a tolerant strain. With continued exposure, each succeeding generation contained a larger number of offspring carrying the trait for tolerance. Effective control required increasing rates of the insecticide and eventually forced growers to switch to other compounds within the same insecticide class, and then to completely different classes.

The development of herbicide resistance in weed species has been slow to actually occur. As compared to insects, most weeds which infest cultivated row crops have much longer life cycles, are generally exposed to only one or two applications of a single herbicide annually, and would thus require a longer period of time for a tolerant population to develop through random selection pressure from the herbicide.

In reviewing the results of a 14-year integrated weed management system research program conducted in Illinois, Shaw (1982) reported there was no evidence of increased resistance to any specific herbicide by any specific weed species. The results of the use of chemical weed control programs were: significantly increased yields of corn and soybeans, reduced weed seed populations in soil, reduced tillage, improved harvesting efficiency, reduced labor and increased net farm income.

Mudge *et al.* (1984) confirmed the presence of a dinitroanaline-resistant biotype of goosegrass in South Carolina. He reported that resistant goosegrass had been suspected since the early 1970s in a cotton-producing area, and that subsequent field experiments with trifluralin (Treflan®) and related dinitroaniline compounds confirmed the low level of activity reported by growers in the area. Laboratory research conducted by Vaughn and Koskinen (1987) in Mississippi traced resistance to one gene and one protein in the resistant goosegrass plants.

The most recent assessment of the development of herbicide-resistant weeds was given by LeBaron (1987) who reported that 58 species of weeds have become resistant to seven different types of herbicides in 32 states and 13 countries. He further stated that several are present and spreading in several of our southern states. However, we estimate that less than one percent of herbicide usage worldwide is impacted by resistant weeds.

From an overall economic viewpoint, herbicide resistance is unlikely to be a significant threat to the financial well-being of the United States Cotton Belt. Climate, soils, weed species and cultural practices vary widely across the Belt. Control practices therefore vary widely. The presence of several weed species, including both annuals and perennials, precludes reliance upon single herbicides or single cultural practices for control.

While the Beltwide threat of resistant weeds is considered remote, the occurrence is more likely in localized areas where cotton is grown continuously and the same weed control programs and herbicides are used repeatedly. Shaw (1982), in his review of the 14-year study with corn and soybeans, reported that net profits were greater where both rotational cropping and rotational herbicides were used. The cotton grower is fortunate in having at his disposal an array of weed control tools, chemical and mechanical. Seldom is he dependent upon herbicides alone or upon single herbicides. Due to the variety of control methods employed in today's integrated weed management programs, genetic resistance to herbicides is unlikely to be economically important outside localized areas.

Care must be taken to ensure that one new favorable development—herbicide-resistant cotton (and other crops)—does not exacerbate the unfavorable situation of herbicide-resistant weeds. A very effective herbicide used on one crop in a rotation system could be used on other crops on the same land in a rotation system if those crops were genetically modified to be resistant to the herbicide. However, the increased use of the herbicide on the same land could expedite resistance development in the weeds.

Additional studies should provide information on the cultural practices required to give the best balance between the avoidance of weed resistance or herbicide susceptibility to microbes while maintaining an effective, low cost herbicide program. With proper effort, those two objectives should not be mutually exclusive.

Harvey and Schuman (1981) reported degradation of EPTC (Eradicane®) by naturally occurring soil organisms which feed upon the active ingredient and result in detoxification. The manufacturer added a compound to extend the herbicidal life of the active ingredient against microbial breakdown. Results of the addition of the protectant were positive, however, rapid degradation and unacceptable weed control have since been reported by growers with repeated use on the same fields.

COMPUTER TECHNOLOGY AND WEED CONTROL

COMPUTER-ASSISTED FARM MANAGEMENT

The computer age has not left the cotton producer on the outside looking in. Desktops, PCs, CRTs, RAM and disk drives are now part of the vocabulary on many cotton farms. Once primarily used to store and organize financial, production and personnel records, they are being used increasingly as an aid in both financial and production planning including weed control programs.

Several factors will accelerate the adoption of computers as a routine tool for the farmer. The costs of information systems, the computer and the software are dropping rapidly so that the cost per unit of information is dropping even faster.

Small computers are now available that can easily handle a large, complex farm operation. With the trend toward larger farms, the owner and/or manager will be capable of and more likely to utilize computers as part of a management system.

Most land-grant universities across the Cotton Belt have programs available to their growers through the county extension office. For instance, the state extension weed specialist in Mississippi[1] has a program on sprayer calibration available to county agricultural agents. He also has a spread sheet available in disk form to aid in herbicide selection. The grower can use it with the computer located in the county agent's office or with his own compatible PC. In Alabama, the state extension weed control specialist[2] has disks with sprayer calibration information and herbicide weed control ratings charts for the major crops. Computers in the county extension offices are telephone-connected to the Auburn University campus. Georgia[3] and North Carolina[4] have similar programs. The programs and equipment differ within each state but are designed to meet the specific needs of cotton and other crop producers within their respective states.

