ECONOMIC EVALUATION OF CLIMATOLOGICAL STRESS FACTORS IN COTTON PRODUCTION IN THE TEXAS HIGH PLAINS REGION

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Abstract

Drought and extreme temperatures prompt economically important reductions in grain and fiber production of most agricultural crops. Reductions are often significant and can lead to financial difficulty for producers and in the broader economy. Statistical and econometric analyses were used to estimate the value of cotton fiber lost annually to thermal and precipitation stress in an area of Texas that produces over 20 percent of the nation's cotton crop. The estimated value of lost cotton fiber in the Texas High Plains Region was found to be about $87 million. Demonstrating the importance of agriculture to the Texas economy, the $87 million loss in the value of cotton production generates an estimated $295 million annual effect on the overall Texas economy.

Introduction

Since the turn of the century, technological innovation in production agriculture has given rise to far-reaching changes in the techniques used to produce agricultural commodities in the United States. The transition from horsepower to mechanical power, the widespread use of chemicals, and the development of new and improved seed varieties have resulted in substantial and continuing increases in agricultural productivity. "Revolutions" in agri-cultural production, such as those mentioned above, have brought about significant shifts in the aggregate supplies of most agricultural commodities. Shifting supplies have had meaningful social and economic impacts in society at large, as well as in the agricultural community. Common to innovation in most American industries, widespread expectations are for technological progress to continue to meaningfully impact the production of agricultural commodities.

Biotechnology is a rapidly evolving technology, generally expected to make positive impacts on agricultural productivity. Broadly defined, biotechnology includes "any technique that uses living organisms or processes to make or modify products, to improve plants or animals, or to develop microorganisms for specific uses" (Office of Technology Assessment, 1992). Common techniques such as traditional plant breeding and fermentation are part of the broader implication. However, popular use of the term more commonly refers to technologies identified with genetic engineering.

Techniques in biotechnology can be used to enhance the ability of plants to counter insects and disease and to tolerate stressful enviromental conditions. The importance of these techniques may first be realized in the amount of time required to develop improved crops. Biotechnology allows for shorter plant development periods. Researchers can isolate genes that regulate specific crop traits much more quickly than with traditional plant breeding methods. However, the success of new biotechnology, like many innovative technologies, depends largely upon consumer and producer acceptance.

Agricultural productivity is determined by a number of relationships between crop plants and the diverse environments in which they are grown. A crop plant's environment includes all the conditions surrounding and affecting its development. Included within an environment are biotic and abiotic factors which regulate or help determine the crop varieties that may be grown. Factors may be added to the environment to make production possible or to increase productivity of a plant in a given environment. Among applied factors are soil nutrient levels and water levels in the form of fertilizer, irrigation water, and other agricultural inputs. Unapplied factors include rainfall, insects, soil type, and atmospheric temperatures. Depending upon their intensity, some environmental factors (usually unapplied factors) may be classified as stresses to plants.

A stress situation is an environmental condition affecting plant development in such a way that plants realize a level of growth below the expected level. Biotic factors causing stress to crop plants include: insects, weeds, and pathogens. Abiotic factors affecting productivity include: excessively high and low temperatures, water deficit and excess, physical and chemical properties of the soil, electromagnetic energy, growth regulators and pesticides, air pollution, and mechanical damage resulting from forces such as wind, hail, and dust.

Assuming that demand for food will continue to increase as a consequence of the growing world population, increased supplies can only be made avail-able by either expanding production into areas not presently suitable for agri-culture, or by raising yields on crop land currently used for production (Hein-richs). Coordinated with traditional plant breeding methods, biotechnology allows researchers to develop and change plant characteristics. Plant species can be modified to have increased resistance to biotic stresses, such as insect infestation, and to better tolerate abiotic stresses, such as extreme temperatures. Biotechnology could allow yields to be raised on currently producing crop land and production to be introduced into areas previously

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unsuitable for agriculture. By designing plants with the capacity to counter stressful conditions, researchers may positively affect average production levels and/or reduce production variability.

The economic feasibility of biotechnological innovation must be determined to provide guielines on the types of biotechnology research approached. The economic damage resulting from plant stress provides an upper bound for the level of benefits that could be captured by mitigating plant stress.

