Discover natural fibres 2009

THE ICAC RECORDER

International Cotton Advisory Committee

Technical Information Section

VOL. XXVI No. 1
MARCH 2008

Update on Cotton Production Research

Contents

Introduction

Global warming will have consequences for cotton production. An article entitled 'Global Warming and Cotton Production – Part I' published in the December 2007 issue of *THE ICAC RECORDER,* discussed the impact of increases in temperature and atmospheric carbon dioxide on cotton production. There is a possibility that some areas will benefit from increases in temperatures but in general negative effects will be much more pronounced and wide spread. The first article in the current issue of the *ICAC RECORDER* is on a more specific situation in Turkey. A team of researchers from the Çukurova University in Adana have contributed the article 'Climate Change Effects on Cotton Production in the Seyhan River Basin of Turkey.' The average temperature in Turkey increased in the cotton-growing season (April–October) by around 1.12^{0}C between the 1930s and 2000s. Researchers used field data to examine the effect of the change on cotton. The experiments were undertaken in the Seyhan basin of Turkey between 1970 and 2007. The results show that the growing period of cotton decreased with the increase in temperature, and higher temperatures in the presence of decreased water availability resulted in a considerable decrease in cotton yields. The data also showed that as degree-days increased, yields decreased because of the shortening of the growing period and the increase in the average temperature. Thus, higher temperatures induced growth but had a negative effect on cotton yields.

Organic fertilizer use is on the decline. The costs of commercial fertilizers used to grow cotton are on the increase. ICAC's cost of production data show that on average a cotton grower spent 23 cents on fertilizers to produce a kilogram of lint in 2006/07. Costs of other inputs including insecticides were significantly lower than fertilizer costs. There is a drastic variation among countries in the amount of nitrogen applied to cotton. Argentina, Northeast region of Brazil, Ethiopia, Mozambique, Tanzania, Uganda and Zambia have cotton production systems where most of the cotton area is not treated with fertilizers. Farmyard manure is commonly used in China (Mainland), particularly in the Yellow River Valley and Yangtze River Valley where land holding are small. Egypt, India and Mali are other countries where farmyard manure is still used on almost half of the cotton area. The increased use of nitrogenous fertilizers makes it difficult to maintain a healthy balance between vegetative and reproduction growth. There is a need to explore non-traditional sources of nutrition in agriculture that are less expensive and environmentally sustainable.

The third article is on Biotech Cotton: Benefits and Concerns. ICAC estimates that biotech cotton was planted on 44% of the world cotton area in 2007/08, accounting for 51% of production and 48% of cotton traded internationally. Biotech crops were planted on 114.3 million hectares in 2007/08, and cotton was only 13% of the total biotech crop area. The countries that have officially approved commercial production of biotech cotton are Argentina, Australia, Brazil, China (Mainland), Colombia, India, Indonesia, Mexico, South Africa and the USA. It is expected that Burkina Faso will approve insect-resistant biotech cotton for commercial production before the start of the 2008/09 season. India has reaped the maximum benefit of biotech cotton. Cotton yields have increased by 80% in six years from 308 kg/ha in 2001/02 to 555 kg/ha in 2007/08. Conventional breeding and biotech cotton are complimentary to each other. Insect resistant biotech cotton has been used as an alternative to insecticide for controlling lepidopteron insects. There is a need to enhance the use of insect resistant biotech cotton as an important component of integrated pest management systems. However, the cost of biotechnology is limiting its spread to more countries. Many countries still have a very cautious approach toward biotech products. All these issues are discussed in the third article.

This issue also includes a short note on farm structure in the USA and how it has changed over the years.

4TH MEETING OF THE ASIAN COTTON RESEARCH AND DEVELOPMENT NETWORK

(See announcement on page 19)

The ICAC RECORDER (ISSN 1022-6303) is pulbished four times a year by the Secretariat of the International Cotton Advisory Committee, 1629 K Street, NW, Suite 702, Washington, DC 20006-1636, USA. Editor: M. Rafiq Chaudhry <rafiq@icac.org>. Subscription rate: $195.00 hard copy, $160.00 electronic version.

Climate Change Effects on Cotton Production in the Seyhan River Basin of Turkey

Burçak Kapur, Rıza Kanber, Mete Özfidaner, Servet Tekin, Mustafa Ünlü and D. Levent Koç
Çukurova University, Agricultural Structures and Irrigation Department, Adana, Turkey

Cotton occupies a crucially important place in the agriculture, industry and trade sectors of Turkey's economy. Climate conditions are of the utmost importance in cotton farming. Cotton grown in some future environment may be subjected to a climate for which it was not developed and cultivated. In this regard, climate changes, associated with the accumulation of greenhouse gases, are expected to have a profound affect on agricultural sustainability in Turkey. There has been an active debate whether global warming will result in a net gain or net loss for Turkey's agriculture. Accordingly, a team of researchers in Turkey used field experiment results to examine the effects of climate change on cotton. These experiments were undertaken in the Seyhan Basin between 1970 and 2007. The results indicate that the length of time needed for maturity decreased with the increase in temperature. Conversely, higher temperatures in the presence of decreased water availability produced a considerable decrease in cotton yields.

Introduction

Cotton production is very important economically for Turkey, which accounts for 4.3 % of the global trade in raw cotton. With production of about 820,000 tons from 700,000 hectares, Turkey ranked as the seventh largest cotton producing country in 2006/07. Cotton area in Turkey has always been variable within a range of 10-15% but has never reached one million hectares. Average cotton yields improved during the 1980s and 1990s. The average yield in Turkey was 1,171 kg/ha in 2006/07, compared to world average of 754 kg/ha. Cotton yields were exceptionally high in Brazil in 2006/07, but normally Turkey lags behind only Australia and Israel in national average yields. Cotton production in Turkey increased in the last two-plus decades spurred on by advances in technology (http://www.tzob.org.tr/tzob/tzob_urun_rapor/rapor_2003_pamuk.htm). Thus, given the economic importance of cotton, exploring how it may fare under climate conditions likely to develop later this century, is an important research endeavor.

In the last 100 years or so, the earth's surface and the lowest part of its atmosphere have warmed on average by about 0.6^{0}C (Jones *et al.*, 1999). During this period, the amount of greenhouse gases in the atmosphere has increased, largely as a result of the burning of fossil fuels for energy and transportation, and land use changes. In the last 20 years, awareness has grown that these two phenomena are, at least in part, closely associated, i.e., global warming is now considered most probably due to man-made increases in greenhouse-gas emissions (Hansen *et al.*, 1998). While other natural causes, including changes in the amount of energy coming from the sun and shifting patterns of ocean circulation, can cause the global climate to change over similar periods of time, the balance of evidence now indicates that there is a discernible human influence on the global climate (Crowley, 2000).

The warming trend is expected to continue in the near future (about $3\text{-}5^{0}$C within the next 100 years) and there is strong concern about the impact that such a change will have on the earth's ecosystems, as well as on human life and activity in the different regions of the planet (IPCC, 2001). On the other hand, projected precipitation patterns are more uncertain: globally, some models show decreases, while others show increases (IPCC, 2001). Thus, future global climate may alter climatological and hydrological conditions in arid regions bringing about substantial changes in temperature, rainfall and evapotranspiration. Thus, vulnerability of agricultural productivity in dryland regions is mainly determined by temperature and precipitation change during vegetation period.

The impact of climate change on cotton at elevated temperatures and enriched CO_2 conditions has been determined in controlled field trials and environment experiments (Reddy *et al*,. 2002). These experiments have revealed increases and decreases in boll weights and other yield factors which depend on certain temperature conditions (Reddy *et al.*, 1997a). It was found that variations of CO_2 levels between 550 and 650 ppm could produce 35-60 % increases in yield under current weather conditions and with varying amounts of irrigation (Kimball and Mauney, 1993; Pinter *et al.*, 1996) in earlier studies. Higher CO_2 levels also created higher stomatal resistance thereby decreasing water use per unit leaf area. However, some studies revealed that canopy water use levels per unit of land area remained constant under field conditions. A combined experiment involving elevated temperatures and a controlled CO_2 environment found that at five different temperature levels, with no water or nutrient limitations, boll and square production increased an average of 44% at CO_2 levels of 720 ppm as compared to 360 ppm (Reddy *et al.*, 1997a). Cotton growth and yields are optimal in warm and temperate climates with average temperatures of 26 to 28^{0}C (Reddy *et al.*, 2002). Future elevated temperature and CO_2 conditions may be beneficial to cotton productivity provided the threshold levels for the decrease of photosynthesis rates and the occurrence of premature boll abscission and other environmental stresses are not reached (Reddy *et al.*, 2000). Smaller bolls and lower yields may also come about as a result of higher summer temperatures (Reddy *et al.*, 2000). Water stress levels will most probably increase under the projected climate change conditions unless higher amounts of precipitation prevail in the future. Future cotton yields may have to cope with changing soil types and properties and the baseline climate.

The issue of adaptation to climate change has recently been the subbject of many studies related to the estimation of agricultural productivity under climate change. The research conducted on adaptation to climate change takes into account the changes that must occur in crop management practices, such as planting dates, choice of varieties and different irrigation method. Researchers have often found that the hazards of climate change may be mitigated by such procedures (Brown and Rosenberg, 1999; Gitay *et al.*, 2001).

Despite the numerous modeling studies, only a few have dealt with the impacts of climate change on the yield of cotton and none of these were reported in the recent assessment (Gitay *et al.*, 2001) by the UN Intergovernmental Panel on Climate Change (IPCC). Dudek (1989) conducted one of those studies using an agro-ecological zone methodology to assess the impact on cotton production in California of a double CO_2 environment from two global circulation models. In that study the projected yield change was found to be negative in the estimated climate change conditions without CO_2 enrichment; conversely, it was found to be positive when CO_2 enrichment was included. The determination of the yield changes that may be expected under climate change conditions were overlooked in a study addressing the effects of climate change and elevated CO_2 levels on the mechanistic evapotranspiration (ET) of cotton by the Energy and Water Balance (ENWATBAL) model. The COTTAM model (Jackson *et al.*, 1988) was used to simulate the effects of climate change on cotton throughout the USA (Mearns *et al.*, 2000). In later work, Reilly *et al.* (2001) used the yield changes in an economic sensitivity analysis disregarding the simulations of the observed deleterious effect of high temperature on yields. Thus, with these approaches, the main objective of the present study was to assess the impact of increased temperature and decreased precipitation on cotton production in the Seyhan Basin in Turkey.