Radio Shack and IBM equipment are now common in the county agent's office. Most software programs which aid growers in selecting their weed control programs require that they manually insert the major weed species to be controlled, the herbicides available, rates per acre and purchase costs per unit. The programs then display the most cost-effective options. Once selections are made, a hard copy is printed. Most programs contain information on each product registered for the crop, a species list and control rating by product, and application technique. A few programs also contain information on weed competition and yield response by time and duration of competitiveness. The computer-assisted programs available from all states are evolving toward providing the most cost-effective control programs to growers. In cotton, competition data are available which show the influence on crop yield of these species: pigweed, sicklepod, some morningglories, prickly sida, spurred anoda, johnsongrass, bermudagrass, unicorn plant, silverleaf nightshade, yellow nutsedge, velvetleaf and cocklebur. With the large amount of data available on weed biology and crop interference, it is inevitable that better and more useful computer-assisted programs will be available to growers, consultants and others on how to obtain the most cost-effective and environmentally sound weed control programs.

Farm managers will be helped in their decision-making process by the increasing availability of computer information. Agricultural experts from universities, USDA, seed companies and chemical companies will rely upon computer software as a major means of disseminating information. Much more detailed infor-

[1]Houston, Douglas W., Mississippi State University, Mississippi State, Mississippi, 39762. Personal communition.

[2]Everest, John W., Auburn University, Auburn, Alabama 36849. Personal communication.

[3]French, Michael C., University of Georgia, Athens, Georgia 30602. Personal communication.

[4]Coble, Harold D., North Carolina State University, Raleigh, North Carolina 27695-7620. Personal communication.

mation on each herbicide will be available than now appears on the label because the information can be developed for localized soil and climatic conditions.

In weed research, with utilization of the enhanced capability of computer technology, it should be possible to predict the impact of specific production practices on the weed problems of the cotton farmer ranging from local areas to large regions. Those who interface with the cotton farmer—the suppliers, consultants, researchers and extension workers—must also become computer-literate.

COMPUTER-ASSISTED GROWTH SIMULATION MODELS

Plant growth and yield models for several major agronomic crops including cotton have been constructed. The models are based upon precise observation and measurement of crop growth and development, and the influence of soil moisture or other specific factors upon that growth and development. The growth measurements are repeated, verified and tried for predictability at additional locations. Once a growth response is repeated at a high level of probability, it is stored on software (computer disk). Plant growth and development which occurred under real conditions then serve as the data base to allow the computer to simulate crop growth under a theoretical condition—for instance, to predict the effect of 20 days of dry weather beginning at first square.

The GOSSYM computer model, which simulates the growth of the cotton plant during the entire year, is a highly advanced model with proven value to producers (Baker *et al.*, 1983). It simulates the growth and development of the cotton plant including roots, stems, leaves, blooms, squares and bolls and is updated daily with information on maximum and minimum temperature, solar radiation and rainfall.

COMAX, a computer program that performs logic or analyses of large quantities of data, was developed to work in conjunction with the GOSSYM growth model on cotton (Lemmon, 1986). By using a database (GOSSYM) and daily updated weather data, COMAX can sort information and logically calculate the correct timing for irrigation, fertilizer and defoliants. Use in large-scale grower trials in Mississippi and South Carolina verified its accuracy.

In the future, with increasing availability of computer modeling and more attention to the growth characteristics of weeds, it should be possible to anticipate and predict the impact of changes in production practices on the weed population, and therefore on the need for changes in weed control practices.

Simulation modeling of weed growth and development is in its infancy. Orwick *et al.* (1978) reported on a growth simulation model for *Setaria*. Work on a number of species toward computer modeling is underway in Florida and North Carolina. Bridges (1987) recently developed a model which predicts the date of flowering of seedling johnsongrass within 24 hours. Research on computer modeling of weed growth and development currently is underway on a large number of species in several states. Given an existing database, progress will come quickly. Where a database on an individual species is lacking, several years will be required before information can be made useful to the grower in making weed control decisions. The availability of weed competition data will make growth models even more useful. Much more complex analyses will be required when weed/crop interference data involving several weeds simultaneously are analyzed for their combined influence on crop yield. Weed growth and development information will be needed on each species to serve as a database.

Local environmental measurements (on-farm or near-farm weather data) will be necessary to support decision-making. Without supporting weather information, knowledge of the growth and development of the crop and competing weed will be inadequate to the weed control decision. For instance, McWhorter (1987) determined that moisture stress was basic to the competitiveness of johnsongrass with soybeans. The yield response to johnsongrass population and time and duration of competition were inconsistent from year to year until correlated with soil moisture measurements.