The Specific Situation

Each year environmental stresses prompt significant reductions in crop yields which result in lower than expected producer returns across the United States. Generally regarded as having serious effects on returns to agricultural crop production are weather patterns and conditions during a crop's growing season. Unfavorable and unanticipated weather conditions can lead to economically important reductions in crop yields. In particular, water and temper-ature stresses are the source of common and significant losses in yields.

Although plant productivity is reduced by stress, significant increases in costs of production also result from efforts to minimize the effects of stress (Heinrichs). In many cases, plant stress reduces economic returns to agri-cultural production by increasing the cost of production. Decreased total revenue resulting from reduced yields and increased cost of production resulting from attempts at controlling damage from stress can result in decreased farm profitability.

Texas farms produce a significant portion of the total production of many major field crops in the United States. In 1993, Texas lead the nation in production of cotton, producing about a third of the country's total cotton crop (United States Department of Agriculture). Cotton is a primary field crop produced in the Texas High Plains Region (THPR), a 55 county area (Figure 1) including Texas Crop Reporting Districts 1-N (Texas Northern High Plains), 1-S (Texas Southern High Plains), and 2-N (Texas Northern Low Plains). Most of the cotton produced in Texas is produced in the region. Cotton production for 1993 in the THPR was 3.8 million bales which was 23 percent of total national cotton production (United States Department of Agriculture).

Semi-arid climatic conditions in the THPR cause the area to be subject to frequent and unanticipated periods of deficient precipitation and extreme temperatures. The average annual rainfall at county locations in the region ranges from about 15 inches in the southern counties to about 29 inches in the extreme eastern counties. However, the dispersion around the mean is significant. Areas have received annual rainfall as little as 8 inches to as much as 45 inches (United States Department of Commerce, precipitation). Likewise, temperatures across the region during the summer growing season can range from below 20 degrees Fahrenheit in the spring to above 120 degrees in the summer (United States Department of Commerce, tempera-tures). Plant stress resulting from unfavorable variation in precipitation and temperatures can reduce realized crop yields from expected levels. Negative crop yield differentials, the difference between realized crop yields and expected crop yields, ultimately result in lower than expected farm revenues.

Estimates of the magnitude of reduced cotton production and economic value induced by thermal and precipitation stress in the THPR do not exist. Such estimates could aid in the recognition of the potential benefits of biotechnolo-gy research on cotton. A relatively high estimated economic value of reduced cotton production would signal an urgent need for mitigation of plant stress.

The general objective of this study is to analyze and evaluate the economic consequences to producers of crop yield variability resulting from plant stress in cotton. The specific objectives are to: (a) determine the impacts of precipitation and thermal stress on cotton crop yields in the THPR, and (b) determine the impacts of precipitation and thermal stress on the economic revenues from cotton production in the THPR.

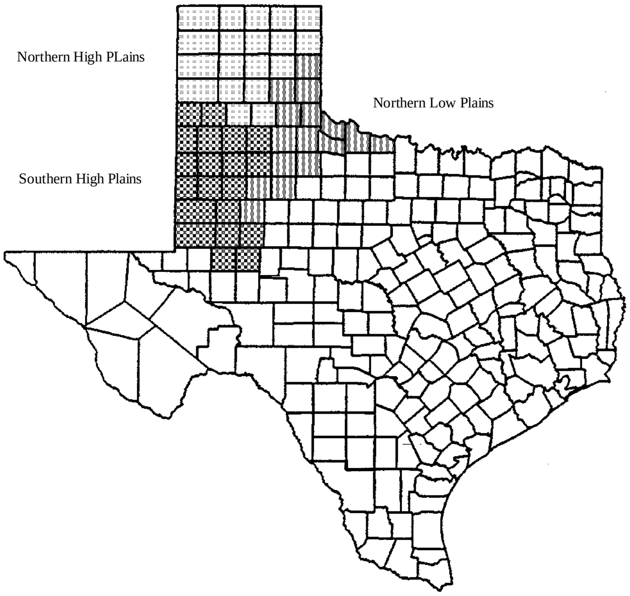

Figure 1. Texas High Plains Region, district boundaries.

