THE ICAC RECORDER

International
Cotton
Advisory
Committee

Technical
Information Section

VOL. XVI NO. 1
MARCH 1998

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

Contents

Introduction

With the ultimate objective to understand plant behavior and response to input applications, efforts have been made to map and monitor plant growth. Computer software has been employed to deal with huge amounts of data and to help in making conclusions. In the last 30 years, a number of crop mapping and monitoring models have been developed in the USA. But farmers still do not use these models extensively. Researchers are trying to identify focal plant characteristics, avoid collecting huge amounts of data, make plant monitoring more farmer-friendly and increase yields through in-season correction of deficiencies. A review of computer-based plant monitoring systems is given in the first article.

World cotton yields have not increased since 1991/92. No growth in cotton yields is attributed to specific problems in some countries and to a general stagnation of yields. In the second article, reasons for stagnation and the role of breeding for high yielding varieties have been discussed in detail. It is concluded that the accumulation of desirable yield genes or the rearrangement of genes through conventional breeding is not likely to bring further improvement in yields. Breeding methods for yield improvement need changes, and there is a need to develop new technology for significant improvement in yields.

Mr. Lucien Seguy of the CIRAD and his colleagues from Brazil have contributed the third article. For the last three years, CIRAD has worked with a private company in Brazil on changing the current monocropping system into a more sustainable cotton production system. Large-scale trials were conducted on direct drilling, crop rotations, cover crops for avoiding soil erosion and improving soil texture. The CIRAD technology resulted in higher yield, lower cost per unit production and consequently higher income to producers. The technology has been adopted on 6,000 hectares.

Preparations for the World Cotton Research Conference–2 have moved to high gear. The Organizing Committee has issued the final announcement and complete details for full registration. The last date for receipt of papers is May 20, 1998. The brochure can be obtained from the Organizing Committee in Greece and the Technical Information Section of the ICAC. The brochure is also available on the Internet at the following address: *http://www.icac.org/icac/meetings/wcrc2/wcrc2.html.*

Computer-Based Plant Monitoring Systems

Plant growth and progressive development can either be monitored in a primitive way by visiting the field more frequently and making decisions based on visual assessment of the crop or through utilization of computer based models. Visual assessment, which requires a high skill in production technology, does not provide quantitative evaluation of the crop condition. However experienced and knowledgeable a producer may be in production practices, visual observations can only reflect approximate condition of the crop. But, it is still the most popular way of assessing crop development and deciding input application to cotton.

Efforts have been made over the last several years to develop

The ICAC RECORDER (ISSN 1022-6303) is published four times a year by the Secretariat of the International Cotton Advisory Committee, 1629 K Street, NW, Suite 702, Washington DC. 20006, USA. Editor: M. Rafiq Chaudhry. Subscription rate: $145.00.

more accurate means of assessing the crop condition. Monitoring crop growth during the season could be an effective component of the crop management decision-making process. Computer-based plant mapping is a relatively new technology in the hands of agronomists, consultants and producers for minimizing the effects of factors affecting yields negatively. Availability of information, not only on current behavior of the plant but also on expected future trend in comparison with the targets, permits utilization of plant mapping information for correcting the problem. Timely correction of the deficiency helps to keep the plant growth close to the target.

Plant mapping is a numerical description of a representative plant in a field or an average of the field/crop as a whole. Plant mapping involves selecting fields from a block and plants within fields and making specified measurements of plant characteristics. Plant measurements vary by monitoring methods but generally all methods require measuring plant stand, plant height, counting number of fruiting branches and recording the presence or absence and location of fruiting forms. Some methods pay more emphasis on one characteristic while others may base their conclusions on some other plant characteristic.

Cotton crop modeling started in the late 1960s. Over the last 30 years, at least 15 simulation models have been developed. The fundamental principle has been the application of mathematical methods to biology. The objective has been to make use of the data accumulated during the previous years and quantitatively measure the impact of a cultural practice on cotton yield. COTMAN, GOSSYM-COMAX, PMAP, CottonPlus, COTTON TALK, CALGOS, Texas Crop Monitoring System and University of Arizona Cotton Monitoring System are among the popular systems developed so far. California Cotton Manager, Texas Crop Monitoring System and University of Arizona Cotton Monitoring System are still limited to research purposes.

COTMAN

COTMAN was developed at the University of Arkansas and provides in-season monitoring of plant growth with the ultimate objective of achieving early maturity and high yield. COTMAN consists of two components: SQUAREMAN and BOLLMAN. Comprehensive data are collected in the SQUAREMAN field reports to compare actual development of the plant with target development. The SQUAREMAN field reports are based on the development of squaring nodes, square retention (rates, analysis of change in retention, and comparison to the shed rate), plant vigor, plant density and first position bolls. The second component, BOLLMAN, is mainly based on monitoring white flowers on the plant with the ultimate objective of determining cutout for the crop. In order to establish the last flowering date, nodes above the white flower are monitored starting from the first flower until the end of the season. The last flowering date (cutout) is determined either by physiological cutout by counting 5 nodes above the white flower or by weather restrictions, also called seasonal cutout. The BOLLMAN field reports include status of boll formation along with the target development curve, mean nodes above white flower (NAWF) and cutout status, heat unit accumulation from cutout, and dates for termination of insecticide and defoliant applications. The focal plant criterion used in the COTMAN is NAWF. In a normal healthy crop, at the time of first bloom, NAWF should be 8-10. NAWF may be constant during the peak flowering stage but begin to fall as the crop progresses toward maturity. At 4-5 NAWF, it is usually understood that 98% of the crop has been set.

One critical element that is essential to make plant mapping useful is a target standard or a base line for gauging what is normal and what is abnormal. The BOLLMAN does not generate a first position boll retention curve but determines first position square retention by using SquareMap codes for the presence and absence of first position squares. Level of square retention, target development curve (TDC) and the latest possible cutout date (LPC) are very important to be considered for reliable evaluation of the crop growth curve by COTMAN. Some targets for normal growth curves are

Appearance of first square	=	35 days after planting
Appearance of first flower	=	60 days after planting
Vertical squaring interval	=	2.7 days
Physiological cutout	=	5 nodes above white flower (at 80 days after planting)
Latest possible cutout	=	880 degree days 60s needed for maturation of the last flower

According to Bourland et al (1997) factors used to interpret growth curves are 1) square retention (high or low); 2) alignment (left, near or right) of the plotted curve relative to TDC; 3) slope (flatter, similar or steeper) of curve relative to TDC; 4) apogee (less, near, above) of curve relative to TDC; 5) change in slope between sample dates; and 6) physiological cutout date relative to latest possible cutout date.

COTMAN was developed about 10 years ago with the objective of helping researchers in their summarization and analysis of plant mapping data. Since 1989, many changes have been made in COTMAN so that more and more information is available on the vegetative and reproductive performance of the crop. A non-computer version of BOLLMAN is also available which requires sequential counting of nodes above white flower, determination of latest possible cutout date and data on accumulation of heat units (DD60s) after cutout. Nodes above white flower are the same (five) as in the case of the computer version but the latest possible cutout date is determined from the historical data for a particular region or a country. It is considered that the crop is ready for defoliation at 850 heat units and insecticides can be terminated safely at 350 heat units.

Studies involving commercial users of COTMAN crop management system have indicated that COTMAN can be integrated into the current pest scouting system very easily. Two persons can complete one set of data, pest scouting and COTMAN, in a field in about 20-23 minutes. COTMAN-based pest scouting improves confidence in the application of fertilizers and insecticides and timely termination of the crop. The system has been tried in Australia but the latest decision of Cotton Incorporated to follow up the promotion of this system may make it popular among the US farmers.

GOSSYM-COMAX

GOSSYM-COMAX is more popular among producers compared with other models but still used by less than 200 growers in the USA. Like COTMAN, GOSSYM-COMAX also has two components, i.e. GOSSYM and COMAX that can be run independently. GOSSYM is a simulation part of the model and deals with the partitioning process between the reproductive and vegetative growth. The first subsystem of GOSSYM calculates carbohydrate supply while the second subsystem determines the demand for carbohydrates. Based on the daily input use, the partitioning process balances the supply and demand in the model and calculates yield. GOSSYM can be used to make decisions before the start of the season or during the season for making changes in the production practices usually referred as strategic and tactical approach respectively. In GOSSYM, data collection used in making daily decisions including daily weather (through a phone line hooked to the field laboratory) is automatic. GOSSYM, utilizing the historical data for a field, recommends the most suitable variety for a particular field. The GOSSYM component also advises on the most suitable time of planting in the current season and what growth regulators and chemicals should be used for maximum profitability. The simulation component (GOSSYM), taking into account data such as row spacing, variety, irrigation, insecticides, etc., forecasts potential yield. The system also provides information on various levels of input use and consequently the expected yield. Farmers have a choice in deciding what to invest and what to expect from that investment under different weather scenarios.

COMAX is the decision support system of the model and provides advice on the application of inputs like irrigation, fertilizer and insecticides. Based on the current crop condition the system will suggest not only whether or not to apply irrigation and other inputs, but also advises the magnitude of irrigation. Studies have shown that the majority of the farmers in the USA use GOSSYM-COMAX for timely crop termination, nitrogen application and irrigation. The second largest utilization has been variety selection and risk assessment. A detailed report on GOSSYM-COMAX was published in the December 1996 issue of *THE ICAC RECORDER*.