Growth simulation models for the major weeds across the Cotton Belt would require information on germination, emergence, growth and development in response to temperature, soil moisture, solar radiation and related factors. Where these data exist, simulation modeling is underway at a number of universities. Benefits to cotton producers would be as follows: (a) knowledge of when to expect emergence of individual species; (b) understanding of when to anticipate certain species in response to certain weather conditions; (c) knowledge of rate of growth under given conditions; and (d) ability to properly time control measure, particularly of postemergence herbicides.

COMPUTER-ASSISTED WEED MAPS

The changing farm practices in the cultivation of cotton become both a cause and effect in the characterization and control of weeds. In some cases, the farmer changes his practices for purposes unrelated to weeds, or the consideration of weed control is secondary to the main purpose. As a result of the change, however, the weed population shifts and therefore the farmer's weed control practices must shift.

On-the-farm mapping of weed infestations is one of the most neglected aids to good weed control management. Like good soil and cropping maps, a weed map of each field is a useful aid to next season's planning. Crop selection and tillage can be dependent on weed control. On land newly planted to cotton or operated by a new tenant, a weed species map is valuable. This is particularly true with the residual herbicides applied preplant, incorporated and preemergence. It is not uncommon to assume that prickly sida infests an entire field when in fact it occurs only across one side. Accurate weed maps allow better decision-making at lower cost.

Herbicide use maps can be equally as useful as weed maps, particularly where crop rotation is used. A two-year history of the weed control program, including herbicides, can pay dividends. This is particularly true where land ownership or management changes hands. Knowledge of the weed control program used the previous year, along with weed maps of individual fields, can prevent a costly herbicide carryover problem and can help match the correct control program to the weeds present. The increasing availability of personal computers and software will aid farmers in developing and storing weed and crop maps as management tools.

COTTON MONOCULTURE

Continuous planting without rotation is no stranger to the Cotton Belt (Broyles, 1987). Most communities have a story about some particular field being in cotton for as long as anyone remembers. Technical advances, particularly in insect control and disease resistance, have allowed continuous cotton production and supported the concentration of acreage on the best producing fields in high-yielding areas. Expansion of planted acreage will, in many areas of the Cotton Belt, result in even greater continuous cotton on the top yielding soils. Shifts in weed infestations, both by individual species and by population densities, can be expected. Continuous cotton eliminates rotation as a potential weed control measure. Frans (1969) attributed an increase in broadleaf weed populations in cotton to widespread and repeated use of trifluralin, reduced cultivation and reduced hand hoeing. Baker (1982) reported on specific weaknesses of individual cotton herbicides which he believed could result in changing weed problems with continued use of those herbicides. Weaknesses reported were cyanazine (Bladex®) on annual grasses, diuron (Karmex®) on prickly sida and norflurazon (Zorial®) on pitted morningglory. Baker predicted that with long-term repeated use of the individual compounds, changes in the weed infestation would require the use of supplemental practices such as directed postemergence herbicide sprays and hand weeding. Based upon later research, Baker (1984) reported on a three-year field study in which diuron and fluometuron (Cotoran®) were weak on erect spurge. With continued use of both products which are recommended and widely used in cotton, spurge infestations would be expected to increase unless supplemental control measures were employed.

An advantage to continuous cotton is that it allows the use of long residual herbicides which might otherwise pose rotational restrictions. Concentration of the cotton acreage into monoculture areas could allow the development of herbicides having long residual activity (Broyles, 1987). Annual applications routinely practiced today might not be required, particularly as new products having high unit activity (grams/acre rates) are developed. Application timing in the off season several months ahead of the planting date when schedules are less hectic could become routine.

In summary, monocropping is expected to increase in high-producing cotton areas. Shifting weed populations will require shifts in weed control practices which can be effective with today's materials. In the long-term, producers may benefit by the development of more effective residual herbicides which are selective only in cotton.

IRRIGATION

While irrigation is necessary to cotton production in much of the western United States, the rainbelt area has largely been dependent upon natural rainfall. For several reasons, the use of irrigation in the rainbelt area has been increasing. These include drought and unstable prices during the early 1980s. Many growers are reducing their risk of crop loss by installing irrigation. Its increasing use has resulted in increasing weed infestations. As with rainfall, a new flush emerges with each irrigation. Some growers have been unprepared to handle this problem, particularly where rainfall followed the irrigation and prevented timely control measures. Greater weed infestations may be present before layby or may occur after layby, particularly where the crop canopy is not closed. Irrigated skip-row cotton can be particularly susceptible to mid- and late-season weed infestations. Unless fields are relatively weed-free, irrigation often results in increased need for postdirected, topical and layby herbicides. Perennial species including purple nutsedge and bermudagrass as well as annuals have been reported as troublesome by growers who irrigate. The products and recommendations are available to control weeds in irrigated cotton. New irrigation users, particularly on skip row plantings, will find that late postemergence and layby programs are more important.