Material and Methods

The study took into account numerous field experiments in cotton which were conducted in the Seyhan Basin to examine the sensitivity of cotton yields under increased temperature and decreased precipitation. These studies were published in the Regional Soil-Water Research Institute –RSWRI (Research Reports of 1972, 1974, 1978, 1979, 1981, 1982, 1987, and 1992). Furthermore, the three-year experimental results (2005, 2006 and 2007) of the Deficit Irrigation for Mediterranean Agricultural Systems (DIMAS) Project were take into consideration. This project was designed to help reduce the consumption of water by crops in the irrigated lands of the Mediterranean Basin so as to release water resources for other uses in the basin.

Study Area

The Seyhan River Basin (Figure 1), with an area of about 25,000 km^2 is located in a semi-arid part of Turkey with a significant water and land resource potential. The area is bordered by the Mediterranean Sea on the south, the foothills of the Taurus Mountains on the north, the Berdan River on the west and Seyhan River on the east. Almost the entire basin is located in the Mediterranean climate zone, with hot and dry summers, and mild wet winters and winter precipitation in the vicinity of 700 mm annually. The maximum, minimum and average temperatures are 45.6^{0}C, 8.1^{0}C and 18.7^{0}C, respectively.

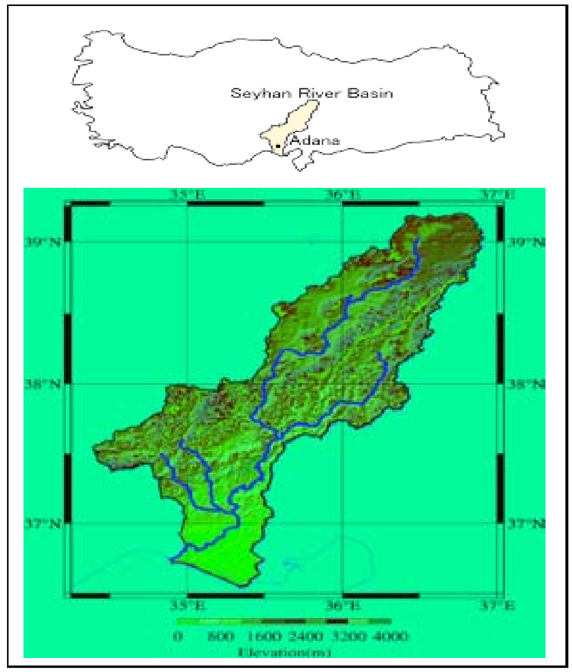


Figure 1. The Seyhan River Basin, Turkey

Meteorological Data

Climatic data for this study were obtained from the Turkish State Meteorological Service's meteorological stations located in the Seyhan Basin. This data set starts from 1930 and continues to 2007.

Mann-Kendall Trend Test

Mann-Kendall (MK) tests are non-parametric tests used to detect trends in time series. Trend analyses of time series of environmental data are often carried out to assess human impact on the environment under the influence of natural fluctuations in temperature, precipitation and other factors that may affect the studied response variable (Libiseller, 2002). Researchers examined the trend in monthly temperature (1930-2003) and precipitation (1932-2002) during the cotton-growing period using the Mann-Kendall trend test in the study area.

Table 1. Average Temperature of Cotton Growing Months

	Average Temperature During Cotton Growing Months (^{0}C)							
Year	April	May	June	July	Aug.	Sept.	Oct.	Average
1930-1939	16.76	21.08	24.78	27.53	28.18	25.2	21.3	23.38
1940-1949	16.51	21.34	24.82	27.37	27.78	24.98	20.21	23.12
1950-1959	17.13	20.81	25.19	27.58	28.14	25.13	20.47	23.33
1960-1969	17.14	21.21	25.26	27.62	28.1	25.16	20.78	23.45
1970-1979	17.4	21.6	25.41	27.85	27.74	25.66	21.34	23.7
1980-1989	17.78	21.5	25.26	28.06	28.21	26.23	21.08	23.85
1990-1999	17.5	21.66	25.44	28.09	28.42	26.19	21.56	23.95
2000-2007	17.79	21.54	26.82	29.08	28.97	26.41	21.53	24.44
[2000-2007]-[1930-1939]	1.02	0.45	2.05	1.55	0.79	1.21	0.23	1.12

Table 2. Total Precipitation of Cotton Growing Months

	Total Precipitation of Cotton Growing Months (mm)							
Year	April	May	June	July	Aug.	Sept.	Oct.	Total
1932-1941	35	44.47	16.92	4.66	6.63	11.91	54.29	173.88
1942-1951	34.66	57.74	14.78	5.57	4.69	31.21	50.39	199.04
1952-1961	49.79	39.88	18.22	0.47	4.63	8.48	24.81	146.28
1962-1971	64.71	50.48	24.1	3.57	1.09	11.19	26.79	181.93
1972-1981	76.73	42.68	25.88	7.25	4.56	14.34	44.91	216.35
1982-1991	40.74	39.73	24.47	8.38	7.62	12.43	63.62	196.99
1992-2001	57.03	54.96	13.66	11.11	8.55	17.93	38.41	201.64

Table 3. Mann-Kendall Test Results for Detecting Temperature (1930-2003) and Precipitation (1932-2002) Trend in a time Series

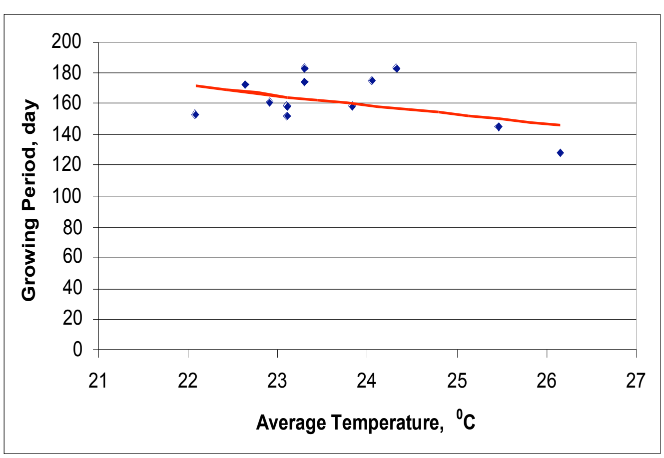
Cotton Growing Period	April	May	June	July	August	September	October
Temperature	1.71	2.504*	3.782*	3.975*	2.049*	3.589*	1.964*
Precipitation	1.578	0.352	0.01	0.179	0.372	0	-0.144

*Trends significant at the 5% level ($-1.96 \geq Z \geq +1.96$) are marked by solid triangles

Results

The data from the meteorological stations revealed that the average temperature increased during the growing season (April–October) by around 1.12^0C between the 1930s and 2000s. The highest increase was detected in June with 2.05^0C. Furthermore it is evident that there is a temperature increase at an interval of one decade (Table 1). However, researchers found precipitation increases/decreases between the decades, but did not identify any trend (Table 2).

Figure 2. Relationship Between Average Temperatures and Growing Period in Days (Experimental results of 13 years)

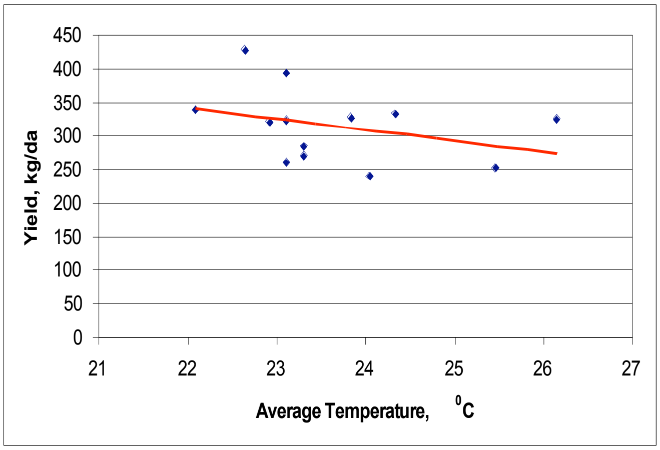


Additional time series of annual temperature and precipitation by Mann-Kendall trend analysis are reflected in Table 3. The results show that increases in temperature from 1930 to 2003 were statistically significant (at 5%) for May, June, July, August, September and October for the study area. No significant precipitation trend was detected between 1932 and 2002. In September there was no trend at all.

The figures 2, 3, 4 and 5 come from numerous cotton field experiments conducted in the Seyhan Basin to examine the sensitivity of cotton yields under increased temperature and decreased precipitation. Figures 6 and 7 come from DIMAS project, because the number of entries is different in charts.

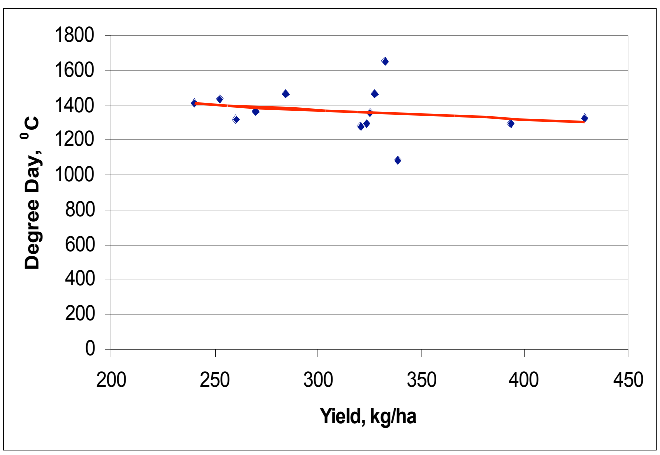
The impact of climate change in the form of temperature increase and precipitation decrease was tested experimentally in field conditions for a 13-year period revealing a considerable reduction in cotton yields. Figure 2, which includes the field studies done by DIMAS and by the RSWRI, illustrates the shift toward shorter growing periods, and with it the effect of climate change, with an increase in average temperatures during the cotton growing period. This leads to a decreased yield in cotton as illustrated in figure 3.

Figure 3. Relationship Between Average Temperatures and Yield of Cotton



The studies conducted at DIMAS and RSWRI have revealed the relationship between yield and degree-days: as degree-days increased yields decreased, because of the shortening of the growing period and the increase in the average temperature. Thus, the shorter periods induced growth but had a negative effect on cotton yields (Figure 4).

Figure 4. Relationship Between Yield of Cotton and Degree Day



Da=dacare is 1/10 of ha.

Furthermore, the shortening of the growing period reflects an increase in temperature in the course of time due to the effect of the changing climate (Figure 5). The findings of the field experiments done by DIMAS and RSWRI are consistent with the studies conducted elsewhere in regions with similar Mediterranean basin climate conditions by Reddy *et al.,* (2000). The 6–10 % decrease in cotton yield observed as a result of an increase of 1^0C during the growing season is consistent with the findings of Rosenzweig and Tubiello (1996), which indicated yield decreases due to higher daily temperature without CO_2 enrichment. Additionally, Haim *et al.* (2007), found that under the IPCC A2 climate change scenario, an average increase of 5^0C could reduce cotton yields by 52%.