GOSSYM-COMAX has been tried in many other countries including Greece and Spain where results showed that optimum yields could be obtained with low input production systems. Excessive levels of major production inputs, such as nitrogen fertilizer, irrigation water and plant population did not result in yield increase as compared to lower levels of these inputs. The system also showed that optimization of management had a positive effect on yields. Evaluation still continues.

PMAP

Plant Map Analysis Program (PMAP) is a flexible data entry and retrieval system with text and graphic display to simplify data analysis and interpretation. PMAP was developed about 5 years ago with the purpose of comparing the impact of treatments with untreated checks. The original approach was to utilize PMAP for research purposes but it is said to have utility for consultants and growers as it allows the user to explore the plant map data for assessing current growth status and yield potential. When you run the program, you see a plant on the screen with all fruiting points. If for example, a growth regulator has been applied, the program lets you compare the effect of that growth regulator application with untreated plants in respect of fruiting characteristics of plants. PMAP provides expected lint yield data based on the assumption that first position bolls contribute more than other positions and that contribution of each boll decreases with the increase in branch number. The differences can be seen in the form of plant map and graphic charts in many formats.

Earlier versions could compare only two treatments at a time but version 7 is capable of comparing more than one treatment at the same time. PMAP has also been helpful in the study of phenological differences among varieties. In 1993 Landivar et al (1993) recommended running plant maps at four stages: match-head square, early bloom, late bloom, early open boll and optional end of the season mapping. According to Landivar et al (1993), match-head square stage is usually reached 10-15 days after the appearance of the first flower bud, early bloom 7-14 days after the first white flower and late bloom is reached in the third or fourth week of flowering. Early open boll mapping stage is reached after 10-15 days of appearance of the first open boll on the plant. Lately, recommendations (Landivar 1998) have been simplified to 1) 12-14-node stage; 2) first week of bloom; 3) third week of bloom; and 4) 20-30% boll open stage. Optional sampling prior to final harvest remains the same.

It is recommended that for every 100-acre field, plant maps should be taken on 32 to 36 individual plants from 6 to 8 locations. Data requirements for commercial cotton production are cultivar grown, row spacing and plant population of the selected site. The inputs on plant parameters are plant height, node number of the first fruiting branch and presence of squares, green bolls, open bolls and abscised bolls on first and second position of fruiting branches. The new version can display graphically the frequency distribution of plant mapping parameters like squares and bolls.

In order to monitor plant height and vigor, a growth simulation component called MEPRT–The PIX Rate and Time Program, has been added to the revised version. MEPRT (Mepiquat chloride Rate and Time) program, based on the frequency distribution of plant height and taking into consideration the plant weight and the amount of mepiquat chloride applied, estimates the amount of PIX needed to adjust main stem growth rate to a desired level. Research showed that maintaining the PIX concentration in the 10-12 ppm range resulted in an adequate regulation of vegetative growth. It is assumed (Landivar 1998) that the PIX concentration in the plant decreases over time due to "biodilution." If the MEPRT program projects a PIX concentration in the plant below 5 ppm, a second application of PIX is recommended for maintaining further reduction in the main stem growth.

COTTON TALK

In the systems discussed above, data are collected and manually entered in the computer. Researchers are working on a system, which does not require physical entry of the data into the computer. A complete crop monitoring system is not available yet but significant progress has been achieved which is termed by authors (Liang et al, 1996) as "proof of concept." The system is called COTTON TALK and allows researchers/producers to directly talk to the computer. This system is motivated by the desire to improve efficiency and speed of getting the necessary information for crop monitoring and management.

Once the program is started, the producer, or whoever is entering the data, responds to questions by the computer. After each entry there is an audio response and the screen changes accordingly. If you are not ready to respond to a specific question, you can put the system on hold by saying, "wait a minute." COTTON TALK can be put to work again by saying "back to program." The system has the capability to detect input errors and indicate them in the form of a yellow color in the background. A brief message also shows up which indicates why the input is invalid. If you make a wrong entry and you wish to correct it you say "go back," but currently only one previous entry can be corrected. Help can be obtained to answer questions and an option is also available to quit the program without saving the data by saying, "quit."

Once the data have been entered, the operator can specify "MAIN" or "VEG," to view the plant map from the point of view of the main stem or vegetative branches respectively. The plant map would indicate A=missing flowering point, B=boll, F=flower/bloom, G=green boll and T=terminate.

Compared with other systems, COTTON TALK is said to be easy to learn (Liang et al, 1996). The most important point is how you speak while responding to different questions. In all other systems, there are three steps involved until the data is ready for developing a map for analysis: counting the data in the field, recording in the notebook and entering it in the computer. A voice-entering device eliminates at least one stage. The system is still being improved and the speed of the system in producing a plant map could be improved to be equivalent to other systems.

CALGOS

In addition to developing new models, researchers have tried to improve existing models through modifications in the fundamental characteristics of the base models. One such effort is the development of the CALGOS crop modeling system. CALGOS is a modification of the GOSSYM-COMAX model for utilization under irrigated conditions of the arid regions of the western US. CALGOS gets its name from California and from Gossypium but an Israeli researcher has also contributed in the modification of the model. CALGOS is a process-level simulator of the cotton plant, soil processes and the microenvironment. Growers can assess the alternate uses of inputs and results can be seen as output files and graphs. Further improvements are being fine-tuned to include the plant's response to a variety of pests and assimilation of new varieties unknown to the model. Root response to irrigation and fertilization under semiarid irrigated conditions has a significant impact on plant behavior and CALGOS is one such a system where more emphasis has been placed on root simulation. Potential growth in leaves and bolls was later included in the model.

CottonPlus

CottonPlus was originally called SIGMA+ and it was an effort to improve the GOSSYM part of the GOSSYM-COMAX model. Dr. Hal Lemmon, with his colleagues at the Agricultural Research Service of the USDA, worked on the model for almost 10 years (personal communication) and produced a revised version of the GOSSYM-COMAX called CottonPlus. The first system was introduced in early 1995 but did not properly predict a plant's leaf water potential. If the plant was not in water stress or was only in light water stress, the system made reliable predictions. But, in case of reasonable water stress, CottonPlus could not provide accurate warning for correcting the problem. Lately, improvements have been made in the model to compensate for water stress conditions. CottonPlus simulates stems, leaves, fruiting points, roots, and movement of water and nitrate nitrogen, evapotranspiration, and uptake of water and nitrogen. Plant growth is determined by taking into consideration factors like variety, planting pattern and density, soil conditions, availability of nitrogen and water, solar radiation, air temperature, humidity, wind, rain and irrigation, and the application of fertilizer. The extent of limitation is termed stress; carbohydrate stress is the ratio of available carbon to carbon demand, and nitrogen stress is the ratio of available nitrogen to nitrogen demand. The model computes separate stress values for roots, fruit and the vegetative parts (leaves and stem). The soil modeling concerns the movement of water and nutrients in the soil. The CottonPlus program also closely follows the rate of evaporation and plant respiration.

CottonPlus could not be compared with GOSSYM-COMAX in wide application because of lack of interest by private companies to promote the model. According to the developers of the model, it is very good and provides a sound and reliable basis for plant growth management. CottonPlus is still not used by farmers in the USA but could become popular if efforts were made by a private company to promote it. CottonPlus has been recently introduced in China (Mainland) and results are pending.

Changes in Mapping

In the last 15 years, changes have occurred in crop monitoring systems. Mapping started with huge amounts of data recorded on various aspects of plant development including number of fruiting points on the plant. Such an experience has led to the identification of key factors responsible for plant development. Efforts have been made to concentrate on focal components and make mapping simpler and faster. The latest versions of plant mapping and monitoring systems are not only less laborious but they are also closer to the actual condition of the crop rather than suppositions.

Initial efforts concentrated on developing monitoring systems, which are available now. Efforts have been made to identify parameters that are indicative of more important plant characteristics. Accordingly, focus has now changed from collecting more and more data to utilization of available data. Still there is a need to make mapping and monitoring systems more simple, farmer friendly and practicable for direct adoption by producers.

In most systems emphasis has been on degree-days and accumulation of heat units. According to Brooking (1997) some important data like solar radiation, pan evaporation, rainfall and wind, etc., are not taken into consideration. He has recommended using nodes above bloom (NAB) and also including some other weather data in the systems for more accurate forecasts of crop maturity. Supak et al (1993) suggest applying desiccants at 3 nodes above cracked boll.

Utilization of Plant Mapping Information

The plant mapping systems discussed here have two components, a computer component and a data-recording component. Variations in the interpretation of data and conclusions drawn depend first on the data fed to the computer and second on the importance assigned to each data input. However, the data generated from the computer-based crop modeling systems can be used in many ways. Since extensive data are available on vegetative and reproductive performance of the crop during the season, systems can be used to correct deficiencies to meet the target trend. In the USA, much emphasis has been placed on determining more precisely the time of crop maturity. Plant mapping models can be used for different purposes in different countries.