NEW APPLICATION TECHNOLOGY

Cotton growers have used a myriad of new application techniques and tools to control weeds in the past three decades. These have ranged from subsurface injection and subsurface layering to recirculating sprayers and wiper devices for postemergence herbicide applications. Carrier volumes per acre have been reduced to save time and money while maintaining effective control. Adjuvants to reduce drift from postemergence herbicides and the use of helicopters with specially equipped booms allow more precise placement with reduced threat of off-target drift. Controlled droplet applicators (CDA) produce spray patterns in which particles can be confined to a narrower size range with fewer fines and oversize droplets. Highly accurate speedometers which are independent of engine speed or wheel revolution are in common use. Injection pumps and metering devices now available on sprayers allow delivery of undiluted liquid and flowable products to be injected in the liquid carrier line between the pump and nozzle. Advantages of this system are that unused product can be returned to the original container, incompatibility of products can be reduced, and small quantities of both herbicide and carrier can be accurately measured. A trend in herbicide application has been the use of higher travel speeds. It is common to see large three-wheel and four-wheel field sprayers operating at 15 mph across the Cotton Belt.

More precise spray tips produced from a variety of materials, including hardened stainless steel, are available, as are those designed to reduce drift. New nozzle body and cap designs with color coding allow quick, convenient and safer maintenance and changes. Some technologies including electronic weed control with high-voltage, tractor-drawn generators have not proven practical in field use. Others, including electrostatically charged particles, appear promising for better retention and deposition of postemergence herbicides.

The advancements listed above have been useful, particularly at the practical level for grower benefit. Yet, it is widely perceived among professionals working in weed science that advances in chemical technology have outdistanced application technology.

At a conference on application technology sponsored by the Agricultural Research Institute, USDA's Agricultural Research Service, and the U. S. Environmental Protection Agency in 1985, it was concluded among other things that research in this area is inadequate in spite of public concern for potential environmental contamination and a growing need for precision application (Hall, 1985).

This view also is expressed in a report by McWhorter and Barrentine (1988) in which weed science research needs were ranked. Members of the Weed Science Society of America ranked high the research area to "develop new application techniques that minimize or eliminate herbicides and their residues in air and water." Increased focus on the mechanics of herbicide delivery and placement and upon equipment operation, in fact, can be expected to reduce herbicide residues from air and water. Major breakthroughs in the basic systems used to apply herbicides in the past three decades have been direct wipers and CDAs. Based upon these developments, it is predicted that continued progress will be on the order of steady small steps with occasional giant leaps forward. It is further predicted that progress in the giant-leap category is likely to occur from a joint effort by the product formulation chemist, engineer and weed scientist.

Previous advances have been made in the design and component perfection of either liquid, granular or air carrier systems and in products formulated for those systems. It is now appropriate that the reverse order will prevail—that new delivery systems will be developed to meet the rapidly occurring advances in formulation technology. Dry flowables, water soluble granules, water dispersable granules, microencapsulation, time-released formulations and new grams/acre activity levels of new classes of herbicides will be of most benefit to the cotton grower when application systems and components are designed specifically for this technology rather than retrofitted.

NEW CULTURAL PRACTICES

Current production trends and research investigations into new control techniques and strategies point the way toward future weed control programs in cotton. These are responsive to the trends toward reduced preplant tillage, increased mechanization, less labor availability, the need for tighter production budgeting, heightened awareness of environmental safety, more stringent registration requirements, and the cancellation of some products such as dinoseb (Premerge®). The trend toward reduced tillage, particularly preplant tillage, was accelerated by petroleum price increases and the need to reduce production costs. Growers who had traditionally used six to ten preplant tillage trips learned that yields were maintained with fewer trips. In fact, in response to reduced soil compaction, yields may be increased.

No-tillage, the ultimate in reduced tillage, appears promising in upland rainbelt cotton. Interest in no-tillage cotton is increasing in response to the soil conservation provisions of the 1985 Farm Act. Soil erosion losses which exceed the tolerances established by the Soil Conservation Service on many upland fields can be reduced to acceptable levels with no-tillage production. The elimination of preplant tillage will result in the substitution of chemical for mechanical weed control. Some growers are cultivating the row middles after no-tillage crop establishment; however, this allows increased erosion loss and may stimulate additional weed seed to germinate. Most herbicides registered for use at preplant, preemergence and postemergence timings in conventionally tilled cotton also are used in no-tillage cotton. Thus, the products and programs are available to allow effective weed control in no-tillage cotton. Refinements in rates of application and timing, particularly in the use of directed postemergence applications, will be required as adoption of no-tillage increases. Sandy soils still present a problem for effective no-till operations.

