CROP YIELD RESPONSE TO DROUGHT IN ALABAMA

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THESIS ABSTRACT

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A model was used to estimate crop yield response to drought in Alabama for corn, cotton, hay, peanuts, and soybeans. The analysis includes Alabama County level data for crop yields and weather variables for the years 1986-2005, along with drought, hurricane, and policy variables. The results indicate that independent weather variables, extreme weather events, and government policy significantly affect crop yield per acre in Alabama.

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I. INTRODUCTION

The United States is the world's largest producer and leading exporter of agricultural products. The evaluation of fluctuations in crop production in the United States has become increasingly important in recent years, due to increased world population and increasing climate variability in all regions of the world (Kogan, 2000). If crop production in the U.S. experiences low yields for even a few successive years, a decrease in the quality of produce available and an increase in the cost of produce will be seen both domestically and internationally. Many factors shift crop yields and production from year to year, but the most important factor is commonly agreed to be extreme weather events (Luttrell and Gilbert, 1976).

The 1990's were named the "International Decade for Natural Disaster Reduction" on December 11, 1987 by the United Nations General Assembly Resolution (CDC, 1994). Extreme weather events makeup almost eighty five percent of all natural disasters, and the most damaging environmental phenomenon is drought. During 1967-91, 2.8 billion people were affected by weather-related disasters, and 51% of these people were affected by drought. Also 3.5 million people perished from weather-related disasters with 45% of the fatalities being related to drought (Obassi, 1994; Kogan, 2000). Severe and extreme droughts occurring in the years 1991-2000 claimed 50-150 million tons of grain, the main source of food for the world's 6 billion people (a number that is likely to double by 2050). Satisfying the world demand for food and feed will become more difficult due to increasing population and the negative effects of frequent droughts on agricultural production (Kogan, 2000).

All parts of the United States are vulnerable to drought. The significant economic, social, and environmental costs are experienced at the local, state, and regional levels. Each year an average of 12% of the United States (excluding Alaska and Hawaii) experiences severe to extreme drought, and in 1934 a record breaking 65% of the population were affected (Wilhite and Svoboda, 2000; Wilhite and Buchanan-Smith, 2005). The U.S. National Drought Mitigation Center (NDMC) found that severe and extreme drought affected more than 25 % of the country in one out of four years (Wilhite and Svoboda, 2000). Annual losses attributed to drought were estimated, by the U.S. Federal Emergency Management Agency (FEMA), to be $6-8 billion (Wilhite and Svoboda, 2000; Wilhite and Buchanan-Smith, 2005, FEMA, 1995). However, the U.S. vulnerability to drought is much different than most developing countries, where major concerns are food security and nutritional needs, environmental degradation, and the development process (Wilhite and Svoboda, 2000; Wilhite and Buchanan-Smith, 2005). The economic, physical, and social effects of drought could be detrimental in developing countries, resulting in famine, abandonment of whole geographic regions, and even human suffering or death (Riebsame et al., 1990; Changonon, 1999; Kogan, 1997, 2000).

In the last 50 years the United States has seen an agricultural technology boom, known as the Green Revolution. The advancing technologies associated with this revolution have increased crop yields per acre dramatically in a relatively short period of time (Kogan, 1997, 2000). Biological sciences have produced hybrid seed that are high-yielding and disease tolerant. Chemistry advancements have resulted in fertilizers and insecticides that produce higher yields at a lower cost. More efficient machinery and agricultural equipment can be attributed to better engineering. Most important to increased crop production has been the technological advancements made in the field of agronomy. Agronomy has improved crop rotations, soil management, planting, cultivation, and harvesting by examining the specific needs of different crops and crop varieties (Luttrell and Gilbert, 1976).

However, technological efforts of the Green Revolution are not enough to offset the negative impacts experienced when widespread drought occurs. Unpredictable weather fluctuations from year to year cannot be controlled with technology. It is even thought that the adoption of high-yielding and disease tolerant hybrid seed in combination with improved crop management techniques can have a negative effect on crop yields during drought years. The uniform planting practices and field operations can cause crop yields to become overly sensitive to weather conditions. Agricultural production should be adjusted to meet climatic conditions each year. This can be found difficult due to the unpredictable nature of weather and the lack of information available to farmers (Isik and Devados, 2006).