The DIMAS field measurements indicated that the leaf water potential (LWP) decreased causing a parallel reduction in cotton yields (Figure 6). Hence, precipitation will probably decrease as predicted by the climate change scenarios that have been developed in connection with determination of global losses in cotton yield.

Furthermore, in additional experiments conducted at DIMAS higher cotton yields were obtained under well-watered conditions than in water stressed conditions. The average LWP in well-watered conditions was determined to be -17 bars for a yield of 3,900 kg/ha, whereas water-stressed conditions of -21 bars a produced a yield of only 2,700 kg/ (Figure 7).

Figure 5. The change of the growing period with time

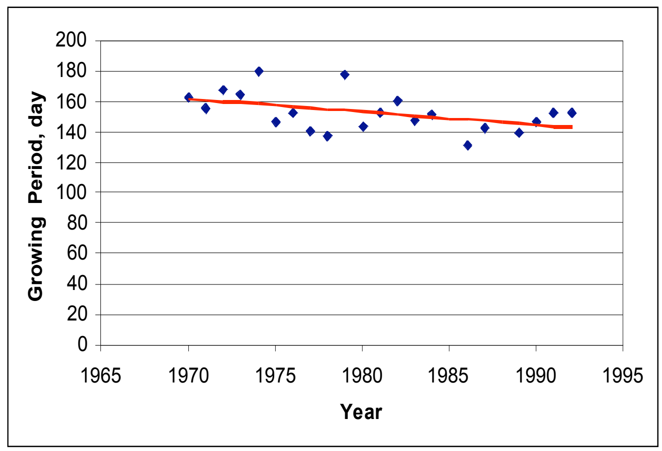


Figure 6. The relation between the leaf water potential (LWP) and yield

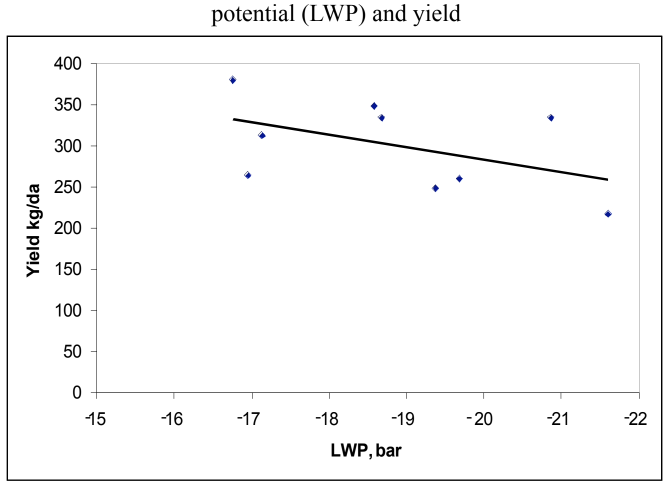
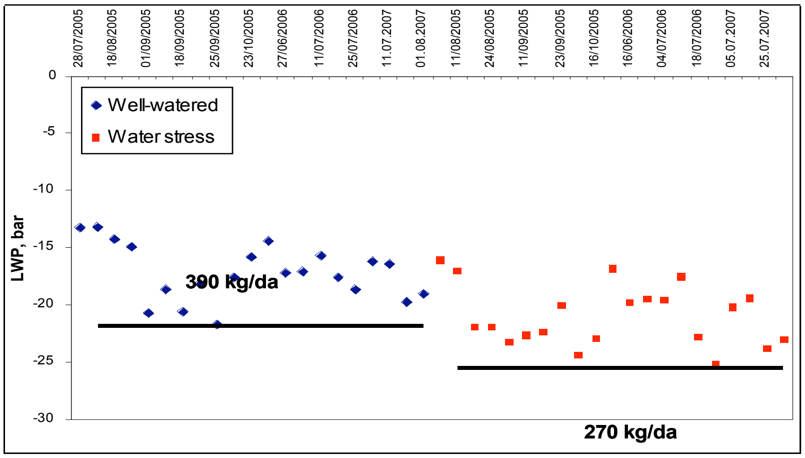


Figure 7. Relationship Between Leaf Water Potential and Yield under Two Irrigation Treatments



(da=dacare is 1/10 of ha.)

Conclusions

The results of the experiments reviewed above indicate the probable changes that may occur in cotton yields under the water-stressed conditions and increasing temperatures that may be expected as a result of climate change. These studies, however, did not take into account the probable results of the interaction produce by increasing CO_2 in the presence of higher temperatures and water stress. The findings of adaptation experiments confirmed the need for supplementary agricultural practices. These strategies are given below:

- Modification of cropping pattern by using different crops and varieties more tolerant to water stress.
- Changes in farming practices to conserve soil moisture and reduce runoff.
  - Land leveling.
  - Bench terracing.
  - Deep plowing.
  - Contour cropping to slope.
- Improvements in management practices in order to increase water use efficiency.
  - Use of non-conventional water resources (saline and treated waste water)
  - Improve performance of water distribution network.
  - Concentrate irrigation during the most sensitive period
  - Change existing irrigation system to more efficient systems like drip-irrigation.
  - Use lower planting densities.
  - Advance sowing dates to offset moisture stress during warm period.

References

Brown, R. A. and Rosenberg, N. J. 1999. Climate Change Impacts on the Potential Productivity of Corn and Winter Wheat in their Primary United States Growing Regions. *Clim. Change* 41, pp. 73-107.

Crowley T. J. 2000. Causes of Climate Change over the Past 1000 Years. *Science* 289: pp. 270-277

Douglas E. M, Vogel R. M, Kroll C. N. 2000) Trends in Floods and Low Flows in the United States: Impact of Spatial Correlation. *Journal of Hydrology* 240: pp. 90-105.

Dudek, D. J. 1989. Climate Change Impacts upon Agriculture and Resources: A Case Study of California', in Smith, J. and Tirpak, D. (eds.), The Potential Effects of Global Climate Change on the United States, Appendix C: *Agriculture*, Vol. 1, EPA-230-05-89-053.

Gitay, H., Brown, S., Easterling, W., and Jallow, B. 2001. Ecosystems and their Goods and Services, in McCarthy, J. J., Canziani, O. F., Leary, N. A., Dokken, D. J., and White, K. S. (eds.), *Climate Change 2001: Impacts, Adaptation and Vulnerability*, Chapter 5, pp. 234–342.

Hansen J. E., Sato M., Lacis A., Ruedy R., Tegen I. and Matthews E. 1998. Climate Forcing in the Industrial Area. *Proc. Natl. Acad. Sci.*, USA, 95: pp. 12753-12758

Hirsch R. M., Slack J. R. 1984. A non-Parametric Trend Test for Seasonal Data with Serial Dependence. *Water Resources Research* 20: 727–732.

http://www.tzob.org.tr/tzob/tzob_urun_rapor/rapor_2003_pamuk.htm

IPCC. 2001. Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Houghton J. T., Ding Y., Griggs D. J., Noguer M., Van der Linden P. J., Dai X., Maskell K., Johnson C.A. (eds). Cambridge University Press, Cambridge, UK and New York, NY, USA, 881 p.

Jackson, B. S., Arkin, G. F., and Hearn, A. B. 1998. The Cotton Simulation Model "COTTAM": Fruiting Model Calibration and Testing. *Transactions of the ASAE* 31, pp. 846-854.

Jones P. D., New M., Parker D. E., Martin S., and Rigor I. G. 1999. Surface Air Temperature and Its Changes over the Past 150 Years. *Rev. Geophys*., 37: pp. 173-199

Kimball, B. A. and Mauney, J. R. 1993. Response of Cotton to Varying CO_2, Irrigation, and Nitrogen: Yield and Growth. *Agron*. J. 85, pp. 706–712.

Libiseller, C., and Grimvall A. 2002. Performance of Partial Mann-Kendall Tests for Trend Detection in the Presence of Covariates. In: *Environmetrics* DOI: pp 71-84

Mearns, L. O., Carbone, G., Gao, W., McDaniel, L., Tsvetsinskaya, E., McCarl, B., and Adams, R. 2000. The Issue of Spatial Scale in Integrated Assessments: an Example of Agriculture in the Southeastern U.S., in Preprints of the 80th AMS Annual Meeting, 11th Symposium on Global Change Studies, January 9–14, 2000, Long Beach, CA, American Meteorological Society, Boston, pp. 38-41.

Partal, T., and Kahya E. 2006. Trend Analysis in Turkish Precipitation Data. *Hydrological Processes* 20, pp. 2011-2026.

Pinter, P. J. Jr., Kimball, B. A., Garcia, R. L., Wall, G. W., Hunsaker, D. J., and LaMorte, R. L. 1996. Free-Air CO_2 Enrichment: Responses of Cotton and Wheat Crops" in Koch, G. W. and Mooney, H. A. (eds.), Carbon Dioxide and Terrestrial Ecosystems, Academic Press, San Diego, CA, pp.215-249.

Reddy, K. R., Doma, P. R., Mearns, L. O., Bonne, M. Y. L., Hodges, H. F., Richardson, A. G., and Kakani, V. G. 2002. Simulating the Impacts of Climate Change on Cotton Production in the Mississippi Delta. *Clim. Res.* 22, pp. 271-281.

Reddy, K. R., Hodges, H. F., and Kimball, B. A. 2000. Crop Ecosystem Responses to Global Climate Change: Cotton, in Reddy, K. R. and Hodges, H. F. (eds.), *Climate Change and Global Crop Productivity*, Chapter 8, CAB International, U.K., pp. 161-187.

Reddy, K. R., Hodges, H. F., and McKinion, J. M. 1997a. Crop Modeling and Applications: A Cotton Example, in Sparks, D. L. (ed.), *Advances in Agronomy*, Vol. 59, Academic Press, San Diego, CA, pp. 225-290.

Reilly, J. M. and U. S. National Assessment Agriculture Sector Team. 2001. Agriculture: The Potential Consequences of Climate Variability and Change for the United States, Cambridge University Press, Cambridge, U.K., 136 p.

Rosenzweig, C., Tubiello, F. N. 1996. Effects of Changes in Minimum and Maximum Temperature on Wheat Yields in the Central U.S.A. Simulation Study. *Agric. For Meteorol* 80: pp. 215–230.

Nitrogen Fertilization in Cotton

Plants require nutrients from the soil to grow, bear fruit and mature. Nutrients in soil are much like a deposit in the bank. If you only withdraw money without making deposits, very soon the account will be empty and your checks will start to bounce. Soils get depleted if nutrients are not added. Fortunately, there are some natural mechanisms of nutrient fixation in the soil so that they do not get completely depleted like a bank account. However, growth and fruit formation are seriously affected if there is a shortage of nutrients or if there is an improper balance of nutrients in the soil.