Review of Literature

Each crop season, reported crop yields of individual producers, counties, and states fall below producer expectations in many areas of the United States. The shortfall in yield is generally the result of plant stress. Stress may result from among other conditions, insect pest infestation, drought, severe temperatures, and crop diseases. Impacts on crop yields of stress conditions have been estimated by several researchers using different procedures. The estimation process used in each of the studies in this section was considered in developing the estimation procedure used for this study.

Masud, et al. determined the impact of bollworms on cotton yield in a 20 county region of the Texas High Plains from 1979 to 1981. Using auto-regressive procedures, they estimated cotton yield response models. The data used in the estimations were collected from a survey of farmers and secondary data sources. The authors found that bollworms did not have a serious effect on cotton yields when insecticides were applied for pest control. However, when no insecticides were used, analysis indicated a significant decrease in yield. The study considered the development of bollworm resistance to insecticides. They concluded that the comparative economic position of cotton production in the region could be threatened if insecticide resistance were to develop among insect pests.

Thompson used a weather model to determine the impact of weather variability on corn yield from 1891 to 1983. Five states (Illinois, Indiana, Iowa, Missouri, and Ohio) producing over 50 percent of the corn in the nation were included in the study. He employed multiple curvilinear regression analysis of corn yields in a subset of the study period, 1930 and 1983. The variables included in the regressions were 3 time trends and 6 weather factors. The weather factors were preseason precipitation (September through June), June temperature, July rainfall, July temperature, August rainfall, and August temperature. Corn yield was found to be increasing during the period from 1930 to 1960, and the increase accelerated during the period from 1960 to 1972. However, in 1972 the rate of increase slowed, attributed to increased weather variability and a decreased acceleration in the use of fertilizer. Thompson found that the highest corn yields were associated with normal preseason precipitation, normal June temperatures, below normal July and August temperatures, and above normal rainfall in July and August.

Kaylen and Koroma estimated the distribution of U.S. corn yields using a model incorporating a stochastic trend and weather variables. Lagged pre-diction errors, historical weather data, and the corn yield model were used to develop the distribution of 1989 corn yields. This distribution was developed conditionally upon weather data available prior to the 1989 planting season. The value of this study lies in its development of a model using historical weather information to estimate the empirical distribution of corn yields.

Methods and Procedures

An econometric analysis of production and weather related data was conducted to estimate economic losses from thermal and precipitation stress. Estimated yield losses and actual planted acreages were used to determine the levels of decreased production for each year. Decreased production levels and commodity prices received by farmers were used to calculate the economic losses for each year. The estimated annual economic loss caused by precipitation and thermal stress was finally determined for each of the 3 crop reporting districts included in the region.

The county-level calculated losses were aggregated across counties in each district to generate estimates for each of the 3 crop reporting districts within the THPR. The loss estimates of the crop reporting districts were aggregated to determine an estimate for the entire THPR. The economic loss for each year was calculated as merely the estimated crop yield loss on a per acre basis multiplied by the number of acres planted to cotton and the appropriate commodity prices received by farmers.

The estimated crop yield losses for each county and crop were made on an annual basis. Each estimated economic loss was derived by taking an arithmetic average of the calculated economic losses from each year of the sample period. The estimated crop yield losses from precipitation and thermal stress were calculated using annual cotton yield data series spanning the 22 year period between 1972 and 1993. Estimated crop yield losses were calculated as the difference between expected cotton yields and actual cotton yields. The calculated loss estimates are subsequently referred to as cotton yield differentials or simply differentials. Specifically, cotton yield differentials were calculated as:

$$Differential_t = Actual\ Crop\ Yield_t - Expected\ Crop\ Yield_t, \tag{1}$$

where $Differential_t$ is the cotton yield differential at time t resulting from precipitation and thermal stress.

Calculation of the cotton yield differential required finding the difference between the actual cotton yield and the expected cotton yield. The actual crop yields were taken from USDA County Crop Statistics. Next, estimates of expected cotton yields were obtained using ordinary least squares regression. Expected cotton yield for each county was estimated by following 3 steps. First, several regression equations relating cotton yield to growing season precipitation and daily temperatures were estimated for each county. Next, a selection process was used to choose the most appropriate functional form. Finally, mean values of the independent variables were substituted into the regression equations to derive annual expected cotton yield levels for each county.