Drought: Definitions and Characteristics

Drought occurs in almost all climatic regions, and is a normal, temporary, and recurring feature of climate (Wilhite and Svoboda, 2000; Wilhite and Buchanan-Smith, 2005). A natural reduction in the amount of precipitation received in an area over an extended period of time causes drought to occur. The timing and effectiveness of the precipitation is also an important factor. Each drought year is unique in its climatic characteristics and impacts. Drought can devastate even very productive lands and can go undetected. The severity of a drought can be aggravated by high temperatures, high winds, and low relative humidity. Severity of drought is normally determined by duration, intensity, and spatial extent of the drought episode. Also important to determine the severity of drought on a specific region, is to examine the demand placed on the water supply of that region by human activities and vegetation (Wilhite and Svoboda, 2000; Wilhite and Buchanan-Smith, 2005).

Drought has three main differences from other weather-related natural hazards (Wilhite and Svoboda, 2000; Wilhite and Buchanan-Smith, 2005). The first difference is that the onset and end of a drought are difficult to determine. The impact of drought can not immediately be observed by eye or even ground data. The effects of drought may linger for years accumulating slowly over an extended period of time. Drought is referred to as a creeping phenomenon due to its cumulative impacts (Tannehill, 1947; Wilhite and Svoboda, 2000; Wilhite and Buchanan-Smith, 2005).

Climatologists struggle to determine the onset of a drought and scientists and policy makers debate the criteria for declaring an end to a drought. This confusion leads to the second difference separating drought from other weather-related natural hazards; there is no universally accepted definition of drought. The existence and degree of severity of a drought must be regionally specific. It can occur in high as well as low rainfall areas and can affect even the most fertile lands. The principal season of occurrence, delays in the start of the rainy season and the occurrence of rains in relation to principal crop growth stages all play an important part in defining a drought in a specific region. Scientists and policy makers need definitions of drought that are formulated with actual drought situations taken into consideration. There are numerous definitions for drought; many of them hold no meaningful content for declaring drought or specific impacts in key economic sectors (Wilhite and Svoboda, 2000; Wilhite and Buchanan-Smith, 2005).

Finally drought impacts, in comparison to floods, hurricanes, tornadoes, or other natural hazards, are nonstructural (Wilhite and Svoboda, 2000; Wilhite and Buchanan-Smith, 2005). These impacts are felt over a much larger geographical area than the region where the drought actually occurred. An example of this is the U.S. drought of 1988 which was felt on the global scale and is discussed below. Because drought impacts are not structural or localized, government development of drought contingency plans are hindered by many complications. Accurate, reliable, and timely estimates of the impacts of drought are becoming increasingly important as world demand for food and feed increases (Wilhite and Svoboda, 2000; Wilhite and Buchanan-Smith, 2005).

Major US Droughts

Drought, a very common phenomenon in the United States, occurs on average in 12% of the nation every year (Wilhite and Svoboda, 2000), and agriculture is often seriously affected. Economic, environmental, and social impacts of drought are substantial in the United States, the world’s largest producer and leading exporter of agricultural products. The impact of the large-area severe drought in 1988 on the U.S. economy has been estimated to cause around $40 billion in damages to the environment, human health, and wildlife. This number can be compared to the $15 billion in damages from the 1989 San Francisco (Loma Prieta) earthquake. For the first time in the last half century grain production fell below domestic consumption (Reibsame et al., 1990; Kogan 1997, 2000).

The 1988 drought occurred in the most productive area of the Great Plains, the breadbasket of the United States (FAO, 2000; Kogan, 1997, 2000). By the end of June 1988 moisture and thermal stress, combined with the critical timing of the drought, had devastated corn and grain crop growth. U.S. corn production was reduced by 30%, a number that was felt globally. In 1988 total world grain production dropped 3% and corn production was 50 million tons less than in 1987 (FAO, 2000; Kogan, 1997, 2000). In 1989 the U.S. experienced a drought very early on and by the end of April winter wheat crops were affected. Vegetation stress continued on into the summer months, but only a few states of the central and northern Great Plains saw a reduced spring crop production (Kogan, 1997, 2000).

The southwest and south central states experienced severe drought conditions in 1996, resulting in serious losses in crop and livestock production, increased wildfire and forest fires, and decreased public water supplies (Wilhite and Svoboda, 2000; Wilhite and Buchanan-Smith, 2005). Water-based tourism and recreational activities also took an economic loss due to the decreases in surface and ground water supplies. High temperatures also increased the demand for energy. Kansas, Oklahoma, Arizona, Utah, Nevada, New Mexico, Texas, and Colorado were among the states with the most substantial losses (Wilhite and Svoboda, 2000; Wilhite and Buchanan-Smith, 2005). Texas alone was estimated to have had nearly $5 billion in losses (Boyd, 1995).