It may rightly be claimed that fertilizers have been inadvertently used to grow crops ever since agriculture began. What is new in fertilizing techniques is the introduction of synthetic fertilizers, which have revolutionized agriculture. Synthetic inorganic fertilizers were introduced almost a century ago and have been commercially available in most countries over the last 60-70 years. The adoption of fertilizers in most countries coincided with the development and introduction of short stature varieties of rice and wheat, which emerged together to form the 'Green Revolution.' Short stature cereal varieties were able to tolerate higher does of nutrients, particularly nitrogen, that boosted yields. There is no doubt that soils were starving without external nutrient supplies. Just try to imagine for a moment what would happen to the Green Revolution if we were to eliminate synthetic fertilizers from current production systems. On the other hand, overloading soils with un-necessarily heavy doses of nutrients translates into uneconomical, inefficient and environmentally unfriendly uses of fertilizers.

Fertilizer Classification

Fertilizers can be divided into four major categories: granular (dry) fertilizers, liquid fertilizers, synthetic fertilizers, and organic fertilizers. Granular fertilizers have become the most commonly used fertilizers in agriculture. Granular fertilizers can be made to release nutrients slowly or quickly, depending on their chemical composition. Liquid fertilizers can supply the same quantities of nutrients as granular fertilizers but they differ in the method of application. Liquid fertilizers may be applied alone by spraying them over crops from tanks, or they may be delivered by adding them to irrigation water. When applied by spraying, liquid fertilizers can only provide nutrients in much lower doses due to the burning effects they can produce. Synthetic fertilizers are usually manufactured in chemical plants and are used to provide nutrients in measured doses for quick fixes of nutrient deficiencies. Organic fertilizers are the original fertilizers. They are safer and capable of sustained effects. Synthetic granular fertilizers are considered to be unsustainable and damaging to the environment and, hence, are not permitted in certified organic production systems.

Nitrogen and Its Impact

Nitrogen is one of the three major nutrients that are indispensable for normal plant growth. Nitrogen enhances plant growth, increases fruit formation (flowers, seeds or any other reproductive forms), production and quality. In the case of those crops where the seed, fiber or fruit output is not an issue, such as the case of forage leaf crops, quality is also improved. However, major nutrients such as nitrogen do not become available to the plant until the applied fertilizer has gone through a physical, and in some cases chemical and microbial, breakdown process. These processes depend on external factors such as soil temperature, soil moisture, pH and microbial activities in the soil. Nitrogen applied in the form of ammonia, or any other form, must be converted into nitrite or nitrate (nitrification) before it is capable of being absorbed by plants. The nitrification process may take longer when the soil is dry or when it is too wet. For the most efficient use of nitrogen and other nutrients, it is necessary to keep soil pH in the range of 6 to 6.5. If soil pH drops below 5.5, it will have a negative effect on the cost efficiency of the money spent on fertilizers, and toxicity becomes a concern. And if pH goes higher than 7.0, it will also lower fertilizer efficiency. The other factors mentioned above can also have consequences for the nitrification process.

The nitrification process can be controlled, and one of the technologies used to achieve that goal is coating the urea with a polyolefin containing a surfactant that allows for a predictable and measured release of nitrogen. Slower release of nutrients into the soil can optimize nutrient uptake and lower fertilizer doses. Oosterhius and Howard (2008) studied the effect of slow-release nitrogen and potassium fertilizers and observed that cotton yields were not reduced when the nitrogen rate was reduced to 60% of the recommended rate and applied as Meister programmed slow-release nitrogen. Yields were reduced, when nitrogen applications were further reduced to only 40% of the recommended rate. Similarly, in-furrow applications of the slow-release potassium (K) at 60% of the recommended rate did not affect yields. Oosterhius and Howard (2008) observed that programmed-release of soil-applied fertilizers can potentially allow for a one-time fertilizer application at planting with no detrimental effects on seedling germination, growth or yield. The nutrient efficiency rates of the slow-release materials were further corroborated by their ability to maintain high yields at reduced fertilizer application rates.

The most obvious symptom of nitrogen deficiency in cotton is the yellowish green color of leaves . Discoloration appears in the older leaves, but nitrogen deficiency will also become evident in the reduced size of younger leaves. Other symptoms of nitrogen deficiency in cotton are: reduced plant height, shorter fruiting branches, and shedding of fruiting forms (buds, flowers and young bolls). Early season nitrogen deficiency can delay flowering by increasing the time to first bloom and by increasing the time interval between the appearances of flowers on the same fruiting branch. However, when these nutrient deficiency symptoms become visible, damage has already occurred. Thus, it is important to analyze soil samples before planting and take necessary measures to add fertilizers before and after planting. Techniques are available to help identify the status of nitrogen in the soil before damage occurs. One simple approach is to monitor crop development and compare it with the pattern of normal growth without nitrogen deficiency. A reliable measure of crop vigor can be obtained from the plant's height–to-node ratio. The height is taken as a simple measurement of the distance from the cotyledon nodes, or base of the plant, to the terminal, and then counting the number of main stem nodes. Jeffrey C. Silvertooth (2001) of the University of Arizona, USA has discussed some of these approaches. There is no doubt that fruit load is related to the nitrogen supply available to the plant, but greater fruit loads demand more nitrogen, thus making it necessary to continuously monitor the nitrogen need of plants and its availability in the soil. The most significant advantage of precision agriculture is the effective use of inputs, including fertilizers. Accurate nitrogen application is one of the foremost benefits of precision agriculture as it allows farmers to apply variable rates of nitrogen even within a single field.

Another approach, which is more popular among cotton researchers, is to estimate the nitrogen status of soil by measuring petiole nitrate nitrogen. It is known that petiole nitrate nitrogen is a good indicator of the relative amounts of un-used nitrate nitrogen and phosphorous in the plant's vascular system. It is generally accepted that if at the moment of peak flowering, nitrates are decreasing and phosphorus is increasing, it is an indication of adequate moisture, heavy fruiting and rapid use of nitrogen. When both nitrates and phosphorus are decreasing, this is an indication of drought stress. A sharp increase in both is an indication of imbalance between vegetative and reproductive growth and poses an increased threat of pest attack. When nitrates are increasing and phosphorus is decreasing, it indicates that, although moisture may be adequate, fruiting is poor, and fruit loss is possible.

Sources of Nitrogen

Natural nitrogen fixation, farmyard manure, green manuring, plant residue and inorganic fertilizers are the key sources of nitrogen supply to the soil. Inorganic sources have come to be relied upon in recent years as the primary sources of nutrients for the recuperation of soil nutrition capabilities. Plants can capture nitrogen from the atmosphere. Structurally, molecular nitrogen (N_2) has five electrons in the outer shell and is therefore trivalent in most forms. The triple chemical bond prevents gaseous nitrogen in the atmosphere from bonding with other elements. Nitrogen gas simply does not participate in any chemical reaction at standard atmospheric temperature and pressure. On the other hand, plants can make use of atmospheric nitrogen, but only if it is fixed with other elements, which means that nitrogen atoms in that form can combine with other elements. The only two natural phenomena that can fix nitrogen are lightning and bacteria. Lightning frees nitrogen molecules that then combine with oxygen and become a nitrate, NO_3—a form of nitrogen that plants can absorb. According to some estimates, lightening contributes about 10 million metric tons of total fixed nitrogen per year, which can be used by plants and animals. Some bacteria convert molecules of nitrogen trapped in air pockets in the soil into ammonia (NH_3), which other types of bacteria then convert into nitrates. Scientists estimate that microorganisms add approximately 140 million metric tons of fixed nitrogen to the soil every year. Now, through science, mankind has acquired the ability to fix nitrogen industrially to speed productivity.

The two ways that nitrogen applied to the soil can be lost are: denitrification; and water run off or leaching due to deep drainage. The physical losses may be minimal, but the consequences are serious. Drainage is a direct pollutant of underground water. The denitrification process pollutes the environment through release of nitrite. According to Knox and Vadakattu (2007), nitrate is also used by many microbes when oxygen is limited. This tends to occur under wet soil conditions and is responsible for denitrification, which results in the release of nitrogen from the soil as nitrite, a potential greenhouse gas. Heavy doses of nitrogen can enhance leaching as well as the denitrification process.

Nitrogen Use in Various Countries

Nitrogen and phosphorous are indispensable elements wherever fertilizer is used. But, there are countries where potassium is not recommended, and when it is used, it simply adds to the cost of production with no impact on yield or fiber quality. This happens when the availability of potassium in the soil is high enough. Examples include countries where cotton follows wheat or other crops to which potassium fertilizer was applied; it is usually not recommended to apply additional fertilizer to the cotton. However, experiments have shown that potassium needs are at their peak at the time of boll maturity and under extremely high yield farming conditions; foliar K application may have a positive impact on yield.

On the other hand, nitrogen does not stay in the soil and must be replenished, no matter what production system is used. Soil composition, nitrogen content in the soil, yield target and variety are some of the important criteria that will determine the quantity of nitrogen to be applied. The timing of nitrogen applications may vary slightly depending on crop conditions and water availability (if irrigated) or rainfall, the quantity does not vary drastically from year to year. Every three years, the ICAC undertakes a survey of cotton production practices. An updated report will be available from the ICAC Secretariat in October 2008, but the information contained in the last report published in September 2005 shows that there are drastic variations in the level of nitrogen applied to cotton.

Argentina, Northeast region of Brazil, Ethiopia, Mozambique, Tanzania, Uganda and Zambia have cotton production systems where most of the cotton area is not treated with fertilizers. This is not because there is no need for nitrogen but because planters simple have no access to fertilizers, either because of an inability to buy them or for some other reason. Organic fertilizer is used in only few countries. Farmyard manure is commonly used in China (Mainland), particularly in the Yellow River Valley and Yangtze River Valley where land holding are small. Egypt, India and Mali are other countries where farmyard manure is still used on almost half of the cotton area. In general, the use of farmyard manure is declining.

The country with the highest use of nitrogen is China (Mainland) where there is actually an over use. With 90% of the cotton area getting farmyard manure, the use of an additional 225-300 kg of nitrogen results in excessive vegetative growth. To remedy the excess growth farmers in China prune plant tips at peak fruit formation time. Trimming the growing tip diverts plant food towards sympodial growth, which results in more fruiting points and ultimately more bolls. Fertilizer doses of around 50 kg/ha or less of nitrogen are not sufficient, which may be due either to non-availability of fertilizer or inability to afford it. The table below shows that nitrogen use is close to 180 kg/ha in countries where average yields are close to or higher than one ton of lint.