What is the right time to defoliate a crop? It is a common recommendation in many countries that a crop can be safely defoliated without any significant effects on quality when about 60-70% of bolls have opened. Data show that boll opening chemicals can be applied with no effects on yield even when only 12% of the bolls have opened (Smith et al, 1986). Reports are available which indicate that defoliation at less that 60% boll opening has no significant effect on yield and quality. The percentage of open bolls as a measure to decide the time of crop maturity is not a reliable tool because it does not take into consideration the frequency of boll formation over the period. Computer based crop monitoring systems take into account the rate of boll formation and consequently signal the time for crop defoliation. Proper timing of defoliation can help to preserve quality and yield.

It is assumed that fields are uniform but usually they are not, particularly after planting when factors like weed intensity and soil level also play their role. Varieties may be pure but all the plants in a field are not clones. Genotypic response to soil conditions creates variability in the population, which is not desirable for monitoring systems. Moreover, some observations of the monitoring systems are signals of future events.

Cotton yields are not increasing at a desired rate in many countries as discussed in the first article of this issue. Producers are finding ways and means to bring even small increases for sustaining the profitability of cotton. One such approach that is becoming popular in the USA is precision or site specific farming. But, the fundamental component of precision farming is in-season yield estimation so that problems can be corrected. Non-availability of the reliable equipment for accurate measurement of yield at the time of harvesting further necessitates the utilization of plant mapping systems.

The genotypic structure of a variety and growing conditions have a great role in quantification of plant development and vigor. Plant architecture is different in different countries. Crop monitoring systems of one country may need some changes before they are applied in other countries.

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Breeding for Yield Improvement Needs Changes

Cotton was grown in 68 countries on 33.5 million hectares during 1997/98. In the last 50 years, while the area grown to cotton in the world has fluctuated, total production has increased as a result of increases in yields. Yields increased in every country; however, the increases have varied depending upon the development and use of production technology. From 1950 to 1990, the world cotton average yield increased at the rate of 2% or 8 kg lint/ha/year. The world average yield was 597 kg/ha in 1991/92, which is the record so far. It seems that the world cotton industry has entered into a period of no growth in yields.

Since 1992 world cotton average yields have failed to keep pace with the long-term average increase of 2%. 1997/98 was a good year in most cotton producing countries and, according to ICAC forecasts, the average yield for 1997/98 will be 583 kg/ha which is 14 kg lower than 1991/92. However, the six year average data from 1992-97 shows a 4% decrease in yields.

Specific Problems in Major Producing Countries

Over the last nine years, cotton yields have not increased in the USA. Comparing cotton-growing conditions at the world level, cotton production conditions have been steady in the USA compared with other large cotton producing countries; yet yields have not increased.

In China (Mainland), in 1980/81 the average yield was 550 kg/ha. The 1991/92 average yield stood at 867 kg/ha, but since then there has been no increase in yields in China. Due to pest problems, particularly in the Hebei, Henan and Shandong provinces, cotton production has moved northwest in Xinjiang province, where new areas have been brought under cotton production. A slight recovery in yields in China can be attributed to replacement of the bollworm-affected area with new area in Xinjiang. Since bollworm resistance became a problem in China, the share of Xinjiang province has increased from less that 10% to over 25% of national production.

In India, due to high yields, total production reached 3.0 million tons during 1996/97. The average yield was 327 kg/ha, which is a record. The current ICAC estimates for India suggest that the average yield during 1997/98 will be 278 kg/ha. The forecast for 1998/99 does not show any increase over 327 kg/ha either. India did not suffer from any serious production problems until 1997/98, and growing conditions also suggest that India is one of the few countries where the full potential has not been utilized yet. But widespread attack of leaf curl disease (in the northern region) and resistance to insecticides by *Helicoverpa armigera* may make it difficult to maintain the current yield level.

In Pakistan, the leaf curl virus disease is responsible for heavy losses in yields. Highest yields were achieved during 1991/92, and there has been no increase in yields since. Whitefly is responsible for transmitting the virus, and it is not possible to eliminate whitefly from the production system. The national breeding priorities had to be reconsidered for inclusion of resistance to leaf curl virus disease as the most important criteria for approval of varieties. Through a project from the Common Fund for Commodities, ICAC is also helping Pakistan to produce transgenic cotton resistant to the disease.

Uzbekistan is passing through a transitional period of structural changes, which have affected input supply for cotton production. In 1980/81, the average yield in the Central Asian countries was as high as 890 kg/ha. After 16 years, during 1997/98 the average yield in Uzbekistan is expected to be 712 kg/ha. Recently, the input supply has improved and yields have recovered slightly.

Cotton yields in four of the five other largest cotton producing countries of the world, i.e. Argentina, Australia, Egypt, Greece and Turkey, are also not increasing. In Turkey, the GAP (Southeastern Anatolian Project), consisting of 22 dams and 19 hydroelectric power plants, will provide irrigation facilities to 1.7 million hectares. About one third of the total area irrigated by GAP is expected to go to cotton. Part of the project has already been working since 1995/96, with an impact on yields. Further expansion of the irrigation system will increase yields in Turkey in the next few years.

Reasons for Stagnation

Yield is an outcome of genotype interaction with the environment. Breeders invent new genotypes and try to accumulate as many favorable genes/characters in a plant as possible for obtaining the highest yield. All cotton varieties always have a huge genetic potential exploitable under suitable growing conditions. Growing conditions include climate and input applications. In the recent past, since the use of agrochemicals became popular in agriculture, technological innovations for best utilization of inputs have become of critical importance. Thus, in addition to genotypic constitution and environment, knowledge of the most efficient use of inputs has also become an important criterion for realizing optimum yield.

Unfortunately, the mechanism of genetic determination of yield is not properly understood in cotton. Yield is a complex quantitative character and breeders and geneticists do not have control over inheritance of hereditary material. According to Meredith, Jr. (1991) the increases in yield of cotton are due largely to many unidentified quantitatively inherited gene combinations. The nature of genetic control of yield or factors responsible for determination of yield do not permit breeders to manipulate the plant genetics according to their wishes. The available knowledge on inheritance of yield does not allow establishing what desirable genes have been transferred in the new genotype. Techniques are also not available to isolate desirable yield genes and induct them in the new genotype according to a breeder's wishes. Consequently, it seems that a stage has been reached where further accumulation of desirable genes through conventional breeding is likely to contribute little to yield improvement. Meredith et al (1991) also concluded that cotton breeders are not improving yields as much as they were 25 years ago.

The cotton plant has an enormous yield potential but only a part of that potential is realized. Under production practices, currently followed in most countries, input use has attained a dominant role. But, there is an upper limit for most efficient use of inputs. Given the limitations (some which can be resolved and some which cannot) in every country, it seems that the available technological innovations for maximum profitability have been utilized, and consequently yields have stagnated (ICAC 1997). Yields vary among countries because of growing conditions and levels of adoption of production technology. Under current growing conditions, the available options have been utilized in many countries, including both the world's highest yielding countries as well as low yielding countries.

Breeders Contributions

Yield records on cotton are available for about 140 years, divided into four periods of prominent yield behavior. The four phases are 1860s to 1930s, 1930s to 1960s, 1960s to 1980s and the current regime, which started from 1992 onward. The first and the longest phase is characterized by almost no growth in yields. Development of varieties was based on non-scientific methods, as fundamental principles of inheritance of characters were not applied. Mendel's fundamental principles of genetic control and inheritance were widely accepted and applied from 1915 onward. During the second phase 1930s to 1960s, scientific cotton breeding started in most countries and synthetic fertilizers were introduced. Yields in most countries increased. The third phase coincided with the introduction of insecticides. Yields increased depending on the extent of losses due to insects in various countries. The current phase is characterized by most efficient use of genetic development, synthetic fertilizers, insecticides and knowledge about physiological behavior of the plant. Plant reaction to growing conditions is widely understood and utilized to a larger extent. Though the situation may vary from country to country, breeders' contributions were most significant during the second phase.

Role of Agrochemicals in Cotton Production

Perusal of the historical data on yield indicates that cotton yields were fairly at par in most countries until 1940, with the exception of Egypt and Peru where yields were very high, and Southeastern African countries like Mozambique, Uganda and Zaire where yields were very low. From 1950 cotton yields improved in almost every country for almost 30 years, but with a divergent trend irrespective of the developed or developing nature of countries. This is the time when the cotton industry experienced drastic changes in production practices. In the last 5-6 decades, there have been two significant developments in the form of agrochemicals, fertilizers and insecticides that affected cotton yields in every country. If both inputs are eliminated from the production practices, it is doubted that 50% of the current yield level may be achieved. There are no efficient alternatives to synthetic fertilizers, and cotton production has to bear the use of nutrient supplements in the form of inorganic fertilizers. In addition to meeting plant needs, synthetic fertilizers have played a great role in manipulating the cotton plant for utilizing its maximum potential. Large increases in yield, occurring in every country of the world, can directly be attributed to fertilizer use.