The regression equations were of the following general form:

$$YIELD_t = f(PREC_t, GDU_t, TREND), \tag{2}$$

where $YIELD_t$ is the actual cotton yield, $PREC_t$ is the amount of total precipitation received during the growing season, GDU_t is the number of growing degree units during the same growing season, and *TREND* is an incremental variable that captures trends in cotton yield levels through time. The variable for precipitation was calculated as the sum across the growing season of monthly precipitation observations collected by the National Climatic Data Center (United States Department of Commerce, precipitation). The growing season for cotton included the period, May-October. The cotton growing season was assumed to hold across counties in the study area. The cotton growing season is not precisely the same across the wide range of counties in this study, however the selected growing season broadly includes the general cotton growing season for the THPR.

The GDU_t variable represents the number of growing degree units during the growing season. The GDU_t variable is calculated as the sum of daily growing degree units during the growing season. This variable was calculated using daily high and low temperatures obtained from the National Climatic Data Center (United States Department of Commerce, temperatures). The growing degree units for a given day were calculated using the following formula (Lascano):

$$GDU = (\text{High} - \text{Low})/2 - 60\ . \tag{3}$$

The daily growing degree units for cotton were calculated by subtracting the daily low temperature from the daily high temperature, dividing the difference by two, and subtracting the constant at the end of the formula. The *TREND* variable had a value of 1 for 1972 and increased by 1 each year. Consequently, the *TREND* variable took a value of 22 for the 1993 observation. *TREND* was designed to capture trends in the cotton yield levels resulting from improved technologies or production practices.

Fourteen regressions of differing functional forms were estimated for each county. Each combination was tested for a trend pattern in the data. Two sets of 7 functional forms were identical except for the inclusion of the *TREND* variable. Several of the functional forms included quadratic specifications of $PREC_t$ and GDU_t. In addition, an interaction term between $PREC_t$ and GDU_t was included in some of the functional forms.

The regression form with the best fit for each crop reporting district (not the best fit for each county) was selected. The form exhibiting the best fit for a specific crop reporting district was made by first grouping the 14 regressions from all counties in the crop reporting district. The regressions were then ranked in descending order of the adjusted coefficients of multiple determination (adjusted R-squared). The regression form occurring most frequently in a previously specified upper percentile of the regression ranking was selected as the most appropriate functional form for the particular crop reporting district.

The estimated regression equation for each county in the crop reporting district that coincided with the form selected for the district was used to estimate the county level expected yield. Long-run mean values (from the sample period, 1972 through 1993) for $PREC_t$ and GDU_t were substituted into each county equation. If the appropriate regression form contained the *TREND* variable, the incremental substitution was made, precisely as the variable was defined in the original regressions. That is, the *TREND* variable used for calculating the 1972 expected cotton yield level was 1 and the *TREND* variable used for calculating the 1993 expected cotton yield level was 22.

The calculations from the regressions with the named values substituted provided the expected cotton yield level for each year by county. The expected cotton yields were subtracted from the actual cotton yields for each year to develop the annual cotton yield differential. Obviously, the cotton yield differential could take on any value, positive, negative, or zero, depend-ing upon the precipitation and temperatures during the growing season. Because of the definition of cotton yield differential, a negative cotton yield differential demonstrates a yield reduction from the expected or normal yield level. Therefore, only those cotton yield differentials having negative values were considered in determining cotton yield losses from stress.

The negative cotton yield differentials were multiplied by county acreages to calculate estimated lost production for each county. County cotton acreages are from USDA County Crop Statistics. The acreages used to calculate lost production are the “acres harvested” in the given county. Perhaps a better acreage value would have been “acres planted for harvest” because the stress conditions likely reduce the acres harvested to the level reported. However, data for “acres planted for harvest” were not available.

Decreased production levels for each year in each county were multiplied by a price reflecting the average price received by producers in the area. The prices were taken from the Texas Agricultural Extension Service Basis Handbook. The cotton price for the entire region was the price of cotton at Lubbock. Prices were multiplied by the decreased production for each year to determine the yearly nominal value of lost production for every county. The nominal value of lost production was deflated to 1993 real U.S. dollars. The price deflator used was the Index of Prices Received for cotton reported by the USDA. Annual losses for the period 1972-1993 expressed in 1993 real values were averaged to provide the estimated annual economic loss due to precipitation and thermal stress. The county estimates were aggregated to develop aggregate economic loss estimates.