Major ecological shifts in weeds can be expected to accompany reduced and no-tillage culture. These will be manifested in changes in the complex of species which infest fields as well as in different population densities. Just as Frans (1969) reported an increase in broadleaf weed populations in cotton which he attributed to widespread and repeated use of trifluralin, reduced cultivation, and reduced hand hoeing, in no-tillage the elimination of preplant soil-incorporated dinitroanilines and of cultivation would be expected to result in increasing populations of annual grasses. Also, increasing populations of the perennial weeds, horseweed and trumpetcreeper, have been observed by the authors of this chapter in no-tillage cotton fields. Conversely, repeated flushes of annual grass and dicot weeds associated with conventional tillage and cultivation have not been observed in no-till cotton. Thus, the changes in weed infestations may tend to be offsetting, but weed-control programs will need to be responsive to changing weed ecology. It is predicted that six significant changes in control practices will occur in no-tillage cotton:

1. The use of preplant foliage-absorbed herbicides having perennial weed activity;
2. The use of preemergence annual grass products;
3. An increase in the use of topically selective grass active herbicides in-season;
4. An increase in the use of post-directed broadleaf herbicides in areas where usage is currently low;
5. Increased use of broadcast applications; and,
6. Increased use of pre- and post-harvest herbicides to reduce overwintering populations of perennial species.

Integrated weed control programs will be incorporated into integrated pest management programs. Research into new technologies such as biological weed control will be integrated with traditional methods to support the overall goal of profitable cotton production. On-farm use of computers with their large memory capacity and ability to sort information and simulate logic will greatly assist the pest-management decision process.

A trend which has moved from west to east across the Cotton Belt has been the increasing use of consultants for pest control, including weed control. Consulting pest control in cotton was once synonymous with insect control. Private consultants who provide weed control recommendations to growers have increased since petroleum price hikes. Many growers find that dealing with one consultant is better than obtaining information from many different sources. For others, the convenience of dealing with one source is secondary to the desire to obtain quality recommendations, routine inspections, and weed maps which allow weed control decisions to be updated on a more timely basis than staying with one plan put together during the winter months.

ENVIRONMENTAL AND REGULATORY ISSUES

INTRODUCTION

Environmental and regulatory issues will have an enormous impact on the practice of controlling weeds in cotton in the future. As knowledge expands about herbicides and their fate in plants, soil, water and the air, then concern for environmental impact will increase. This process will accelerate in response to improved analytical methods and greater sensitivity of detection, and increasing public concern about the environment. The farmer will be brought under direct regulatory control on environmental issues dealing with use of cotton herbicides.

GROUND AND SURFACE WATER

Herbicide usage in cotton will be impacted by the presence of herbicides and their metabolites in ground and surface water. In recent years, studies have led to a number of conclusions by legislators, public groups, farm groups, and industry that substantial attention must be devoted to the care and management of our groundwater on a long-term basis. Non-point sources are now recognized as a factor that must be considered in any program designed to protect and improve groundwater.

The concern will probably have several consequences. Intensive studies will be required of present and new cotton herbicides as to leaching, persistence and presence in groundwater. These studies will be costly, time-consuming and necessary to maintain or obtain registration. Based on these studies and other considerations, label restrictions will be placed on the use of herbicides by soil type, rate of application, rainfall patterns, irrigation practices and state of the groundwater in the area of projected herbicide use. It is likely that some cotton herbicide usages or the products themselves will become unavailable for farmer use. These developments will have an impact on the weed problem of the farmer, and the solutions available to the farmer.

Surface water issues are not substantially different from those of groundwater. An impact of new technology is that monoclonal and/or polyclonal antibodies can be used for detection and quantitative analysis of pesticides in water. Monoclonal and polyclonal antibody kits are now commercially available that will detect several key cotton pesticides quickly and accurately down to fractions of one part per million in water. As it stands now, any person can buy a kit, dip a strip of paper in water, and determine what, if any, level of certain pesticides is present. This technology is evolving rather rapidly. The implication of the use of this technology by the farmer, the citizen, the regulator and the inevitable plaintiff are numerous. Used as an aid in judging whether a rotational crop can be planted following a particular herbicide, it has a potentially enormous benefit. As an adversarial tool, it also could prove extremely significant.

Availability of surface and groundwater for irrigation will diminish in the cotton-growing regions of the United States. Frequency and amount of irrigation will obviously impact the dynamics of weed population and therefore the herbicide programs used by the grower.

ANALYTICAL SENSITIVITY

New and more sensitive methods of analysis continue to support the pragmatic expression that zero is theoretical and does not exist in the analytical sciences. Traces of pesticides are now measurable at levels a million times more sensitive than a decade ago. This enhanced sensitivity will lead to the detection of pesticides, including cotton herbicides, both in the field and on non-target organisms. The ramifications of this are several. Appropriate studies must be designed and implemented that will provide information on the biological significance, if any, of the residues found. The protocols for such studies, indeed the need for such studies, are not subject to general agreement in the scientific community at this time.