In 1998, the drought affected the southwest and south central region of the Great Plains again and expanded into the southeastern states (Wilhite and Svoboda, 2000;

Wilhite and Buchanan-Smith, 2005). Agricultural losses were felt in Texas, Oklahoma, Louisiana, South Carolina, and Georgia, and Florida experienced wildfires. Drought conditions in these areas returned in 1999. This drought also expanded into areas of the mid-Atlantic and northeast states, causing concerns about U.S. vulnerability to drought conditions. Widespread drought in the spring and summer months of 2000 resulted in severe impacts on agriculture and municipal water supplies in three regions of the country: southwest and south central states, southeastern and Gulf Coast states, and central and western Corn Belt states. The southeast region had the greatest devastation due to three years of reoccurring drought in Georgia, Florida, South Carolina, and Alabama (Wilhite and Svoboda, 2000; Wilhite and Buchanan-Smith, 2005).

The impact of drought in the southeastern United States is likely to increase in magnitude as fresh water becomes increasingly scarce and as populations grow. Reliable and up to date information related to surface moisture conditions could be used to forecast crop yields, assess distressed areas for allocation of disaster relief funds, and could help resource managers and government officials plan ahead for difficult financial times. In the state of Alabama drought has caused serious problems for farming communities for the past several years and most recently in the summer of 2006. These conditions place farming communities in difficult financial situations, which also substantially affect other economic sectors within the state. In efforts to improve understanding of environmental weather factors associated with moisture stress, this study examines crop yield response to drought in Alabama.

Research Objectives

This study has four objectives for the analysis of crop yield response to drought in Alabama. The first objective of this thesis is to identify a framework for analyzing crop yield response of major crops to climate fluctuations in Alabama. The second objective is to test and expand the weather variables examined by previous studies. The third objective is to econometrically use yield and climatic data from 1986 through 2005 to estimate the impacts of weather variables on crop yields. The fourth objective is to take into account government legislation affecting agricultural programs. This study looks at the Federal Agriculture Improvement and Reform Act of 1996, and the Farm Security and Rural Investment Act of 2002.

II. ALABAMA CROP PRODUCTION

Crop production is an important aspect when considering the effects of drought on agriculture. Some crops produced in Alabama during the summer growing season include corn, cotton, hay, peanuts, and soybeans. Not all crops are grown in every county in Alabama and planting dates vary among these commodities. Also, which crops are produced in each county differ from year to year. However, agricultural producers in Alabama only have the option to plant one type of crop on each acre of land during a single April-September growing season.

This study examines Alabama crop production for corn, cotton, hay, peanuts, and soybeans during the 1986-2005 summer growing seasons. Crop production statistics for each crop were collected from the United States Department of Agriculture's (USDA) National Agriculture Statistic Serves (NASS) Quick Stats website (http://www.nass.usda.gov/QuickStats/) and are presented in tables (2.1) through (2.10). When examining crop production in Alabama it is also important to look at the same crops on a national level. Each major crop produced in Alabama is evaluated on both the state and national level in the following sections.

Corn

Corn is the primary feed grain making up 90% of the total feed grain production and use in the United States. Corn is produced for both human and animal consumption, and for industrial use. Most U.S. states grow corn, but the majority of corn production occurs in the Heartland region (USDAa, 2008). Alabama corn production from 1986-2005 is found in Table 2.1. U.S. corn production from 1986-2005 is found in Table 2.2. On average 217,250 acres of corn are harvested and 17,989,000 bushels of corn are produced during the 20 year period. The average yield per acre for 1986-2005 is 84 bushels, which is approximately 33.5 % less than the U.S. average yield per acre for the same time period.

Table 2.1 Alabama Corn Production

Year	Planted Acres	Harvested Acres	Yield (Bushels/Acre)	Total Production (Bushels)
1986	340,000	270,000	57	15,390,000
1987	300,000	250,000	72	18,000,000
1988	240,000	170,000	44	7,480,000
1989	230,000	180,000	81	14,580,000
1990	290,000	240,000	58	13,920,000
1991	260,000	210,000	80	16,800,000
1992	330,000	295,000	94	27,730,000
1993	300,000	250,000	55	13,750,000
1994	290,000	260,000	96	24,960,000
1995	250,000	220,000	75	16,500,000
1996	300,000	270,000	82	22,140,000
1997	280,000	250,000	87	21,750,000
1998	300,000	200,000	63	12,600,000
1999	220,000	200,000	103	20,600,000
2000	230,000	165,000	65	10,725,000
2001	180,000	150,000	107	16,050,000
2002	200,000	180,000	88	15,840,000
2003	220,000	190,000	122	23,180,000
2004	220,000	195,000	123	23,985,000
2005	220,000	200,000	119	23,800,000