Soil analysis should be the yardstick used to decide the amount of fertilizer to be applied, but this is not the case in most countries. Soil analysis is not practical when land holdings are small and farmers do not have ready access to soil testing labs. In other cases, farmers do not want to pay the fee or put up with the hassle of drawing soil samples and delivering them to a testing lab. Consequently, many growers decide the amount of fertilizer to be used on the basis of the general recommendations for the area, or they make their own decision, which may only be close to the required dose.

Most cotton plantations receive fertilizer applications at two times: before sowing and at the pre-flowering/boll formation stage. All phosphorous (P) and potassium (K) are invariably applied before or at the time of planting, while all or most of the nitrogen (N) is applied in the interval from pre-flowering to peak flowering. It is recommended to split the total nitrogen application into two doses to keep a balance between vegetative and reproductive growth. Foliar application of fertilizers is not popular but it is still practiced, particularly in Australia, Brazil, Colombia, Thailand, Turkey and Vietnam where one-fourth to half of cotton area is treated with some kind of foliar fertilizers. When a crop shows premature senescence or yellowing, a marginal or deficient level of potassium (K) is generally assumed to be the cause, but a nitrogen (N) shortage

Quantity of Nitrogen Applied to Cotton in Various Countries

Country	Quantity (Kg/ha)	Area not Fertilized (%)	Organic Fertilizer (% Area)
Argentina - Northwest	60	90	
Australia	200		1
Benin	74		
Brazil - Central West	180		
Brazil - North East	30	50	
Cameroon	42		
China (Mainland)	225-300		90
Colombia - Sinu Valley	100		
Cote d'Ivoire	50		5
Egypt	145		60
Ethiopia	46	96	
Greece	140-160		
India	85-100	20	50
Iran - Khorasan & Kerman	100		5
Israel	120-160		
Mali	44		40
Mexico	100		
Mozambique	NA	80	15
Pakistan - Punjab	75-150		10
South Africa	130	40	1
Sudan	175		
Syria	190		10
Tanzania - Western	30	70	20
Thailand	38	15	
Togo	40		5
Turkey	140-200		
Uganda	50	99	
USA	99	17	< 1
Vietnam	120		
Zambia	43	91	1
Zimbabwe	30	25	< 5

may also be the cause, and it would be necessary to apply nitrogen fertilizers quickly to remedy the deficiency.

Fertilizer Costs and Nitrogen Use Efficiency

The ICAC cost of production survey published in October 2007 shows that on average a cotton grower spent 23 cents on fertilization to produce a kilogram of lint. There is a great variation in the amount spent on fertilizers to grow a hectare of cotton, and the variation is usually reflected in yield differences, which are also huge among countries. A comparison of the data on fertilizer cost per kilogram of lint shows that China (Mainland) spends an average of 36 cents on fertilization to produce a kilogram of lint, which is the highest in the world. The addition of organic manure in China (Mainland) probably reduces or minimizes the need for inorganic fertilizers, but extremely high doses of fertilizers continue to be used on cotton.

Data were not available from Mali and Togo in 2006 but the data from three other countries in the West Africa showed that the cost of fertilizer per kilogram is higher than in many other countries. This, of course, ties in with lower yields and higher production costs, which is evident from the quantity of fertilizer applied to cotton. Benin uses slightly greater amounts, but in other West African countries the amount of nitrogen applied to cotton is around 50 kilograms. The amount spent on fertilizers in Iran is extremely low thanks to their mixed cropping system. Costs are also low in Argentina, but because only low doses of nitrogen-phosphorous-potassium (NPK) fertilizers are applied to cotton. In the northeast region of Argentina, where most cotton is grown under rainfed conditions, almost no inorganic fertilizer is used on cotton. Despite the fact that experiments have shown that applications of inorganic fertilizers can have a positive impact on cotton, growers are just not convinced that fertilizer application could help increase yields. Fertilizer costs are low in Kazakhstan and Tajikistan because of the combined effect of lower fertilizer costs, higher yields and lower doses. The cost of fertilizer per kilogram of lint is higher in Sudan due to lower yields.

The nitrogen use efficiency was measured by dividing the lint yield in kilograms/ha by the kilograms of nitrogen per ha applied to cotton. A kilogram of nitrogen produces more lint in Argentina than in any other country, but that might be due to the fact that lower doses of nitrogen have a higher cost:benefit ratio. The nitrogen impact on yield is also very high in Israel and Mexico. Irrigation water is in short supply in Israel and that is why effluent waters are processed and used for irrigation. Effluent waters are rich in nitrogen, which is not included in the 140-160 kg nitrogen applied to grow cotton. In Mexico, it is the combined effect of production technology and production conditions that results in higher yields than even in the USA. It is usually assumed that the reason for using biotech cotton is that it provides good pest control and guarantees optimum use of fertilizer. This hypothesis, however does not seem a limiting factor in India, where yields have improved by over 60% since the adoption of biotech cotton in 2002/03. The nitrogen impact on yield is not apparent in the above table because the data in the third column are for 2004/05. This information is updated by ICAC every three years, and the revised data should be available in October 2008. The extremely low impact on yield in Sudan would indicate that Sudan might be able to reduce nitrogen use on cotton and still retain the same yield level.

Fertlizer Costs and Nitrogen Use Efficiency*

Country	Fertilizer Cost (US$/ha)	Fertilizer Cost (US$/Kg lint)	Nitrogen Use Efficiency
Argentina - Northwest	37.9	0.05	13.8
Australia	198.2	0.09	9.5
Benin	113.2	0.27	5.9
Brazil - Central West	385.9	0.27	7.9
Cameroon	97.2	0.26	9.1
China (Mainland)	401.1	0.36	4.8
Colombia - Sinu Valley	171.4	0.18	8.6
Cote d'Ivoire	126.0	0.21	5.7
Egypt	175.3	0.20	6.3
India	72.0	0.12	5.7
Iran	16.9	0.02	5.2
Israel	213.8	0.13	12.1
Kazakhstan	72.8	0.07	9.9
Mali	NA	NA	8.3
Mexico	194.0	0.17	12.5
Pakistan - Punjab	94.2	0.16	6.1
Sudan	104.8	0.31	2.2
Syria	122.8	0.10	5.5
Tanzania	NA	NA	5.4
Tajikistan	74.0	0.09	NA
Thailand	43.6	0.10	11.7
Togo	NA	NA	6.9
Turkey - GAP	454.6	0.28	6.9
USA	110.1	0.14	9.2
Uzbekistan	186.8	0.20	NA
Vietnam	166.6	0.21	4.1
Zambia	101.2	0.14	5.8
Zimbabwe	NA	NA	8.7

* Lint yield in kg per ha/nitrogen fertilizer in kg/ha

The data in the above table may also be interpreted in a different way. Rochester *et al.* (2007) observed that a nitrogen use efficiency (NUE) value of 11-13 indicates that nitrogen fertilizer use was sufficient. NUE values of less than 11 indicate that excessive rates of nitrogen may have been applied. Values greater than 13 indicate that insufficient nitrogen may have applied to the crop and the crop was suffering drought stress or some other nutrient limitation that affected its development.

Nitrogen Recommendations: A Challenge

What constitutes the right amount of nitrogen for a particular area or region will depend on many factors. Varying weather conditions, soil types and production systems make it difficult to make universal recommendations for the many growers in a given region. Even a single grower may have to follow different dose protocols on his farm, depending on sowing time, variety, previous crop in the cotton field and level of other inputs to be used on cotton. Production efficiency may be at risk if nitrogen is not applied at the right time, even though the total amount of nitrogen applied during the growing season may be perfectly right. The biggest challenge is to meet the nitrogen needs of the plant as closely as possible for only then can the grower achieve the best production efficiency. The nitrogen need of the cotton plant is lowest early in the season; it picks up through early fruiting and reaches its maximum at peak flowering time. Demand for nitrogen decreases as the plant reaches the boll maturation stage. Excessive nitrogen in the soil late in the boll ripening stage might not only delay crop maturity but also affect fiber quality. Over-dosing with nitrogen at late maturity may have a positive impact on fiber length, but it will lower fiber strength and maturity.

A factor that has increased the use of nitrogen in cotton is the adoption of early maturing varieties. Early maturing varieties are usually of short stature and can tolerate higher doses of nitrogen. Unlike determinant crops, cotton runs the risk of delaying the initiation of the reproductive phase if nitrogen is applied before effective flowering or if nitrogen is applied in quantities above that recommended. Early maturing varieties have minimized this risk and shifted attention toward maintaining a balance between reproductive and vegetative growth until the target number of bolls has been formed. The other major concern regarding nitrogen over dosing is that whatever nitrogen is not taken up by the plant becomes a pollutant to underground water.

Poultry Litter as a Source of Nitrogen

There is a need to move toward non-traditional sources of nitrogen that are also environmentally friendly. The decreased use farmyard manure and more formal poultry farming in developing countries are focusing attention on poultry litter as a source of nitrogen in agriculture. Poultry litter has several advantages over nitrogen fertilizer produced from natural gas or other nutrients that are mined. Studies in the USA have shown that if the poultry farms are not too far away from cotton fields, it may be economical to use poultry litter as a source of nitrogen and other nutrients. Poultry litter contains organic matter — which commercial fertilizers do not — increasing the soil's ability to hold water and nutrients. The nitrogen in poultry litter is released slowly and is less likely to leach and contaminate underground water.

Poultry litter contains almost equal amounts of nitrogen and phosphorous. The nitrogen becomes available to cotton in a slow-release manner but the phosphorous from commercial fertilizers, being largely water-soluble, tends to percolate into the soil and bind with clay particles. Poultry litter phosphorous, on the other hand, is bound to organic matter and less subject to percolation so that microbial action in the soil slowly releases the organically bound phosphorus via a process called "mineralization." Thus, sustained use of poultry litter accumulates phosphorous in the soil unless heavy rains wash the organically bound material away before the mineralization process occurs.