Insect pressure on the cotton plant increased and insecticides were developed which are now extensively used on cotton. Most countries adopted chemical control during the 1970s and 80s. Insecticide use increased to the extent that it caused a serious impact on the economics of cotton production. While countries like Australia and China (Mainland) are faced with insecticide resistance problems, some Central American countries had to stop cotton production because of inability to control insects. Australia has been able to overcome the problem to some extent through an effective resistance management program. China is currently implementing a resistance control program. Resistance problems have been noted in India and Pakistan, and similar programs may be launched in the next few years.

Breeding for Yield Improvement

A paper, "Cotton Yields Stagnating," was published by the ICAC in the March 1997 issue of *THE ICAC RECORDER*, which also tried to identify the factors responsible for slow growth in yields. Most yield improvements in every country are ascribed to variety development. It is often claimed that high yielding varieties are responsible for yield improvement. While this phenomenon does not seem likely to lead to drastic improvements in the near future, the role of new varieties can be identified by the following methods.

Option 1

If the quantitatively inherited characters have been accumulated in the new genotypes, they should out-yield obsolete varieties even under obsolete production practices. Thus, it is proposed that modern varieties be grown under obsolete growing conditions and yield increases compared to old varieties.

We have no data to report on such trials.

Option 2

If yield potential is due to superior genetic constitution for higher yield, low yielding varieties would always perform poorly at least at the same location. Growing obsolete varieties under the current production practices can assess such a genetic potential. A trial was conducted at a research institute in Pakistan during 1985/86 and the yield data are reproduced here.

Obsolete Varieties Trial in Pakistan

Variety	Year of Release	Lint Yield Kg/ha
4 F	1914	1378
LSS	1933	1197
124 F	1945	1231
AC - 134	1959	1473
BS - 1	1962	1419
B - 557	1975	1463
MNH - 93	1980	1496
NIAB - 78	1983	1162

The trial was thrice replicated and was grown in a field along with other experiments. 112 kg of nitrogen and 45 kg phosphorous per hectare were applied to the field. Irrigation was applied as required and four applications of insecticide were given to control insects. These were normal treatments at the time of conducting the trial.

Yield data were statistically analyzed and yield differences among varieties were found non-significant. 4 F is the oldest and the first commercially grown variety since cotton was adopted in the Indian subcontinent. 4 F was as high yielding as were the latest varieties MNH-93 and NIAB-78, showing thereby that the yield potential has not changed in 70 years. It seems that 70 years ago varieties were able to give high yield equivalent to today's varieties but their potential was limited due to some other factors. It is assumed that if fertilizer is not applied and insecticides are not used yields will not be more than in 1914.

Option 3

A third option is to grow the same varieties after every 2-3 decades and assess their yield level under the changed growing practices. It is possible to assess the role of breeders' contributions to yield improvement by this method if long-term trials are planned. Fortunately similar trials have been conducted in the USA. Ramey (1971) has reported the yield performance of same varieties after 32 years. Data are available for bolls/m^2, seeds/boll and lint /seed. Yield data are reproduced here.

Yield Performance of Varieties in the USA

Varieties	1935 to 1938 (kg/ha)	1967 & 1968 (kg/ha)	% Change in 1967 & 1968
Deltapine 11A	628	1072	71
Stoneville 5A	622	1014	63
Ambassador	591	871	47
Stoneville 2B	568	861	52
Washington	538	858	59
Missdel 1WR	440	780	77
Average			62

Yield increases ranging from 47 to 77% are due only to the change in the growing practices. The six varieties' average increase of 62% in 32 years is equal to the long run world average increase of 2% per year.

Breeders' Role

Reporting of the above yield data in no way attempts to undermine the role of cotton breeding for yield improvement. Breeding has contributed significantly and still constitutes the largest segment of contributions made to improve yields in cotton. Breeders have changed the cotton plant from a perennial tree to an annual plant. Yet, no other science except breeding and genetics has contributed to bringing genetic improvements in fiber quality characteristics. Change in the plant shape and its ability to grow in a variety of climatic conditions is all attributed to breeding efforts. Evans (1980) has rightly observed that plant breeders' contributions in increasing yields can be divided into four categories as follows:

- **Adaptation to local environments**

  Breeders develop varieties under local conditions and, knowingly or unknowingly, they select varieties most suitable for the local environment. Local conditions may have cool early temperatures, extremely high summer temperatures, high humidity, shorter growing season, etc., but all varieties having gone through a selection process under such conditions have the capability to resist such climatic adversities.

- **Resistance to pests**

  Insects are no doubt limiting factors for yield improvement. Some programs like the multi-adversity resistance program of Texas A&M University are exclusively devoted to resistance to pests but all current breeding programs include resistance to insects in their primary breeding objectives. Minimization of losses due to insects consequently increases yield.

- **Selection for higher yield potential under favorable conditions**

  Selection under specific irrigation methods and soil types automatically screens the highest yielding genotype for specific conditions.

- **Suitability to continually changing agronomic and management practices**

  Production practices vary greatly among countries. From the segregating population, breeders identify the most suitable genotype for production practices of various regions.

Evans (1980) has also concluded that breeders are now placing higher priorities on local adaptation than they did before. Varieties now change after every short distance, possibly contributing to increased yields.

Impact of Yield Stagnation

The stagnation of cotton yields has significantly affected the world industry. World production is lower than it would be if yields had continued to rise during the 1990s, resulting in a tighter world supply, higher average prices and reduced consumption of cotton. Further, rising costs for inputs applied in the production of cotton have not been offset by increases in productivity.

The average Cotlook A Index over the past two decades has been 74 cents per pound of lint. However, the Index rose to more than 90 cents in 1994/95, and, while lower now, the Cotlook A Index remains near the long run average. Because of reduced import demand from China (Mainland) and concerns about world economic growth arising from the devaluation of currencies in East Asia, world cotton prices have declined this season, and an additional reduction in imports by China (Mainland) could result in lower prices again in 1998/99. Nevertheless, because yields are not rising while income and population growth continue to boost the demand for cotton, international prices are expected to remain near the long run average through 1998/99, and prices are expected to climb higher than average during the next five seasons.

Cotton's share of world textile fiber consumption dropped from 50% in 1986 to 44% in 1997, and further declines in market share are inevitable if production does not rise to match demand. Because yields have not risen while input costs have continued to climb, the cost of cotton production per kilogram of lint has increased in the 1990s.

How Could Cotton Yields Be Improved?

Currently available technology has been utilized and consequently yields have stopped growing. Researchers in many cotton producing countries are confronted with maintaining the current status of yields in their countries. However, the cotton producing countries that have not utilized the available technologies to their fullest extent have a chance to improve yields. Further perfecting the technology can also bring slight improvements in yields. Slow growth in some countries may be coming from such improvements. But, for any significant increases in world yields, like the one achieved during the last 3-4 decades until 1991, there is a need to invent new technology. This technology has to be different from the routine work done to develop varieties, assess agronomic requirements of varieties, control insect pests, etc. If new technology is developed, yields can be improved in every country. How much improvement depends on the ability in technology to increase recoverable potential of the cotton plant. However, the target could be to increase the number of bolls equal to the number of leaves on the plant. How to get there is an issue for researchers.

It seems that a new technology capable of bringing improvements in yield equivalent to synthetic fertilizers and insecticides will not be available for many years. Consequently, the world cotton production industry has entered into a long-term period of slow growth. Demand for cotton is increasing and the current ICAC projections show that the world cotton industry would need 22.3 million tons in 2005. In the absence of new technologies, solutions to the specific problems in the affected countries should be expedited to enhance world cotton supply for the textile industry.

Currently, one of the areas of most interest to the cotton industry is development in the field of genetic engineering. Recent advances in the field of genetic engineering have provided an additional tool in the hands of breeders and geneticists for directed breeding. The technology provides for induction of non-species genes into the cotton plant and their utilization generation after generation. Single or multiple genes can be identified in relatives and non-relatives of the cotton plant, isolated and fused into the cotton genome. The effect is permanent and stable. One such example is Bt cotton wherein a gene from the soil bacteria was inserted into the cotton plant for obtaining resistance to bollworms, particularly tobacco and cotton bollworms. Similar direct efforts could be made to exploit genes responsible for improvement in harvest index. But, in order to do so breeding methods need to be changed.

Whether genetic engineering can convert the cotton plant from C_3 to C_4 plant is not known. Again no work is reported to be going on on this aspect. Cotton is a C_3 plant and photorespires at about 30% of the photosynthetic rate. If cotton is converted from C_3 to C_4 there could be a large increase in yield.

A broader genetic base is a must for genetic improvement in the population by conventional breeding or directed breeding. There is no formal way to exchange cotton germplasm among breeders at the international level. The modern trend to patent more and more varieties/germplasm is likely to further curtail open exchange of germplasm, thus limiting genetic progress. It is important that easy exchange of germplasm be encouraged for continued growth in yields.

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Large Scale Mechanized Direct Drilling of Cotton in Brazil

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Introduction

Brazil is the sixth largest cotton producer in the world and the biggest producer in Latin America. Cotton production has increased over the last 20 years due to the development of large mechanized farms and the main producing states are now Paraná and São Paulo, followed by Minas Gerais, Mato Grosso, and Goiás (Figure 1). Producers encounter two main difficulties:

- Extreme climatic fluctuations, in particular high humidity and variations in annual rainfall.
- Water and wind erosion which causes rapid soil degradation, threatening the sustainability of cropping systems; increasing levels of inputs are required to maintain high yields, which reduces profitability.