Results

The results of the economic impact analysis show that the farm level estimated annual economic loss in the THPR due to thermal and precipitation stress in cotton is slightly over $87 million per year (Table 1).

Table 1. Expected regional and district losses, in 1993 dollars.

	Irr Cotton	Dry Cotton	Total
Northern High Plains	14,657,351	2,463,388	17,120,739
Southern High Plains	21,610,897	33,833,974	55,444,870
Northern Low Plains	1,345,277	13,664,373	15,009,651
THPR	37,613,524	49,961,735	87,575,260

Also, it is important to point out that the Southern High Plains (Crop Reporting District 1-S), due to the relatively high concentration of cotton production, is expected to experience the highest district impact at approximately $55 million per year. The other districts are expected to have annual losses of $17 million for the Northern High Plains (Crop Reporting District 1-N) and $15 million for the Northern Low Plains (Crop Reporting District 2-N). Tables 2 through 5 depict the breakdown of calculated economic losses for each year by farming practice (irrigated and dryland) for the entire region and by district.

Table 2. Estimated losses for the THPR, in 1993 dollars.

	Irr Cotton	Dry Cotton	Total
1972	0	34,908	34,908
1973	0	239,247	239,247
1974	292,719,624	35,012,263	64,284,225
1975	42,973,328	15,816,001	58,789,329
1976	29,272,437	10,897,957	40,170,394
1977	0	2,772,819	2,772,819
1978	26,299,245	128,036,579	154,335,824
1979	95,159,665	3,756,872	98,916,536
1980	162,389,674	444,421,705	606,811,379
1981	29,749,567	19,572,121	49,321,688
1982	83,116,026	55,200,165	138,316,191
1983	67,168,507	856,147,618	152,783,268
1984	35,716,777	64,005,147	99,721,924
1985	71,133,322	21,530,900	92,664,222
1986	44,668,339	50,523,272	95,191,611
1987	4,067,258	0	4,067,258
1988	2,370,712	75,756,721	9,946,384
1989	34,510,615	65,778,830	100,289,445
1990	378,989	15,263,688	15,642,676
1991	569,128,048	618,956,829	118,808,486
1992	8,800,934	1,793,743	10,594,676
1993	3,537,379	9,415,842	12,953,222

Table 3. Estimated losses for the Northern High Plains, in 1993 dollars.

	Irr Cotton	Dry Cotton	Total
1972	0	455	455
1973	0	0	0
1974	14,537,081	1,431,592	15,968,673
1975	17,367,286	992,674	18,359,960
1976	14,521,239	6,795,541	15,200,792
1977	0	0	0
1978	5,918,298	9,486,735	15,405,033
1979	56,762,998	974,119	57,737,117
1980	30,138,961	17,428,809	47,567,770
1981	25,093,496	24,147,578	27,508,253
1982	32,228,445	4,520,720	36,749,165
1983	35,743,291	4,839,330	40,582,620
1984	2,267,721	1,247,721	3,515,442
1985	30,622,670	2,861,625	33,484,295
1986	4,164,148	621,883	4,786,031
1987	4,067,258	0	4,067,258
1988	2,321,547	0	2,321,547
1989	23,345,040	34,959,617	26,841,001
1990	193,572	648,687	842,259
1991	17,226,924	377,869	17,604,793
1992	5,941,740	1,172,051	7,113,791
1993	0	0	0

Table 4. Estimated losses for the Southern High Plains, in 1993 dollars.

	Irr Cotton	Dry Cotton	Total
1972	0	0	0
1973	0	239,247	239,247
1974	13,433,463	23,017,696	36,451,159
1975	25,053,813	14,415,555	39,469,368
1976	11,238,770	2,014,009	13,252,779
1977	0	979,569	979,569
1978	20,329,330	97,877,098	118,206,427
1979	38,000,624	1,464,975	39,465,599
1980	121,570,514	300,140,727	421,711,241
1981	2,669,734	579,715	3,249,450
1982	48,828,177	34,140,769	82,968,947
1983	28,626,932	44,904,989	73,531,921
1984	31,696,923	46,520,319	78,217,242
1985	40,462,304	17,818,505	58,280,808
1986	39,953,160	38,659,036	78,612,196
1987	0	0	0
1988	12,644	0	12,644
1989	8,796,370	46,014,409	54,810,779
1990	185,416	13,503,460	13,688,876
1991	38,355,863	55,365,521	93,721,384
1992	2,688,308	288,460	2,976,768
1993	3,537,379	6,403,359	9,940,738

Table 5. Estimated losses for the Northern Low Plains, in 1993 dollars.