Improved monitoring devices for measuring the non-target distribution from the application of pesticides will be required. Application equipment and techniques must be modified to further reduce the non-target distribution of pesticides.

New requirements by various regulatory bodies demand that protective clothing be worn by the applicator and that reentry restrictions be placed on the use of the herbicides. These new label restrictions must be supported by thorough, costly applicator exposure studies submitted by the registrant, together with appropriate metabolism and toxicology studies that will be used to establish the limits and significance of the exposure. In the future, we can expect these requirements to be demanded for all pesticides.

The reentry label restrictions will specify when it is permissible to reenter a field treated with a pesticide. In the past, this requirement has been applicable for the most part to insecticides. Current trends in regulation indicate it will be extended to herbicides, including a number of those used in cotton. Such restrictions do not impact grower operation in corn and soybeans nearly as much as in cotton, where far more in-crop operations are carried out.

THE ENDANGERED SPECIES ACT

The concern for animal and plant species in danger of extinction led to a federal statute, the Endangered Species Act of 1973, and many similar state laws. The current impact of the Endangered Species Act on the grower has been limited largely to the use of certain insecticides in specific locations. The environmental considerations were to protect endangered species of insects, or in some cases, avian or amphibian species. The greatest impact heretofore has been on industrial operations, such as the manufacture of herbicides.

A change is taking place in the administration and scope of the regulations under the Endangered Species Act. The EPA is responsible for the administration and enforcement of the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA), which is the law covering the production, marketing and use of pesticides. Using both the Endangered Species Act and FIFRA as statutory authorities, the EPA will place severe restrictions on a wide range of pesticides, including cotton herbicides. These restrictions will limit or prohibit the use of products in areas ranging from a few square miles to large regions of the country. In some cases, county-by-county label uses will be spelled out. Some restrictions will be by habitat, others by soil type, and still others, by time-of-year.

The implications to the cotton farmer are significant. For many farmers, choices of effective herbicide will be limited. In some cases, less effective products requiring higher rates and/or more frequent applications will be the only ones available. This, in turn, could lead to other environmental issues such as soil carryover and surface and groundwater problems as well as the more obvious ones of crop safety and yield loss.

The issue is further clouded by the fact that far more candidates are under consideration for the endangered species list than are currently listed. The restrictions not only will apply to cotton acreage, but also to sources of water, streams that handle run-off from crop land and land adjacent to crop land.

Several of the environmental issues addressed would be far less significant if it were not for pesticide drift and volatility, which will receive increasing attention because the ability to measure has improved. Couple this ability with increased concern about non-target exposure, the endangered species issue, pesticide residues on non-target crops, contamination of surface water, the possible toxicity of low-level exposure to pesticides and, finally, the increasing interface of urban and farm in cotton-growing regions, and the issue could become one of major proportion to the producer and user of cotton herbicides.

REGULATORY DIRECTION

Trends in regulation can be examined from the research process through the commercialization of a cotton herbicide or genetically modified cotton variety resistant to a herbicide; to farmer use; to the fate of the herbicide in the crop, soil, water, and non-target areas and species; and disposal of the container. Extrapolation of trends to assess future implications can then be made.

First, one of the most rapidly emerging trends is the increasing regulation of the research process. FIFRA for several years has required an experimental use permit (EUP) for large-scale testing of an experimental candidate.

The applicant's submission to the EPA for an EUP must include detailed plans for locations, cooperators, rates, amount and areas to be treated. Substantial data also must be submitted. Completing the approval process could require from several months to well over a year. Detailed reporting on a quarterly basis is required. In addition, state requirements also come into play. In the past, an EUP was submitted in the third year or so of the commercialization process. Now, particularly in the biotechnology area, EUP's are being required at a much earlier stage for a candidate product. This shift means a great deal more research effort is required for more candidates, and greatly lengthens the number of years required to commercialize a new product. Since only a few candidates survive the various technical and commercial hurdles through the third to fifth year, this also means substantial research resources will be applied toward "near misses" since EUP's will be required earlier in the research process on products that will not survive to commercialization. This wastes resources, inevitably slows down the flow of new products, and increases the cost of those that make it to the marketplace.

Evolving technology in analytical sciences, toxicology, environmental sciences and other scientific disciplines will result in additional regulatory requirements. As we can detect pesticides and metabolites at lower levels, then the requirements become far more costly and expand to include new areas for study.

REGISTRATION AND REREGISTRATION COSTS

The investment required for registration of any new cotton herbicide will continue to increase. Costs will increase at an accelerated rate (increased research required x increased costs per unit of research = accelerated cost of registration).

Current products also will be affected by the above changes as regulatory requirements for reregistration force the databases for old products to be updated to the new registration standards. A few products have already been cancelled voluntarily by registrants because the additional costs cannot be justified. Currently registered old products will be lost at a faster rate in the future.