If cotton production is to continue on these large farms, the agronomic problems need to be overcome and production costs reduced in order to make these systems profitable and sustainable in the long term.

In order to deal with these problems, the MAEDA group, Brazil's largest private cotton producer, called on CIRAD (Centre de coopération internationale en recherche agronomique pour le développement, France) to analyze the situation and introduce new soil and crop management methods. The initial technical recommendations, which were immediately applied on all of MAEDA's cotton-growing land, led to instant increases in yields. However, in order to maintain long-term soil fertility, further complementary action was necessary. The MAEDA group and CIRAD have recently set up cropping systems based on direct drilling into plant mulch. The objectives of these systems were to restore and maintain soil fertility and achieve high stable yields of cotton. Research results convinced the MAEDA group and in 1996/97, these systems were applied on 25% of their cropland.

The MAEDA Group: Research Partner and a Major Private Cotton Producer

The MAEDA group produces 7% of Brazil's cotton and cultivates 33,000 ha of land (22,000 ha of cotton and 11,000 ha of maize, soybean and pasture in central Brazil). It has *fazendas* (farms) in the south of the state of Goiás and in the north of the state of São Paulo (Figure 1). The group is responsible for ginning cottonseed from its own *fazendas* as well as some of the regional production (ginning capacity of 1,200 t/day). It also processes and markets cotton and its by-products (spinning, crushing, delinting seed).

Ecological Conditions of MAEDA's Farms

The MAEDA group's farms are situated in the hot humid low altitude zones in tropical central Brazil. Rainfall occurs during the 6-month rainy season from October to May (Figure 2). The annual rainfall varies from 1,000-1,700 mm and the average annual rainfall over the last decade has been 1,500 mm.

MAEDA's land is situated in an ecology of mesophilic tropical forest with reddish brown lateritic soils overlying basalt. The soil's natural physical and biological properties are suited to intensive cropping. However, they are deficient in phosphorus,

Figure 1. Cotton-producing states and location of the MAEDA group in Brazil.

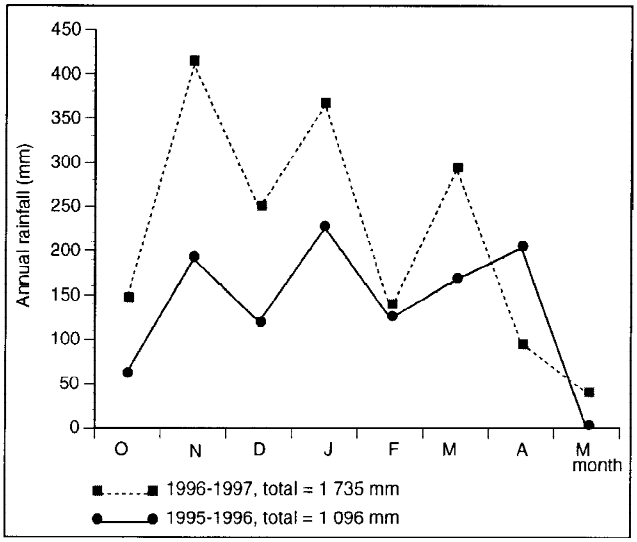

Figure 2. The 1995/96 and 1996/97 rainy seasons and cotton sowing periods on the MAEDA group's Canada fazenda *(Itumbiara, Goiás).*

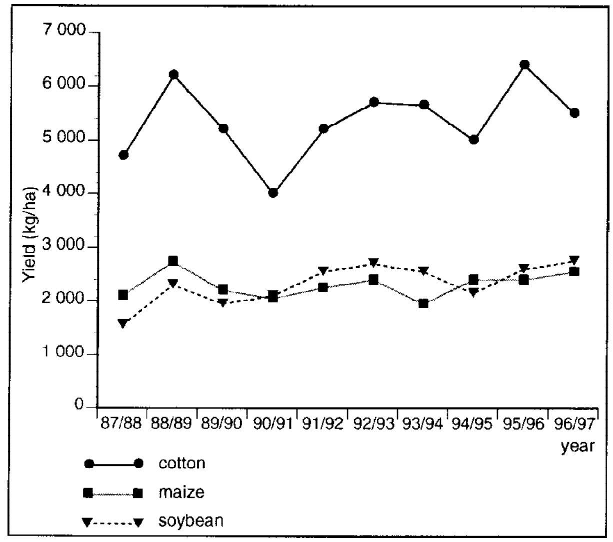

Figure 3. Average yields of cotton, maize, and soybean for the MAEDA fazendas *in the state of Goiás.*

potassium, and exchangeable bases. Magnesium-lime soil conditioners are required to correct this and annual applications of soluble NPK fertilizer are also necessary for cotton production. Long steep slopes (slopes from 2-10% or more) characterize the MAEDA group's land units. The toposequence generally includes the following elements:

- Shallow soils overlying basalt at the top of the slopes (slopes from 2-4%).
- High potential soils on basalt deposit (slopes greater than 8-10%).
- Sloping land accounts for 60-80% of cultivated land. Erosion is apparent with deep gullies appearing every year (long slopes of 8-15%).
- Land at the bottom of the slopes, where erosion is even worse than on the slopes (slopes greater than 15%).

Original Production System

Before the system was improved, cotton was grown as a continuous monoculture, harvest residues were burned, and tillage was carried out using offset disc implements. This resulted in wind and water erosion, soil compaction, and loss of biological and physicochemical fertility of the soil. Yields varied considerably from year to year (Figure 3) despite high fertilizer and pesticide applications. In the same season, yields varied significantly (from 30-60%) between early and medium-late sown crops. Costs of production and economic risks were extremely high.

Agronomic Condition of MAEDA Farms

Initially, CIRAD carried out a quick analysis on the effect of agricultural practices on the development of the cotton crop and of the top soil profile. This analysis highlighted the factors limiting production and the high variability in annual yields, caused by soil management methods that were inappropriate to the environmental conditions (monocropping, burning residues, frequent use of disc implements when the soil is either too dry or too wet).

The breakdown of the topsoil profile shows that the soil structure is particulate when dry and massive (compacted) when cropped. When dry, the pulverized soils are prone to serious wind erosion at the start of the cycle that destroys the young cotton crop and makes resowing necessary (up to 5-10% of cropland). During the growing season, the soil quickly becomes compact, restricting taproot growth to the first 5-30 cm. The formation of a crust on the soil surface leads to severe erosion. In addition to this sheet erosion, deep gullies appear each year causing estimated yield losses of 8-14% on the cultivated land overlying basalt. This erosion is a major cause of chemical and biological fertility losses to these soils. Producers try to compensate for this loss by applying more chemical fertilizers.

The shallow root system makes the crop more susceptible to climatic variation and leads to irregular growth, which is exacerbated by disease and insect damage or by poor weed control. As the taproot growth is restricted to the first 30 cm of soil, the plant's potential to assimilate water and nutrients is reduced. Excess water causes root asphyxiation and favors development and incidence of insects, nematodes (*Meloidogyne* spp.), and some diseases (grey mildew, cotton wilt, damping off, etc.). Competition from dicotyledon weeds such as *Acanthospermum hispidum*, *Commelina* spp., and *Ipomoea* spp. starts early in the season and is difficult to control. In monocropping systems, these weeds proliferate when trifluralin, a gramineous herbicide, is used excessively. Trifluralin has to be incorporated in the soil with disc plow, which increases soil degradation.

Climatic variability and heavy rainfall are very detrimental to cotton production. An analysis of rainfall patterns since 1987 shows that there is a strong negative correlation between yields and annual rainfall: the higher the rainfall, the lower the yields.

The factors highlighted in this analysis show that potential solutions need to include not only improvements in soil management methods but also in weed control and choice of rotations, sowing dates, and varieties (duration, disease resistance, perfection in terms of pest development cycles). These measures were implemented in two stages. The aim of the first measures (to reduce soil compaction and introduce rotations) was to meet the immediate priority of improving the agricultural profile. The second stage consists of radical changes to the cropping systems (direct drilling into mulch) in order to improve and maintain soil fertility sustainably and cheaply.

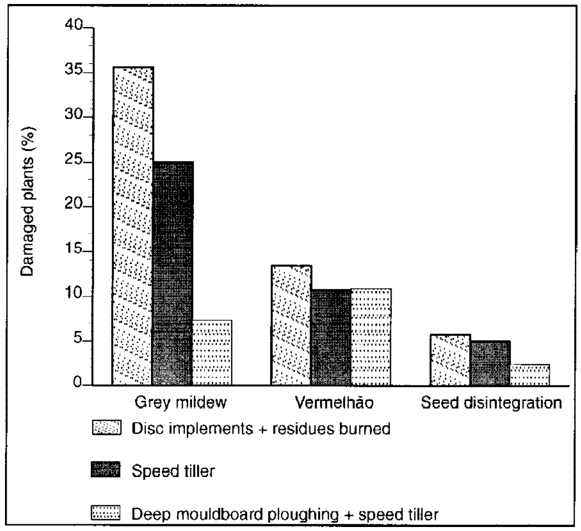

Figure 4. Disease incidence in cotton as a function of tillage methods (cultivar IAC 20, Recanto fazenda*, 1994/95, Itumbiara, Brazil, MAEDA).*

First Stage: Reducing Soil Compaction and Introducing Rotations

At the start, measures were taken immediately to reduce soil compaction, water and wind erosion and create a regular topsoil profile to minimize the effects of climatic variability. These measures included deep mouldboard plowing techniques, combined with crop rotations and successions, and the recycling of all crop residues. Disc implements were replaced by mouldboard ploughs and speed tillers. Deep mouldboard plowing was carried out at the end of the rainy season, which is also a way of incorporating shredded crop residues. A coarse seedbed was prepared using speed tillers. A 3-year rotation was tested at the same time as these new cropping techniques, based on 2 years cotton followed by 1 year with two crop cycles: soybean + sorghum or millet, or maize + *Crotalaria spectabilis*.