Mitchell and Tu (2005) conducted experiments over a period of 13 years to study the long-term effect of broiler poultry litter on cotton and corn production under conventional and conservation practices. The specific objectives were: to evaluate poultry broiler litter as a source of nitrogen for cotton, determine the availability of nitrogen in poultry broiler litter compared with ammonium nitrate fertilizer, determine if plant growth regulators would be needed to control excessive vegetative growth of cotton fertilized with poultry broiler litter and to assess the practicality of using poultry broiler litter as an alternative fertilizer for cotton. The results showed that the addition of poultry broiler litter increased leaf blade concentration of nitrogen, phosphorous, potassium, calcium, magnesium, copper and boron as compared to a no-nitrogen check crop. Application of ammonium nitrate significantly increased the concentration only of nitrogen and sometimes magnesium. At the same rate of total nitrogen (134 kg/ha) application of both Poultry Broiler Litter and Ammonium nitrate resulted in no height differences in the early stages, but in the later stages the Ammonium nitrate produced taller plants. Over the 13-yr period, poultry broiler litter and ammonium nitrate resulted in similar yield increases when applied based on total nitrogen in both conventional till and conservation till cropping systems involving cotton and corn. The residual effect of poultry broiler litter nitrogen was prominent in the following year but produced only half as much yield as there would have been with the optimum amount of nitrogen been applied to the current crop. Fresh poultry broiler litter works out to an NPK ratio of about a 3-3-2 fertilizer, i.e. about 60-60-40 pounds N-P2O5-K2O per ton.

The continuous addition of poultry litter could produce an imbalance of soil nutrients. Charles Mitchell (http://hubcap.clemson.edu/~blpprt/chick.html) has mentioned some of these effects: a) Nitrate leaching to groundwater [extremely high doses of poultry litter in permeable soils, over seven tons/ha, may result in leaching, b) phosphorus buildup to excessive levels, c) heavy metal buildup, particularly zinc and copper, and d) high weed infestation.

The parameters would, of course, vary greatly among countries, production regions, production levels, soil types and many other factors, but on average, the production of a ton of seedcotton will consume about 90 kilograms of nitrogen, 30 kilogram of phosphorus and about 20 kilogram of potassium. Commercial inorganic fertilizers have a high cost:benefit ratio, are abundantly available, are easy to transport and store and, above all, can be tuned to meet the needs of the plant as closely as possible. The need remains, however, to explore other sources of nutrition in agriculture that are not only less expensive but environmentally sustainable.

References

Knox, Oliver and Gupta Vadakattu. 2008. Nitrogen and cotton: A microbial view. *The Australian Cottongrower*, Volume 28, No. 7, December 2007-January 2008.

Mitchell, Charles C. and Shuxin Tu. 2005. Long-term evaluation of poultry litter as a source of nitrogen for cotton and corn. *Agron. J.* 97:399-407, 2005.

Oosterhuis, Derrick M. and Donald D. Howard. 2008. Evaluation of slow-release nitrogen and potassium fertilizers for cotton production. *African Journal of Agricultural Research* Vol. 3 (1), pp. 068-073, January 2008. Available online at http://www.academicjournals.org/AJAR.

Rochester, Ian, Julie O'Halloran, Susan Maas, Doug Sands and Emma Brotherton. 2007. Monitoring nitrogen use efficiency in your region. *The Australian Cottongrower*, Volume 28, No. 4, August-September 2007.

Silvertooth, Jeffrey C. 2001. *Nitrogen Management for Cotton*. University of Arizona, Publication No. 1200, available at http://ag.arizona.edu/crops/cotton/soilmgt/nitrogen_management.html.

Technical Information Section. 2005. *Cotton Production Practices*. International Cotton Advisory Committee, September 2005.

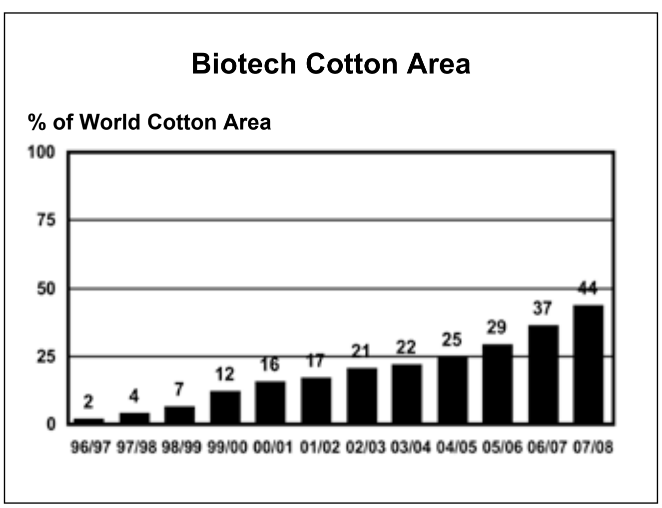
Technical Information Section. 2007. *The Cost of Production of Raw Cotton*. International Cotton Advisory Committee, October 2007.

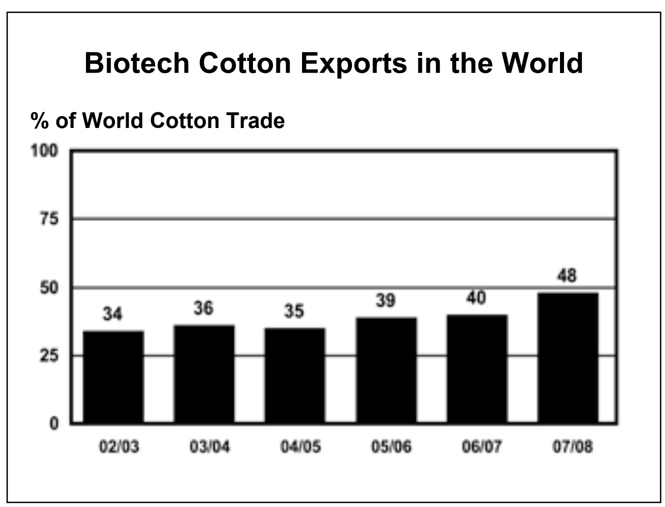
Biotech Cotton: Benefits and Concerns

The International Cotton Advisory Committee (ICAC) estimates that biotech cotton was planted on 44% of world area in 2007/08, accounting 51% of production and 48% of cotton traded internationally. The countries that have officially approved commercial production of biotech cotton are Argentina, Australia, Brazil, China (Mainland), Colombia, India, Indonesia, Mexico, South Africa and the USA. Indonesia planted biotech cotton for a few years in the 1990's, but it is not allowed any more. Many countries are experimenting with biotech cotton, particularly varieties resistant to lepidopteron insects, but Burkina Faso is the next country to commercialize biotech cotton. Burkina Faso will be planting Bollgard cotton commercially in 2008/09. In Africa, Egypt, Kenya, Tanzania, and Zimbabwe have conducted confined trials of biotech cotton but they are years away from approval. Uganda is ready to undertake confined trials in 2008/09. The National Biosafety Committee in Uganda has approved two sites, and planting will be done in May and July 2008 on the Serere and the Kasese sites, respectively.

Herbicide resistant transgenic cotton, alone and in stacked gene form, is allowed for commercial production only in Argentina, Australia, Colombia and the USA. Outside the USA, insect resistant biotech cotton is more popular than herbicide resistant varieties. Biotech varieties were planted on 90% of the cotton area in the USA in 2007/08. Biotech varieties having the herbicide resistant gene, alone and in conjunction with the insect resistant genes, were planted on over 99% of the total biotech cotton area. It is not expected that herbicide resistant biotech cotton varieties will have the governments' approval any time soon in China (Mainland), India and other developing countries. The availability of cheap labor and extensive use of cultivation practices to eliminate weeds, are responsible for the reduced interest in an herbicide resistant character.

The Technical Information Section of the International Cotton Advisory Committee has published many reports and papers on biotechnology applications in cotton. All these reports and papers are available at http://www.icac.org/icac/english.html. The application of biotechnology to crop improvement is comparatively new, and it is often misinterpreted. Genetic engineering or the development of transgenic crops is a specialized fundamental science and requires a basic understanding of how genes operate in the genome of a species. A gene is a primary unit of inheritance and once a gene is transferred into a species/variety it stays there forever and becomes a part of the genomic system. A





gene is a chemical, protein in nature, and can interact with genes of the host species/varieties. Foreign genes are inserted into cotton for specific objectives or functions to perform. However, a foreign gene could create a chain of reactions overriding the target benefit or benefits. The private sector has taken the lead and surpassed the public sector in developing and testing biotech crops. A number of crops have been transformed, and each crop has its own objective. According to the International Service for the Acquisition of Agri-biotech Applications (ISAAA) biotech crops were planted on 114.3 million hectares in 2007/08, and cotton accounted for 13% of the biotech crop area in the world in 2007.

What Is the Right Term?

A number of terms like genetically modified organisms (GMO), transgenic cotton, Bt cotton, genetically engineered cotton, etc., have been used in the popular press and even in the scientific community. Biotechnology is defined as the utilization of living organisms for the improvement of the living organisms. Biopesticides are biotech products, but they may or may not be, and mostly are not, genetically engineered. Genetic engineering technology is one process used in biotechnology. Using the technique of "gene splicing" or "recombinant DNA technology" (rDNA), scientists can add new genetic material to an existing molecular structure in living organisms for initiating a new character. Transgenic cotton has a gene from across species. The currently available biotech insect resistant varieties have a gene from a soil bacterium, *Bacillus thuringiensis,* so the varieties are transgenic and they are called Bt cotton. But, the original source of a transgene could be different, thus the name Bt is not a universal name that can be applied to all crops and varieties that are transgenic. Transgenic varieties could also be developed using non-recombinant techniques, so all varieties may not be genetically engineered. Cotton grown on a commercial scale today has already gone through drastic genetic modifications and is continuously going through additional changes. The cotton varieties, which have been transformed into transgenic varieties, were already genetically modified but now they have been genetically engineered to emerge as transgenic varieties.

Biotechnology applications in agriculture are new, and a much more is yet to come. The nature of products developed through genetic engineering, or other forms of biotechnology applications is not even known yet. So, there is a need to identify a term that is broadly applicable to current and future

Commercialization of Biotech Cotton

Biotech Cotton	Active Gene(s)	Argentina	Australia	Brazil	China (Mainland)	Colombia	India	Indonesia	Mexico	South Africa	USA
BXN™	Nitrolase										1995/96
Roundup Ready®	cp4 epsps (Mon 1445/1698)	1999/00	2001/02			2004/05			2000/01	2001/02	1997/98
Roundup Ready® Flex	cp4 epsps (Mon 88913)		2006/07							2008/09	2006/07
LibertyLink®	bar (LLCotton 25)		2006/07								2004/05
Bollgard®	cry 1Ac (Mon 531)	1998/99	1996/97 (Ingard)	2005/06	1997/98	2003/04	2002/03	2002/03	1996/97	1998/99	1996/97
Bollgard® II	cry 1Ac (Mon 531) + cry 2Ab (Mon 15985)15		2003/04			2007/08	2006/07			2006/07	2003/04
WideStrike™	cry 1Ac + cry 1F (Event 3006-210-23 + Event 281-24-236)										2005/06
Guokang	cry 1A + CpTI				1997/98		2006/07 (GFM Event)				
Roundup Ready® + Bollgard®	cp4 epsps (Mon1445/1698) + cry 1Ac (Mon 531)		2001/02			2007/08			2000/01	2005/06	1997/98
Roundup Ready® Flex + Bollgard® II	cp4 epsps (Mon 88913) + cry 1Ac (Mon 531) + cry 2Ab (Mon 15985)15		2006/07			2007/08				2008/09	2006/07
Event 1	cry 1Ac						2006/07 (Event 1)				
WideStrike™ + Roundup Ready®	cry 1Ac + cry 1F (Event 3006-210-23 + Event 281-24-236) + cp4 epsps (Mon 1445/1698)										2006/07
WideStrike™ + Roundup Ready® Flex	cry 1Ac + cry 1F (Event 3006-210-23 + Event 281-24-236) + cp4 epsps (Mon 88913)										2007/08
Liberty Link® + Bollgard® II	bar + cry 1Ac (Mon 531) + cry 2Ab (Mon 15985)15										2006/07

products. The International Cotton Advisory Committee (ICAC) decided four years ago to use the term 'biotech', which covers current and possible future outcomes of biotechnology uses in cotton.