FIELD-USE RESTRICTIONS

The biggest change in the regulatory impact on the cotton farmer is the trend toward regulation of farmer use as opposed to regulation of the product. In the past, the largest regulatory burden was placed on the herbicide producer who brought the product to commercialization. As described above, this task will grow larger. However, the farmer also will have a substantial regulatory burden stemming from the use of pesticide products. Some requirements are already present. Certification of applicators at the state level, as required by FIFRA, has been in effect for several years. The requirements invoked by the Endangered Species Act will place a further burden on the grower. Drift, volatility and worker protection regulations will add to the effort required of the farmer.

Restrictions on the use of herbicides will increase, impacting on the type of application equipment used, the requirement of nontreated buffer strips, the prohibition of certain pesticides within given distances to other areas such as subdivisions, endangered species habitats, drainage areas, or other crops not cleared for the pesticide proposed for use. Restrictions impacting irrigation, chemigation and ground and surface water will limit farmer flexibility to use the weed control program of choice.

Remarkable progress has been made recently in equipment, formulation and application techniques to reduce drift and volatility. Still more will be required. A significant key to the future will be continued grower and applicator education and skill.

SOIL EROSION CONTROL

Still another looming regulatory issue which will impact the farmer and his weed control program is that of soil conservation. Soil erosion and groundwater concerns easily may be the two most important environmental/regulatory issues of the next three decades. Farmers will be required to implement certain practices (and eliminate others) to reduce soil erosion, and to protect and improve groundwater quality. Practices such as minimum tillage, no-till or conservation tillage probably will be required. Land which cannot be conserved adequately will be taken out of row-crop production and returned to permanent vegetative cover.

IRRIGATION

Dropping water tables will trigger laws and regulation that will control, limit and even prohibit irrigation for some crops under some conditions. The impact on weed control programs will be significant. Weed spectrums can be expected to change and choices of herbicides constrained.

SUMMARY

The regulatory impact on cotton weed control practices, both current and future, will become a substantially increased burden. The regulatory process will take longer, move further back into the research process and become far more comprehensive and costly. In all probability, it will lead to loss of some current products, fewer new products brought to commercialization and increased cost to the farmer for weed control. Probably the most important trend or shift is the impact of the regulations on the farmer's operations as opposed to the producer of herbicides.

HERBICIDE INDUSTRY CHANGES

The herbicide industry that supports weed control in cotton includes the basic research organization, the herbicide producer (most of the time the same company), formulator and packager, distributor and dealer. This industry is in a stage of change as rapid and significant as that of the technical and regulatory arenas. Further, as in the case of the latter two, this change is accelerating and will have major impact on the farmer.

FEWER AND BIGGER

The basic producers who also have the technical capability to discover and commercialize new products are decreasing in number. In the past few years, several basic companies have disappeared. These include Amchem, Diamond-Shamrock, Hercules, Mobil, PPG, Shell-U.S., Stauffer, Union Carbide, U.S. Borax, and Velsicol. It is widely believed that the disappearance of the basic producers will continue. One can assume that in ten years, there will be, at most, ten to twenty companies in the world that have the capabilities of research, commercialization, manufacture and marketing. This would mean survival of three to five United States companies with the above capabilities. A larger number of companies will have one or more of the capabilities. Other companies will synthesize new candidates, but not have the capability of commercialization or sales. Some can produce and/or market products but will not have the discovery or commercialization capability.

It is reasonable to assume that with the number of companies declining from a peak of sixty or more to a low of ten or less, fewer new products will be introduced into the marketplace. Coupled with the regulatory impact, it is virtually certain that new product introduction will decline over the next decade or two.

LICENSING AND ACQUISITIONS

The pesticide industry increasingly will follow the lead of the pharmaceutical industry in that acquisition and licensing will become a more important part of the commercialization and marketing of new products. Licensing of products and candidates is one way of reducing risk and research and development resources while allowing companies to maintain a "full pipeline" of products moving to commercialization. This trend will counteract to some degree the decrease in the number of companies with research and development and commercialization capability.

MARKETING

The distribution channels of agricultural chemicals also are in the throes of change. As with the basic producers, consolidation, mergers and acquisitions are taking place. There is a trend to "one-step and two-step distribution" as opposed to the traditional three-tiered approach of producer/distributor/dealer/farmer. This results in sales directly from the herbicide producer to large dealers or even large growers. Farmer sources of information will shift because of these trends. Farmer purchase and credit terms will change, as will warehousing and ready availability of products.

PATENT AND DATA PROTECTION

The treatment of intellectual property by various government agencies on a worldwide basis is profoundly influencing the availability of pesticides, including cotton herbicides. At present, intellectual property important to agricultural chemicals includes patents, regulatory/registration data, manufacturing-process information and sales and marketing data. Regulatory and registration data have limited protection in the United States, with unsatisfactory protection under FIFRA and the Toxic Substance Control Act (TSCA) against improper use of data obtained in the United States and utilized elsewhere. Virtually all registration data with the exception of process and formulation data are available to the public under FIFRA.