Results

Analysis of the topsoil profile, soil mechanical resistance measures and water infiltration rates showed that the physical properties of the soil improved after deep tillage in the first and second year. Deep tillage at the end of the season, associated with the use of speed tillers prior to sowing, produced a rough seedbed which slows down crust formation and improved weed control. Reducing soil compaction had a significant effect on yields, which were an average of 10-20% higher than yields from cotton monocrops. A significant reduction in disease incidence was also observed (particularly for grey mildew; Figure 4). The increased yields were obtained with lower production costs, even for inputs (fertilizers and pesticides) and equipment, which went up in price considerably between 1994 and 1996. As a result, in 1996/97, the MAEDA group used these tillage techniques (deep tillage with incorporation of residues and scarification) on all of their cultivated land. Rotations with two annual crops grown in succession are the basis for introducing direct drilling of cotton and are already used on 6,250 ha (25% of cultivated land). Simplifying the cropping operations meant a reduction in the number of tractors and has led to a fundamental reorganization of equipment with greater use of agricultural aeroplanes and herbicides and an increase in the size of tractors used.

Profit margins/ha for the new cropping systems, under research management on different MAEDA *fazendas*, are consistently higher than those for conventional monocropping systems. The greatest savings have been made on the pre-sowing and sowing operations (about 30% cheaper than in the conventional system; Tables 1-3).

Agronomic Limitations

The positive effects of lower costs and higher, more stable revenues do have limitations. In the climatic and soil conditions of central Brazil, repeated deep tillage accelerates the mineralization of soil organic matter. CIRAD experts have observed a reduction in organic matter of about 50% over a 6-year period in the humid tropical zone, compromising the medium-term sustainability of a high-yielding, profitable farming system. Therefore, deep tillage should only be used occasionally as a quick way of improving the physio-chemical characteristics of degraded soil. Erosion still occurs in the new cropping systems, and the continued presence of a dominant monocrop means that the nematode problems persist or increase. In order to achieve a truly sustainable agricultural system, soil and crop management methods need to be changed radically. This is exactly what the MAEDA group wanted to achieve when it asked CIRAD to develop cropping systems combining crop rotations, cover crops, and direct drilling into a mulch.

Table 1
Costs and Profit Margins for 1995/96 (Cultivar IAC 22, Recanto *fazenda*, Itumbiara, Brazil. Costs calculated for an area of 50 ha under research management)

Operation (Inputs, labor, etc.)	Unit/ha	Cotton monocrop with conventional tillage (offset disc implements + residue burning)		Rotation following soybean, deep tillage with tines (deep scarification)		Rotation following soybean + millet (direct drilling)	
		Quantity/ha	Cost $/ha	Quantity/ha	Cost $/ha	Quantity/ha	Cost $/ha
1. Pre-sowing							
Maintenance	hours	0.24	7.0	0.24	7.0		
Tillage	hours	3.20	109.7	1.89	75.5		
Total herbicides	hours					0.5	29.2
Sub-total			**116.7**		**82.5**		**29.2**
2. Sowing							
Treated seeds	kg	15.5	23.3	15.5	23.3	15.5	23.3
Herbicides	liters	2.5	38.2				
NPK fertilizer 3-15-15	kg	330.0	68.4	330.0	68.4	330.0	68.4
Seeding	hours	0.5	10.2	0.5	10.2	1.0	22.0
Sub-total			**140.1**		**101.9**		**113.7**
3. Growing							
Mechanical weeding	hours	1.1	30.7				
Hand weeding	days	6.1	41.0	10.4	69.9	5.0	33.6
Herbicides	no. of appl.	2.0	57.9	3.0	116.6	3.0	116.6
Insecticides + Pix	no. of appl.	9.0	181.1	9.0	181.1	9.0	181.1
Fertilizer top dressing NK	kg	297.0	68.5	297.0	68.5	297	68.5
Sub-total			**379.2**		**436.1**		**399.8**
4. Mechanical harvest	**tons**	**2.1**	**211.4**	**2.5**	**249.7**	**2.7**	**279.0**
5. Transport	**tons**	**2.1**	**20.7**	**2.5**	**24.5**	**2.7**	**27.4**
6. Economic costs							
Indirect administrative costs			90.2		90.2		90.2
Compulsory insurance			43.7		43.7		43.7
Sub-total			**133.9**		**133.9**		**133.9**
7. Fixed costs (Direct administrative costs)			**59.3**		**59.3**		**59.3**
8. TOTAL COSTS			**1,061.3**		**1,087.9**		**1,042.3**
9. RECEIPTS seed cotton (Price: $6.7/15 kg)	**kg**	**2,073.0**	**925.9**	**2,450.0**	**1,094.3**	**2,736.0**	**1,222.1**
10. NET PROFIT MARGIN			**- 135.4**		**= + 6.4**		**+ 179.8**

Second Stage: Direct Drilling into Mulch

Background to Direct Drilling in Brazil

Mechanized direct drilling into crop residues began in the 1970s in the southern states in subtropical high altitude zones, after some work was carried out by the ABC Foundation, cooperatives in Paraná, and the IAPAR (Agronomic Research Institute of Paraná). Now, more than 3.5 million ha are cultivated using direct drilling in southern Brazil. In these temperate to subtropical regions, crop residues decompose very slowly during the cold season and so maintain a long-lasting soil cover. The seed is sown in undisturbed soil with special seed drills; only a small furrow or ditch is made and weeds are eliminated with herbicides before and after sowing.

However, in hot humid tropical zones in the west and central Brazil, crop residues decompose extremely quickly and the protection of the soil surface is too temporary to be effective (organic matter mineralization is more than 5%). Some erosion occurs and weed control is difficult. In this situation, the soil cover should be increased and direct drilling should be combined with the cultivation of a high biomass-producing crop into which the main crop can be sown (cotton, maize, or soybean), like the system being developed on the newly cleared land in western Brazil.

Adapting Direct Drilling Practices to MAEDA Farms

These systems are based on a combination of crop rotations and cover crops, rational herbicide use, and direct drilling into a thick plant mulch. The principle is to produce large amounts of biomass that provide a permanent mulch from crops established by direct drilling before and/or after the cotton crop. Ideally, the cost of establishing the biomass crop should be lower than that for the conventional soil management methods (deep tillage and scarification) that these systems are replacing. In this way, the soil is not tilled and all crops are sown by direct drilling. The trials set up on the MAEDA group farms aim to resolve the following questions:

- Which crops for rotation and cover crops will respond to the defined objectives and provide an effective plant mulch for cotton? This choice will be based on agronomic and economic factors.
- How can damping off, which is linked to the microclimate created by permanent plant mulch, be avoided?
- How can herbicide application techniques be managed to establish mulch, control weeds along the row and between rows and eliminate volunteer cotton?

Millet or guinea sorghum and *Crotalaria spectabilis* seemed capable of providing the required plant mulch. They were introduced in four different cover crops where cotton remained the main crop because of its economic importance to the MAEDA group:

- soybean + millet or guinea sorghum;
- maize and *Crotalaria spectabilis*;
- early direct-drilled cotton + millet or guinea sorghum;
- millet or guinea sorghum + late-sown cotton.