Approved Biotech Characters

Only insect resistant and herbicide resistant genes have been approved in cotton. There are more than one insect resistant genes and more than one herbicide resistant genes that have been commercialized in various countries. Insect resistant and herbicide tolerant genes have been stacked in various combinations and selectively commercialized in different countries. Biotech cottons and their official year of commercialization in various countries are given in the previous table.

Conventional Breeding and Biotech Cotton

The processes used in the past to bring about changes in plants by combining the desirable characteristics of one plant with those of another were very slow. As the understanding of cotton plant breeding progressed, scientists found ways of speeding the breeding process and making it more precise and reliable. It is now possible to identify exactly (for many characters) which genes are responsible for which traits and how they can be quickly and safely transferred to the target genotype. Molecular marker assisted breeding will further ease the breeding process. The back cross process is slow and has a number of problems, particularly the linkage between/among various characters and a complex and multiple gene control of a particular character. Biotechnology techniques provide solutions to these problems.

Molecular genetic engineering is just a small component of breeding. Genetic engineering will permit the transfer of characters quickly and efficiently, creating non-existing characters and creating more functions that may not even be known yet. No doubt, genetic engineering can perform many functions much better than conventional breeding, and genetic engineer can perform few functions that are impossible with traditional approaches. Nevertheless, the important role of conventional breeding should not be under estimated. Genetic engineering and other biotechnology applications and conventional breeding are complimentary to each other.

Does Biotech Cotton Have Higher Yield Potential?

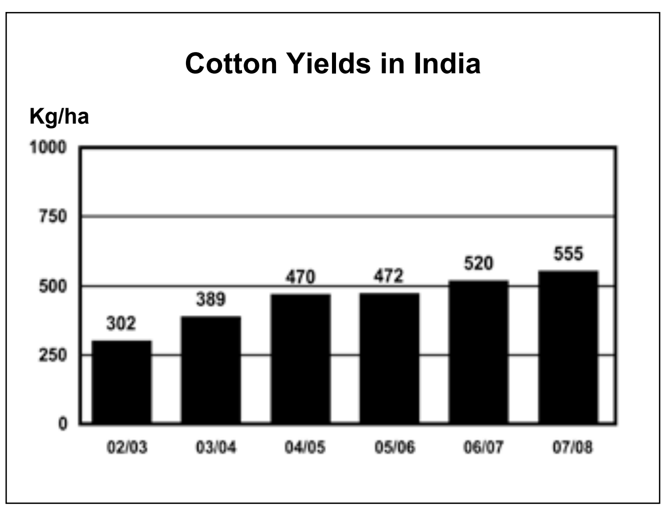
The insect resistant and herbicide resistant transgenic cottons have specific objectives. The addition of a non-cotton gene from a soil bacterium in no way enhances the genetic ability of the plant to perform better in terms of yield. The inherent ability of the plant to produce buds, flowers and bolls remains the same as in the case of a parental line with or without the Bt or herbicide resistant genes. Thus, the genetic potential does not improve with the insertion of a non-cotton gene in the currently available biotech varieties. It is believed that genetic potential cannot be improved, but recoverable potential can be improved. Yield is the most attractive character in most crop species, including cotton, but no biotech product has been developed so far that could improve the recoverable potential in cotton. However, the possibility for future improvement does exist.

Where Does Yield Improvement Come From in Biotech Cotton?

The genetic ability of the plant to produce a higher yield does not improve in transgenic cotton varieties, but some countries, particularly India have experienced significant increases in yield since the adoption of biotech cotton. Cotton is vulnerable to a variety of pests, and losses occur if cotton is not properly protected against insects. The losses in yield due to pests are directly proportional to the pest pressure. Spraying insecticides minimizes losses due to pests, but the loss is not eliminated. It is recommended that insecticides be sprayed at particular threshold levels, which have been established for various pests. Each threshold is a level or a stage at which the benefits of using an insecticide are greater than the cost of the insecticide and its application. But this is a stage when at least some damage to the fruiting forms has already occurred, particularly in the case of a bollworm attack. The use of biotech cotton minimizes/eliminates the pre-threshold losses that could occur before insecticides were sprayed.

Why Are There Huge Increases in Yields in India?

India commercialized insect resistant biotech cotton in 2002/03. The average cotton yield in India in 2001/02 was 308 kg/ha. While some sources place biotech cotton area at 66% in 2007/08, according to Monsanto, biotech cotton was planted on 62% of the total cotton area in India in 2007/08. It is estimated that 72%, 68% and 69% of cotton area in the Central, South and North regions, respectively, were under insect resistant biotech varieties in 2007/08. In six years, the yield in India



increased by 80% to 555 kg/ha in 2007/08. It is expected that India will be exporting 1.26 million tons of cotton in 2007/08 for the first time. The Bt gene cannot bring an 80% increase in yields, but it definitely showed that plant protection was not good in India. If plant protection (through insecticides) is good in any country, there will not be a significant increase in yield due to the use of insect resistant biotech cotton, as is the case in Australia and USA. However, if plant protection is not done well with insecticide applications against target pests, insect resistant biotech varieties can improve yields significantly. However, in India, a program called 'Technology Mission' has also contributed to the improvement of yields.

Effect of Currently Available Non-Cotton Genes on Fiber Quality

The currently available non-cotton genes (Bt and others) are not supposed to have an effect on quality. However, a number of reports indicate a decline in average quality in the USA. This is due to that fact that commercialization of biotech cotton slowed the variety release process for some time. The variety release was slowed by the process of converting existing varieties into biotech varieties. The rate of introduction of new varieties has a proportional impact on fiber quality improvement. Biotechnology companies decided to introduce the Bt gene and herbicide resistant genes through accepted varieties. It took many years to insert a Bt gene into cotton, confirm its performance, complete the regulatory requirements and introduce Bt varieties on a commercial scale. This process automatically slowed the rate of adoption of new varieties with improved fiber qualities. The other possible explanation is that the protection of early-formed bolls in biotech cotton may have changed the location of bolls on the plant that were ultimately harvested. Quality depends upon the position of bolls on the plant, which may have affected lint quality in biotech varieties compared to their parental varieties. One other reason for an effect on quality could be the impact on crop maturity. If a plant retains bolls earlier or keeps setting bolls late in the season, it can also affect quality. The bacterial genes themselves as such are not supposed to have an effect on quality.

What Are Other Benefits of Bt cotton?

Cost of Production

Reports from many biotech cotton-producing countries indicate that the cost of production is lower in biotech cotton. The cost of production is lower due to lower spending on pest control or increased yields (as in India). Thus, pest pressure/number of sprays per season to control target bollworms and the cost of insecticides vs. the cost of the technology fee will determine the extent of savings in the cost of production.

Environmental Safety

Environmental safety is promoted by reduced pesticide use. Fewer sprays means fewer pesticides delivered to the environment, fewer pesticide containers to be disposed of, less damage to the natural flora and fauna, and reduced human exposure to toxic chemicals. The use of herbicide resistant biotech cotton will encourage the use of herbicides, which is contrary to the environmental safety factor in insect resistant biotech cotton.

Improved Biological Control

The Bt toxin is not harmful to natural predators and parasites, and the reduced use of disruptive pesticides will allow increased emphasis on the management and manipulation of beneficial species. Food sprays and many other means of beneficials' conservation and augmentation could be better utilized in insect resistant biotech cotton compared to fields where insecticide use is frequent.

Guaranteed Control

The cost of insecticide control vs. biotech gene control of target insects could be similar. Insecticide applications require continuous monitoring of insect damage in the field, procurement of good quality insecticides and proper application on time. There can be many problems with sprayers, and rains can washout insecticides. The insect resistant gene in biotech cotton provides guaranteed control, and each farmer gets some free time, that would otherwise, be spent on spraying.

Better Grade

Grade in cotton is determined by trash and color. Due to reduced bollworm damage and fewer weeds, biotech cotton is supposed to show fewer yellow spots, thus improving the grade of cotton.

Biotech Cotton and Integrated Pest Management

Integrated pest management (IPM) is the utilization of all possible means of pest control that contribute to an economically feasible and environmentally sustainable pest control approach. IPM involves a multidisciplinary approach that minimizes the use of dangerous chemicals and can be utilized for a long period of time. Biotech cotton, particularly Bt cotton, provides a new tool and foundation on which IPM programs can be based. However, utilization of Bt cotton as a foundation of the IPM system has been minimal so far. There is a need to recognize, and accordingly enhance, the role of Bt cotton in IPM.

What Is a Refuge Crop?

One of the coldest lessons learnt from the use of pesticides is the development of resistance to insecticides by many species of insects. Some of the target species of insect resistant biotech cotton are notorious for the development of resistance, particularly the cotton bollworm *Helicoverpa armigera*. Bt cotton carries an insecticidal protein on which bollworms feed throughout the growing season and year after year. Just as with insecticides, insects can develop resistance to the insecticidal proteins produced by biotech genes. Researchers, utilizing experience with insecticides, have devised resistance development delaying tactics in the form of a 'refuge crop.' The strategy has been strictly implemented and no resistance complaints have been reported so far. Therefore, a refuge crop is required to produce a hybrid population from susceptible insects mating with the resistant population to delay development of resistance to the Cry proteins if alternate host crops do not exist in an area. Refuge crop can be a 5% area grown under unsprayed conditions or 20% area grown under conventional sprayed conditions.

Refuge crops are a must if alternate host crops do not exist in the cotton area. Starting in 2008/09, the U.S. Government will permit farmers not to plant refuge crops in areas where Bollgard II is grown and alternate host crops already exist. This covers most cotton area in the USA.