Patent protection is adequate in the United States, Western Europe and Japan, as well as certain other countries. However, in Brazil and other Latin American countries, Taiwan and the People's Republic of China, patent protection is poor to virtually nonexistent. Considerable effort is being applied to obtain patent extensions on pesticides in the United States. This would allow consideration of the time lost from utilizing a patent because of the delays caused by registration procedures. Such a modification would allow the patent holder an opportunity to have a better possibility of recovering the large investment of commercializing a pesticide. A concerted effort by industry on a worldwide basis to balance the need for public availability of information against the need for intellectual property rights is yielding useful results. On the whole, however, one cannot be optimistic about the worldwide situation on intellectual property rights.

The cotton farmer and the herbicide industry that supports the farmer will have two tasks in face of the scenario just described. The herbicides currently registered for use in cotton must continue to be registered. New herbicides with improved attributes must be discovered, registered and commercialized. The odds are not good. With patents expiring and little or no intellectual property protection for the substantial effort required to maintain registration, there is less incentive to generate data that a competitor can have for free.

As for new products, the enormous cost of bringing one to the cotton farmer—plus a deteriorating economic situation for agricultural chemicals—will have a profound impact on those making decisions as to whether to pursue pesticide development.

FUTURE NEEDS

Hindsight is history and foresight too often is myopic, but this chapter would be diminished in value without some commentary on future needs in weed control in cotton. A statement of those needs now, based upon observation of current conditions and trends, will support better planning by decision-makers—whether grower, scientist or administrator.

At the academic level, increased research on weed ecology and computer-simulated weed growth and development are needed to enable predictions on the impact of changes in production practices and weather conditions upon weed populations, competitiveness, potential losses, and returns to the cost of control.

Increased commitment to reducing herbicide residues in crops, air and water is needed. Improved application equipment allowing more precise delivery to the target would reduce the problem.

At the manufacturer level, additional products are needed for no-tillage and reduced-tillage culture; for example, a consistent and dependable preemergence annual grass herbicide. The search for new chemistries which perform as needed and then degrade to harmless components must continue to be a goal of the synthesis chemist. Public mistrust of technology dictates that this utopian dream not be discounted.

The search for effective and safe biological agents and practical delivery systems must likewise continue.

Government needs to be more responsive to the food and fiber needs of the nation. Increased patent protection of private property, regulations which maintain a high level of safety and health consciousness while supporting advancement in chemical and biological control technology, and practical oversight of the use of weed control products are appropriate roles of government.

The grower needs better label-use directions. More precise rate and timing of applications can increase the grower's profit. Research on the response to given sets of environmental conditions and upon stages of growth and susceptibility is basic to more specific label-use statements. Current labels are broadly written to cover the entire United States and three soil textures. Use directions are written for less than optimum application conditions. More specific and useful label directions can be written by better defining the influence of temperature, relative humidity, soil moisture measurement and light intensity.

From the cotton industry–from producer to ginner and merchant–a stronger and more united voice is needed in defense of current pest control products and in the request for weed science research funds.

PREDICTIONS

Predictions concerning anticipated changes in weed control technology during the next two decades are summarized here. In view of the factors already discussed in this chapter, these predictions seem reasonable.

Herbicides and tillage will continue in use as the primary control agents, but their use will be integrated with slowly evolving new technologies into more broadly based programs. Driven by government policy and by cost factors, the trend toward reduced- and no-tillage planting will continue as grower experience and confidence increase. Infestations of perennial species will increase due to less deep-tillage, and research to determine their control will be needed. Chemical herbicides will continue as the main line of defense in most control programs. Biological agents, *i. e.*, pathogens and insects, with narrow host-specific action will be used on selected weed targets for in-season control. Weed competition research and computer modeling in conjunction with economic analysis will better define economic thresholds. This, in conjunction with available control options and computer generated costs and returns data, will allow weed control decisions based upon expected profitability with higher confidence levels than are now possible. Biotechnology-generated cotton varieties possessing tolerance to specific herbicides plus new products integrated with non-chemical control methods will allow implementation of longer-term control programs covering several years as opposed to one season programs used today.

Products including biologically engineered organisms will be increasingly scrutinized for their effects upon non-target organisms and potential to bioaccumulate. Programs will be set up to monitor suspect compounds for their presence in surface and groundwater, streams and public water supplies. Periodic monitoring will be increased in foods, forage and processed products including cotton seed and oil products, and cotton forage.

The regulatory climate, while stressing environmental and human safety, will be slowly responsive to the economic needs of the grower and new products will be registered. These will be characterized by favorable environmental and safety characteristics, high unit activity, low use rates/acre and use on other crops, thus making commercialization on cotton more attractive.

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