The presence of a permanent mulch creates a micro-climate favorable to the development of harmful fungi (*Fusarium*, *Pythium*, *Rhyzoctonia*, *Aspergillus*, etc.). When direct drilling into a thick layer of biomass that is prone to fermentation such as millet, fungicide treatment of seeds has to be increased, par-

Table 2
Costs and Profit Margins for 1996/97 (Cultivar DP 90, Canadá *fazenda*, Itumbiara, Brazil. Costs calculated for an area of 50 ha under research management)

Operation (Inputs, labor, etc.)	Unit/ha	Cotton monocrop conventional tillage (offset disc harrows + residue burning)		In rotation following sorghum, (direct drilling)	
		Quantity/ha	Cost $/ha	Quantity/ha	Cost $/ha
1. Pre-sowing					
Maintenance	hours	0.35	10.5		
Cotton slashing	hours	0.35	5.7	0.35	5.7
Tillage	hours	2.73	96.5		
Total herbicides	hours			0.5	49.1
Sorghum seeds	hours			0.52	8.5
Nitrogen	kg			50.0	30.1
Sub-total			**112.7**		**93.4**
2. Sowing					
Treated seeds	kg	15.0	16.5	15.0	16.5
Herbicides	liters	2.5	44.7		
NPK fertilizer 3-15-15	kg	330.0	83.8	330.3	83.8
Seeding	hours	0.52	10.4	1.0	22.0
Sub-total			**155.4**		**122.3**
3. Growing					
Mechanical weeding	hours	1.03	15.6		
Hand weeding	days	1.5	12.3	1.0	8.8
Herbicides	no. of appl.	2.0	75.2	4.0	141.3
Insecticides	no. of appl.	8.0	163.4	8.0	163.4
Fertilizer top dressing NK 18-00-20	kg	250.0	82.9	250.0	82.9
Sub-total			**349.4**		**396.4**
4. Mechanical harvest	tons	**2.49**	**205.8**	**2.83**	**233.9**
5. Transport	tons	**2.49**	**25.7**	**2.83**	**29.2**
6. Economic costs					
7. Fixed costs (Direct administrative costs)			**75.8**		**75.8**
8. TOTAL COSTS			**1,009.7**		**1,035.9**
9. RECEIPTS seed cotton (Price: $8.57/15 kg)	kg	**2,490.0**	**1,422.6**	**2,829.0**	**1,616.3**
10. NET PROFIT MARGIN			**+ 412.9**		**+ 580.4**

ticularly against damping off (seed disintegration due to fungi present in the soil and anthracnose). Tests on chemical seed dressings showed satisfactory results, even in very wet conditions. The seed dressings had active ingredients such as thiabendazone + carboxin + thiram, carbendazin, and triticonazole which was the most effective (not yet commercially available). The most effective seed dressings for preventing aphid and delphacid damage at the start of the crop cycle are aldicarb and imidachlopride.

A non-selective herbicide treatment is always applied before the main crop is sown to desiccate the biomass-producing crop and so create the mulch. For example, a crop of guinea sorghum or millet is desiccated 45-60 days after being sown. Herbicide use is also essential for weed control for the establishment of the cotton crop, which has to be kept clean because of mechanical harvesting. The major problem is the control of dicotyledon weeds. With direct drilling into mulch, a pre-emergent herbicide is applied at the same time as sowing but only along the row where the seed drill has separated the mulch (20% of the total area). Cheap non-selective herbicides are applied between the rows with special tunnel applicators that totally protect the crop, controlling the dicotyledons *Commelina* sp., *Acanthospermum* sp., and *Ipomoea* sp. until the cotton crop covers the soil completely (60 days after sowing). Overall, these technical measures are much cheaper than traditional mechanical and chemical weed control methods.

Lastly, volunteer cotton is controlled with 2, 4-D amine which is applied 20-30 days after the cover crop of millet or sorghum has been sown. It can also be controlled with herbicides in other crops elsewhere in the rotation (maize, soybean).

Results

Results confirmed the benefit of the rotations tested. Soybean + millet or sorghum, maize + *Crotalaria spectabilis* improved yields in the following cotton crop. These crops also played a key role in the rotation in limiting nematode infestations, which cause considerable damage to monocropping cotton. There were also clear differences between the crops chosen for mulch. Generally, cotton yields tended to be higher when grown in a mulch of gramineous crops than when grown in a mulch of leguminous crops. For most mulch, a seed dressing should be used because the moist microclimate of the biomass encourages damping off. Comparison of gramineous mulches showed that guinea sorghum is better than millet:

- Guinea sorghum is less prone to fermentation and less favorable to the development of pathogenic fungi that attack cotton seed, even in very wet conditions, which generally encourage fungal development;
- It decomposes more slowly and has strong allelopathic properties, which facilitates weed control.

Analysis of the topsoil profile, measurement of mechanical resistance of soil, and water infiltration rates showed that the soil's physical properties improved with direct drilling. The agricultural profile is much less affected by the passage of machinery with direct drilling than with deep tillage (demonstrated by the changes in the physical parameters along the tramlines).

Direct drilling cotton in a rotation produced cotton yields 10-41% higher than in the improved system with mouldboard plowing + speed tillers + shredding crop residues. Cotton yields depend on the preceding crop, the fertilizer application rate, the land's toposequence, the degree of soil degradation, and rainfall. The increase in cotton yields with direct drilling is attributed to significantly higher boll weight, from 4-21% depending on fertilizer application rates. With maize and soybean, these increases were generally even higher (up to 40%).

The systems tested, based on the combined practice of culti-

Table 3
Costs and Profit Margins for 1996/97 (Cultivar DP 90, Recanto *fazenda*, Itumbiara, Brazil. Costs calculated for an area of 40 ha under research management)

Operation (Inputs, labor, etc.)	Unit/ha	Cotton monocrop deep tillage		Rotation following soybean + sorghum (direct drilling)	
		Quantity/ha	Cost $/ha	Quantity/ha	Cost $/ha
1. Pre-sowing					
Maintenance	hours	0.35	10.5		
Cotton slashing	hours	0.35	5.7		
Tillage	hours	2.73	96.3		
Total herbicides	hours			0.6	43.7
Nitrogen	hours			0.5	30.1
Sub-total			**112.7**		**73.8**
2. Sowing					
Treated seeds	kg	15.5	16.9	17.3	18.9
Herbicides	liter	2.5	31.5		
NPK fertilizer 3-15-15	kg	330.0	83.8	330.0	83.8
Seeds	hours	0.5	10.4	1.2	22.0
Sub-total			**142.6**		**124.7**
3. Growing					
Mechanical weeding	hours	3.1	47.0		
Hand weeding	days	1.6	14.4	1.2	10.4
Herbicides	no. of appl.	2.0	50.2	3.0	86.4
Insecticides	no. of appl.	11.0	249.6	11.0	249.6
Fertilizer top dressing NK	kg	330.0	96.4	330.0	96.4
Sub-total			**457.6**		**442.8**
4. Mechanical harvest	tons	**2.19**	**181.0**	**3.17**	**262.3**
5. Transport	tons	**2.19**	**22.6**	**3.17**	**32.8**
6. Economic costs			**84.9**		**84.9**
7. Fixed costs			**75.8**		**75.8**
8. TOTAL COSTS			**1,077.2**		**1,097.1**
9. RECEIPTS seed cotton (Price: $8.57/15 kg)	kg	**2,190.0**	**1,248.3**	**3,170.0**	**1,806.9**
10. NET PROFIT MARGIN			**+ 171.1**		**+ 709.8**

vating biomass crops and direct drilling, seem to provide conditions necessary for producing stable yields through better use of water and mineral nutrients and reduction in effects of climatic variation. The yield increases resulted from improvements made in the different functions listed below. An evaluation of their positive impact requires further research which goes beyond the direct needs of producers.

- Total protection of soil from water and wind erosion.
- Maintenance of soil porosity and a stable soil structure.
- Regulation of thermic and hygrometric amplitudes (better management of water flow).
- Maintenance of soil organic matter levels (improved management of mineralisation and free nitrogen fixation).
- Recycling of minerals that have been leached deep into the soil surface.
- Improved crop nutrition through the progressive mineralization of biomass.
- Limitation of the development of the most competitive weeds. The best mulches (guinea sorghum, millet, and *Crotalaria spectabilis*) prevented germination of 95% of the weeds found in monocropping systems. However, the remaining 5% remain a problem because the cotton crop needs to be completely clean for mechanical harvesting. Herbicide use is, therefore, essential.
- Cheap pest control due to the combined effect of (i) the re-establishment of the biological cycles broken by monocropping; (ii) development of fungi that control the larvae of Lepidoptera (*Nomuraea rileyi*) that are prevalent with direct drilling; (iii) improvement in the control of soil pests because of the decoy effect and dispersal of attacks (the pest cannot tell the difference between the roots of cotton and the cover crop), for example, the larvae of *Scaptocoris castanea* attack young cotton plants (40-60% of plants are affected in a monocrop with plowing compared to virtually none with direct drilling); (iv) the use of crop rotations which preserve natural pest predators.

The higher levels of profitability of direct drilling systems are of particular interest to private farmers. The cropping pattern used in these systems, in which 67% of land is used for cotton, gives higher yields with lower costs than in monocrops where 100% of land is used for cotton and offset disc implements are used (Tables 1-3). Direct drilling systems have consistently been the most productive: Yields are 10-40% higher than the systems with deep tillage, depending on the *fazendas*. The best reproducible yields now exceed 3 tons/ha. Compared to deep tillage management methods, the direct drilling techniques are more economical for all pre-sowing and sowing operations and net profit margins are always markedly higher with direct drilling (from 41-315% higher in the same conditions, Tables 1-3).

Target for 2001: Widespread Application of Direct Drilling Techniques

The research carried out with the MAEDA group showed how cotton cropping systems that degrade the environment could be improved quickly. Since 1994/95, when CIRAD started working with the MAEDA group, cotton yields have stabilized and are increasing each year despite more extreme climatic conditions than in the previous 7 years (1987-93) (Figure 3). After 3 years of joint research, trials showed that direct drilling into mulch is productive, yields are higher and stable over time, and soil protection is improved.