Are Biotech Cottons Safe in the Long Term?

The answer to this question is "we will never know." It is claimed by companies in the biotechnology business that the proteins in the currently available biotech cotton products have a history of safe use. But the fact is that the non-species genes are being utilized in the cotton genome for the first time and, so far, only 11 years of experience is available with biotech cotton products. There is no assurance that a negative interaction between the foreign gene(s) and the cotton genome will never occur. Moreover, assuming that the currently available transgenic cotton products are safe does not mean that all biotech cotton products will always be safe. The 11-year experience shows that the Bt gene and herbicide resistant genes interact with different varieties differently and their effectiveness is dependent on growing conditions. This is another indication that the long-term impact of these genes is not known for sure. Nevertheless, no unsafe reports of the use of biotech cotton have been discussed so far.

Biotech Cotton and Biosafety Regulations

The application of modern biotechnology to cotton in 10 countries as of 2007/08 has already proved the success of the technology and the two events commercialized so far. There are many countries where Bt cotton could be as successful as in the countries using it so far. But, national and international patent laws prohibit the use of transgenic cotton in many other countries. Some countries have accepted the technology based on the experience in other countries and do not want to be left behind in acquiring the uses and benefits of this new agricultural revolution. But systems are not in place to utilize the technology in all countries. All countries that intend to use this technology on a commercial scale must have in-house systems to introduce or develop, test and commercialize the technology. Governments and the private sector must work together in the debate on the use of agricultural biotechnology. As a matter of priority, governments must establish adequate regulatory oversight and appropriate scientific protocols for agricultural biotechnology. Regulatory protocols are essential for the introduction of agricultural biotechnology in a manner that does not pose unacceptable health and other environmental risks and in which the public has confidence.

Agronomic Requirements of Biotech Varieties

The agronomic requirements of current biotech varieties are not different from normal varieties. Transgenic varieties require the same amount of water and fertilizer as normal varieties. However, pesticides requirements, and accordingly pest control care, is quite different. Herbicide resistant transgenic cotton will not require intercultural operations carried out in many countries for the sake of removing weeds. The Bt cotton may or may not require insecticide applications against bollworms, but certainly sucking insects have to be controlled as in normal varieties.

How to Acquire Biotech Cotton?

There are only two ways to acquire biotech cotton and legally commercialize it, 1) a joint venture with a company or companies that own genes and the technology to develop transgenic varieties, 2) local researchers identify new genes and insert them into cotton. The experience in China (Mainland), India, US and elsewhere showed that it is not easy to identify effective genes that produce the desired effects in the plant. This is one of the reasons that most countries are using insect resistant Monsanto genes, Bollgard and Bollgard II. India has tried and China (Mainland) developed, its own biotech cotton, but the Chinese gene is not as effective as Monsanto's biotech cotton or WideStrike from Dow AgroSciences.

Foreign Gene Location and its Interaction

Generally it is believed that the effect of a gene is limited to a single property, but that is not always the case. The effect of a gene is dependent on its location and its interaction with other genes. Therefore, insertion of foreign genes in cotton is bound to cause surprises, including, in the worst case, the appearance of harmful substances in plant parts. Moreover, the method of genetic engineering is so crude that it is impossible to decide before hand where the inserted gene (s) will stick in the cotton genome. This adds further to the unpredictability of the outcome of artificial gene insertion (genetic engineering).

What Are Other Concerns About Biotech Cotton?

- **Organic cotton** – Biotech cotton is not eligible for certification as organic production. Biotech cotton has affected organic cotton area, particularly in the USA.

- **Weed control** - Herbicide resistant biotech cotton has changed the weed control systems in Australia and the USA. Weed control prior to Roundup Ready cotton involved multi-dimensional approaches to achieve the best control. These approaches involved preplant incorporation, herbicide applications at planting, post-emergence-directed herbicide applications, mechanical cultivations, non-selective herbicides, layby chemical applications, spot spraying with herbicides, and hand weeding. Roundup Ready Flex cotton was approved in the USA in March 2006. Herbicides can be sprayed on Roundup Ready Flex until seven days before harvest, which is only going to aggravate the potential of resistance development.
- **Illegal biotech cotton with all of its consequences** - Biotech cotton has illegally traveled to many countries. Illegal use of biotech varieties is a blatant violation of biosafety regulations, and could spoil seed purity, performance, and safety as well as the credibility of legitimate biotech products and technology. Biotech pirating could affect the confidence and enthusiasm of genuine technology developers. At the same time, pirating is misleading and confusing to farmers.
- **Dominance by the private sector** – The cost of biotechnology products is high, and the private sector is providing technology on its own conditions. This is contrary to the situation in the 'Green Revolution.'
- **Technology limitations** – Biotech cotton is not for every body. If target pest are not a problem in a country, insect resistant biotech cotton is not needed. The search for new genes is expensive and limited.

Short Notes

• Structure of Farms in the USA

There are 2.1 millions farms in the USA of which only 24,800 grow cotton in the southern part of the country from the east to the west. In the USA, farm size has been growing, so the number of farms has been on the decline. The decline slowed during 1980s and nearly stopped during the 1990s. In 2005, only 2% of the labor force was employed in agriculture compared to over 30% in 1910. 98% of U.S. farms are family farms and the remaining 2% are non-family owned or cooperative farms, which produce 15% of the value of agricultural output. Small farms (annual sales less that US$250,000) make up about 90% of the all U.S. farms. Large family farms account for 60% of all production.

The average farm size in the USA is 190 hectares. The annual person equivalent of labor is 1.53 per farm, large farms average more than eight persons and small farms average less than one person per farm (one annual person equivalent equals 2,000 working hours per year). The principal operator (owner/manager) is the most significant source of labor on farms. A primary operator/owner/manager spends half of his/her work time on the farm and his/her spouse spends 12.4% of his/her time in farm work. Self-employed labor is high in the case of small farms, but primary operators spend 19% of his/her time in farm work in the case of very large family farms. 61.8% of the farms are self-owned farms, 32.1% are partly owned (owned and rented) and 6.1% are tenant cultivators.

Small farms tend to specialize in raising beef cattle, other grazing livestock, or they grow a variety of field crops. Most of the time, small farms only grow one crop. Large-scale farms mostly produce poultry, hogs, and high value crops. Large farms tend to specialize in high value crops requiring special marketing skills. Large farm owners can better afford to make heavy investment in high value crops and monitor markets for good prices. Medium scale farms and large family farms mostly specialize in grain crops. In general, 14.4% of farms do not specialize in any commodity, 35.6% specialize in one commodity, 28.8% specialize in two commodities, 9.9% in three commodities and 11.4% in four or more commodities.

Principal operators are mostly white males. Minorities, including African Americans, account for only 5% of all principal operators. 90.7% of principal operators are male. 23.8% of principal operators have a college degree, 24% went to college but did not finish, 41.1% have finished high school, while the rest (11.1%) have spent some years at high schools but did not finish. The average age of a principal operator is 56 years, 17.4% are less than 45 years, 26.3% are 45-54 years, 29.9% are 55-64 years and 26.5% are over 65 years of age. The data also shows that 65% of the second operators are spouses of primary operators.

Most data are for 2004, and the report concludes that profitability measures are strongly associated with farm size. A large majority of small farms generated a positive net farm income, although average net farm income was low compared with large and very large family farms in 2004. The report concludes that generally large and very large family farms are viable economic businesses, with favorable financial ratios. Small farms, though economical, are less viable due to the size of their income. Consequently, small farm household operators/families receive substantial off-farm income.

Source: Hoppe, Robert A., Penni Korb, Erik J. O'Donoghue and David E. Banker. *Structure and Finances of U.S. Farms: Family Farm Report, 2007 Edition*, EIB-24, U.S. Dept. of Agriculture, Economic Research Service, June 2007.

4th Meeting of the Asian Cotton Research & Development Network

23 – 25 September 2008

To be held at the China Cotton Research Institute, Anyang, Henan, China

REGISTRATION FORM

NAME : ____
(Title) (First) (Middle) (Surname)

POSITION :____

ORGANIZATION :____

ADDRESS :____

COUNTRY :____

TELEPHONE :_____________________ FAX :_____________________

EMAIL: ____

TOPIC OF THE PAPER FOR PRESENTATION :_____________________

Tentative Program

22 September 2008	Arrival to Beijing and transfer to Anyang by train (3 hrs) or car (5 hrs). Arranged by the Organizing Committee
23 September 2008	Meeting
24 September 2008	Meeting Afternoon – Visit to Anyang City Evening – Departure to Beijing by train
25 September 2008	Visit to Great Wall and Beijing City
26 September 2008	Departure to Home Countries

Sponsorship
A limited partial sponsorship will be available to selected public sector researchers from the region.

Host Organization: China
Dr. Kunbo Wang
Deputy Director General
China Cotton Research Institute
Anyyang, Henan, China
Email : wkbcri@cricaas.com.cn

Please send the registration form by 15th May 2008 to:

Dr. B. M. Khadi
Chairman, Asian Cotton Research & Development Network
Director, Central Institute for Cotton Research
P.B. No.2, Shankar Nagar Post Office,
Nagpur- 440 010, India
Phone: 07103-275536 Fax: 07103-275529
Email: bmkhadi@rediffmail.com

A COMPREHENSIVE BOOK

COTTON FACTS

COTTON FACTS is a unique publication in the cotton world, bringing together under one cover a broad spectrum of basic knowledge about all aspects of cotton production, consumption and trade. The publication is based on more than 40 years of combined experience in cotton research and marketing by the authors and also incorporates the work of many cotton researchers from around the world.

COTTON FACTS is a comprehensive book (158 pages) including fundamental, common and specific facts about cotton. The book covers all aspects of production, agronomy, breeding, biotechnology, plant protection, fiber quality, ginning, textiles, pricing and marketing of cotton.

COTTON FACTS is a useful educational tool as well as a reference for producers, traders and others with an interest in cotton matters.

Price = US$50

(Hard copy / shipping included)

10% discount on order of 10 books or more

Order Form

Please, send me ______ copies of the ***COTTON* FACTS**

Find enclosed a check of US$________

Find enclosed my credit card details:

☐ American Express ☐ Master Card ☐ Visa Card

Card Number: ____________________________________ Expiration Date: ____________________________________

Billing/Shipping Address:

Name (please print)____

Address ____

City and zip code ______________________________State ______________________ Country____________

Return your order form by mail, email or fax at:

ICAC Subscription Services
1629 K Street, Suite 702 - Washington, DC 20006 - USA
Email: publications@icac.org --- **Fax**: (1) 202-463-6950 --- **Phone**: (1) 202-463-6660 Ext. 111
You may also order online at **http://www.icac.org**