	Irr Cotton	Dry Cotton	Total
1972	0	34,452	34,452
1973	0	0	0
1974	1,301,418	10,562,975	11,864,393
1975	552,229	407,772	960,001
1976	3,512,428	8,204,395	11,716,823
1977	0	1,793,249	1,793,249
1978	51,618	20,672,746	20,724,364
1979	396,043	317,777	713,820
1980	10,680,200	126,852,169	137,532,368
1981	1,986,336	16,577,649	18,563,986
1982	2,059,403	16,538,676	18,598,080
1983	2,798,284	358,704,427	38,668,726
1984	1,752,132	16,237,108	17,989,240
1985	48,349	850,770	899,119
1986	551,031	11,242,354	11,793,384
1987	0	0	0
1988	36,521	75,756,721	7,612,194
1989	2,369,205	162,684,608	18,637,665
1990	0	1,111,542	1,111,542
1991	13,300,179	6,152,292	7,482,309
1992	170,886	333,231	504,117
1993	0	30,124,845	3,012,484

Inspection of Table 2 reveals a significantly higher calculated loss in 1980 than in any other year in the sample period. Greater losses in 1980 are explained by the fact that many areas experienced the lowest precipitation during the summer growing season of all the years included in the sample period. However, if calculated losses for 1980 are removed from the total, the annual farm level estimated economic loss would be about $63 million.

The cotton production industry in Texas significantly impacts the broader Texas economy. In 1993, Texas production of cotton yielded cash receipts of about $1.62 billion (Texas Department of Agriculture). To derive an estimate of the annual total impact on the Texas economy, Type 2 multipliers of the Texas Input-Output model for irrigated and dryland crops (Texas Comptroller of Public Accounts), which include the economic impacts of household expenditures, were applied to the annual expected economic losses (Table 6). The overall state impact of thermal and precipitation stress on cotton in the THPR is estimated to be slightly over $295 million per year (approximately 5.4 percent of the value of the economy-wide impact of cotton production).

Table 6. Expected Texas economy-wide impact, in 1993 dollars.

	Irr Cotton	Dry Cotton	Total
Northern High Plains	48,871,784	8,379,089	57,250,873
Southern High Plains	72,056,888	115,084,535	187,141,423
Northern Low Plains	4,485,538	46,478,669	50,964,207
THPR	125,414,210	169,942,294	295,356,504

Summary and Implications

Statistical and economic analyses were conducted to estimate the value of lost cotton production resulting from thermal and precipitation stress in the 55 counties of the THPR for 1972-1993. This region includes the following crop reporting districts: the Northern High Plains (Crop Reporting District 1-N), the Southern High Plains (Crop Reporting District 1-S), and the Northern Low Plains (Crop Reporting District 2-N). Overall, the THPR is comprised of 55 counties.

The general objective of this study was to analyze and evaluate the economic consequences to producers of cotton yield variability resulting from plant stress caused by drought and unfavorable temperature extremes. Economic losses due to plant stress in cotton grown in the Texas High Plains Region were estimated using econometric analyses of production and weather data. The results of the economic impact analysis show that the farm level expected economic losses in the THPR due to thermal and precipitation stress are estimated to be slightly over $87 million per year. The Type 2 multipliers of the Texas Input-Output model were used to estimate the Texas economy-wide expected impact of thermal and precipitation stress at about $295 million per year.

The magnitude of expected farm level losses and the impact of the expected losses on the Texas economy emphasize potential benefits from biotechno-logical research on cotton in the THPR. Significant economic benefits could be gained through the development of biotechnologies that mitigate thermal and precipitation stress. Only biological research will determine the actual yield gains from stress mitigation, however, probable yield gains in cotton plants genetically designed to tolerate drought conditions and extreme temp-eratures are expected to lead to higher producer profitability. Given that over 20 percent of cotton production in the United States takes place in the THPR, the significance of the expected economic losses in cotton could reveal important economic potential for genetically engineered cotton varieties.

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