The MAEDA group evaluated whether it would be worth abandoning the conventional monocropping system where disc tillage is used and harvest residues are wasted. The new tillage methods (mouldboard plowing at the end of the crop cycle,

Table 4
Summary of Production Costs and Net Profit Margins
(%)

Techniques Compared	Pre-sowing Costs	Sowing Costs	Growing Costs	Net Profit Margin
Situation 1				
Deep tillage rotation/ conventional monocrop	–29	–23	+15	0 for deep tillage/ negative for conventional
Direct drilling rotation/deep mouldboard ploughing rotation	–65	+12	– 8	Positive for direct drilling/ 0 for deep tillage
Situation 2				
Direct drilling rotation/ conventional monocrop	–17	–22	+13	+ 41
Situation 3				
Direct drilling rotation/ deep tillage monocrop	–34	–12	– 3	+315

incorporating residues, preparing the seedbed with speed tillers) are now used on all of MAEDA's land. Cotton monocultures are gradually being replaced by rotations, with cover crops of soybean + millet or sorghum, maize + *Crotalaria spectabilis* once in 3 years. Systems of direct drilling into mulch (which involves establishing biomass at the same time as the main crop) are being set up and priority is being given to biomass-producing cover crops based on soybean and maize (more than 6,000 ha). Direct-drilled cotton in these cover crops accounts for 5% of total land area (about 500 ha). The objective is to introduce direct drilling systems on all of MAEDA's *fazendas* over the next 3 years, which will allow time to convert the equipment.

Perspectives

The CIRAD-MAEDA project showed that a research organization could work effectively in the private sector. Results need to be obtained quickly, made possible in this case by the choice of research methods. This partnership succeeded in developing satisfactory cropping techniques. However, there is still considerable room for an even better economic performance, by optimizing production as well as significantly reducing production costs and environmental degradation. Further research should focus on providing a more detailed evaluation of the positive effects and optimizing the agronomic performance of direct drilling systems, in particular models of the soil-plant system in relation to the type of biomass, so that results can be applied to other tropical environments (forecasting models to aid decision-making). Another priority for research should be reducing the production costs of direct drilling systems and improving the capacity and flexibility of equipment. Reducing costs and protecting soil resources are both important factors for sustainable and profitable agriculture.

Acknowledgements

The authors would like to thank Dr. M. Fok and Dr. C. Fovet-Rabot of CIRAD for their help in putting together this paper.

Short Notes

• A New Source of Cytoplasmic Male Sterility

Hand emasculation and pollination is one of the main limitations in commercial cotton hybrids. Once suitable combiners have been identified, which exhibit sufficient heterosis in F_1 over popular varieties of the area, large scale F_1 seed production could still limit commercial utilization of hybrid vigor. Hand emasculation and pollination of every single flower increases the cost of hybrid seed to the extent that yield gains become uneconomical. Economical seed production is a key to the success of commercial cotton hybrids and currently there are only two ways to produce hybrid seed other than the manual method, i.e. use of cytoplasmic or genetic male sterility systems. While the cytoplasmic male sterility (CMS) system requires the male parent to be converted into a restorer line, genetic male sterility (GMS) demands elimination of half the population in the female fields/plots. Utilization of CMS is also limited by inability of a restorer line to remain fertile under various climatic conditions.

A new system of CMS was developed at the University of Arkansas, USA wherein instead of *G. harknessii* cytoplasm, *G. trilobum* cytoplasm was utilized. The new system of cytoplasm called CMS8 is still undergoing extensive testing and efforts are underway to eliminate undesirable effects of the *G. hirsutum* nucleus interaction with the *G. trilobum* cytoplasm. It is hoped that the low maturity problem will be soon overcome.

Now, reports from India indicate that the cytoplasm of *G. aridum* (genome D4) has been introgressed into the nucleus background of a *G. hirsutum* variety. Crossing work was started in 1991 with the objective of transferring nuclear genes of a cultivated tetraploid variety into the cytoplasm of a wild diploid species. In seven years, a different and another source of CMS has been developed. It is claimed by researchers at the Cotton Research Station of the Punjabrao Deshmukh Krishi Vidyapeeth in Akola, India that the new source of male sterility is complete and can be crossed with all male fertile lines. A contemporary male fertile line has also been developed and used to convert 50 local genotypes into restorer lines. A new source of CMS is a step forward toward diversification of sources of male sterility in cotton.

• Australian Varieties in the USA

Australia is the only country where most of the cotton area is grown in okra leaf varieties. There are no doubts about the usefulness of narrow leaf shape but, like many other special morphological characters, okra leaf is negatively correlated with yield. Australian breeders were able to develop high yielding varieties with okra leaf shape. Okra leaf varieties like Siokra, Siokra L22, Siokra L4 and Siokra S324 are currently grown on more than 50% of the total area in Australia. Australian varieties have been tried in many countries. Currently, Australian varieties make up a major share of the cotton seed business in South Africa and are grown on a significant area in Greece, Spain and Turkey. Yield and quality evaluation trials were conducted in the USA during 1996 and 1997 and found successful.

Five Australian varieties will be grown on a commercial scale for the first time in the USA during 1998. All Australian varieties, okra or broad leaf, will be marketed in the USA under the trade name of FiberMax. The varieties being offered for 1998 are FiberMax 819 (okra leaf), FiberMax 832 (okra leaf), FiberMax 963 (normal leaf), FiberMax 975 (normal leaf) and FiberMax 989 (normal leaf).

The origin of these varieties is not known but they are claimed to be sister lines of the varieties currently grown in Australia. Hoechst Schering AgrEvo GmbH (AgrEvo) and Cotton Seed International Proprietary Limited (CSI) of Australia have established a joint venture called AgrEvo Cotton Seed International (ACSI) headquartered in the USA. ACSI is distributing the seed for 1998 and plans to breed and develop more varieties for the US conditions. Seed will be imported from Australia and if farmers opt to go for Australian varieties about 100,000 hectares may be planted to Australian varieties during 1998/99.

• Cultivation of BXN Varieties Prohibited in the USA

It would have been the third year of commercial cultivation of BXN cotton but the US Environmental Protection Agency (EPA) has prohibited the application of the herbicide bromoxynil on the BXN varieties. In May of 1997, EPA allowed a time-limited tolerance for residues of bromoxynil in undelinted cotton seed, cotton gin by-products, cotton hull, chicken eggs, poultry meat, meat by-products and fat. The time-limited tolerance expired on January 1, 1998, and the EPA has refused to award extension in the tolerance. Thus the genetically engineered BXN varieties cannot be sprayed with bromoxynil and will be treated as normal non-transgenic varieties. Other herbicides can be sprayed, but BXN varieties are not resistant to any other herbicide.

According to the letter issued by the EPA, if bromoxynil is sprayed on the genetically engineered BXN varieties, it leaves sufficient residue for causing developmental risks to infants and children. The EPA decision may be revised if data on non-lethal effects of bromoxynil becomes available but according to the current situation many farmers may opt to grow Roundup Ready herbicide tolerant varieties.

During 1997/98, Roundup Ready varieties were grown on about 325,000 hectares and farmers paid US$12-20/ha as a fee for the technology. Last year, some farmers observed early boll shedding and deformed boll shape in the Roundup Ready varieties and complained to Monsanto and Delta and Pine Land Co. The problem was spread over 4,000 hectares and some farmers suffered losses in yield and demanded compensation.

Early season boll shedding and deformed boll shape problem has been analyzed and is correlated with abnormal weather conditions and agriculture practices followed in the affected area. According to Monsanto, early season cold temperatures and multiple applications of Roundup Ultra at a slow growth period may have caused excessive shedding and change in the boll shape.

Monsanto has increased the technology fee for Roundup Ready varieties to US$17-22 for 1998/99. It is expected that Roundup Ready varieties may be planted on over 1.8 million hectares during 1998. There are no doubts about the technology and effectiveness of both herbicide tolerant genes in cotton; however, excessive shedding or any other abnormal behavior needs to be monitored and analyzed carefully.

• What is Cavitomic Cotton?

All cottons contain some amount of waxes, sugars and microorganisms but under normal conditions they are not harmful. Natural waxes help in smooth processing of fibers and usually are not a problem. On the other hand, the amount of sugars is often increased by whitefly and aphid infestations and results in production of sticky cotton. The activity of microorganisms can also increase on the primary wall that result in cavitomic cotton. The cavitoma condition emerges from the increased microbiological activity due to rains and high humidity in the microclimate of the plant. Rank growth and excessively broad leaves help to maintain high humidity around open bolls which enhances the microbiological activity and fibers get infected.

Cavitoma may affect fiber length, strength and consequently results in interruption of the spinning process. Spinning waste may be increased and, in the case of severe effects, yarn quality may also be affected. Unnecessary microbiological activity on the cotton fiber may also change the fiber color and produce low grade cotton.

Methods are available to test cotton for cavitoma. Perkins and Brushwood in their paper published in the Proceedings of the 1997 Beltwide Cotton Conferences of the National Cotton Council of America have critically reviewed the methods to test cavitoma. Current methods are based on reaction to acid-base indicators and fluorescence effect under UV light. Reports indicate that cavitomic cotton can be mixed with normal cotton to avoid cavitoma effects.

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