Table 2.2 U.S. Corn Production

Year	Planted Acres (Thousand)	Harvested Acres (Thousand)	Yield (Bushels/Acre)	Total Production (Thousand Bushels)
1986	76,580	68,907	119.4	8,225,764
1987	66,200	59,505	119.8	7,131,300
1988	67,717	58,250	84.6	4,928,681
1989	72,322	64,783	116.3	7,531,953
1990	74,166	66,952	118.5	7,934,028
1991	75,957	68,822	108.6	7,474,765
1992	79,311	72,077	131.5	9,476,698
1993	73,239	62,933	100.7	6,337,730
1994	78,921	72,514	138.6	10,050,520
1995	71,479	65,210	113.5	7,400,051
1996	79,229	72,644	127.1	9,232,557
1997	79,537	72,671	126.7	9,206,832
1998	80,165	72,589	134.4	9,758,685
1999	77,386	70,487	133.8	9,430,612
2000	79,551	72,440	136.9	9,915,051
2001	75,702	68,768	138.2	9,502,580
2002	78,894	69,330	129.3	8,966,787
2003	78,603	70,944	142.2	10,087,292
2004	80,929	73,631	160.3	11,805,581
2005	81,779	75,117	147.9	11,112,187

On average Alabama farmers harvest more than half a million acres of corn each year; making corn Alabama's most important grain crop. Corn yields in Alabama can be attributed to several factors. Many factors which determine yield can be controlled with good management practices and technology, these include: soil fertilization and liming, tillage, hybrid selection, planting dates and depths, plant populations and row width, and weed and insect control. Uncontrollable weather factors are also a frequent problem in Alabama corn production. Insufficient moisture and high temperatures during the silking and tasseling stages of growth can dramatically reduce yields (Mask, 2009).

The largest single variable cost in corn production is nitrogen fertilization, which produces consistently large increases in corn yields. However, corn produced during a season experiencing drought conditions can have elevated levels of nitrogen. This nitrogen toxicity in the grain can be harmful to humans and animals (McWilliams et al., 1999). Shortages of phosphorus, potassium, and sulfur in soil can also lead to reduced corn yields. Lime should be added to acid soils (low pH) to prevent poor corn yields. Low pH levels reduce root growth and nutrient availability, and can also result in toxicity of some elements and poor activity of herbicides. Alabama production guide for non-irrigated corn can be found on the Alabama Cooperative Extension System web site (http://www.aces.edu/dept/grain/cornpro.php).

The suggested planting dates for Alabama corn in the different regions of the state are: in South Alabama: March 1-April 20; Central Alabama: March 15-April; and North Alabama: March 25-May 15 (Mask, 2009).

Cotton

The United States is one of the world's four largest cotton-producing countries. Grown annually from seed each year, cotton is produced in 17 states in the U.S. and the cotton industry provides over 400,000 Americans with jobs. Cotton production in the U.S. has seen a decrease in planted acres and an increase in yield per acre due to technological advances and better production practices (USDAb, 2008). Alabama cotton production from 1986-2005 is found in Table 2.3. U.S. cotton production from 1986-2005 is found in Table 2.4. On average 463,050 acres of cotton are harvested and 587,900 pounds of cotton are produced during the 20 year period. The average yield per acre for 1986-2005 is 605 pounds, which is approximately 8.5 % less than the U.S. average yield per acre for the same time period.

Table 2.3 Alabama Cotton Production

Year	Planted Acres	Harvested Acres	Yield (Pounds/Acre)	Total Production (Bales)
1986	315,000	313,000	506	330,000
1987	335,000	333,000	572	397,000
1988	390,000	375,000	486	380,000
1989	328,000	322,000	571	383,000
1990	380,000	378,000	476	375,000
1991	410,000	405,000	655	553,000
1992	415,000	408,000	731	621,000
1993	443,000	430,000	524	469,000
1994	463,000	455,000	766	726,000
1995	590,000	578,000	409	492,000
1996	520,000	516,000	734	789,000
1997	535,000	442,000	597	550,000
1998	495,000	475,000	559	553,000
1999	565,000	561,000	535	625,000
2000	590,000	530,000	492	543,000
2001	610,000	605,000	730	920,000
2002	590,000	540,000	507	570,000
2003	525,000	510,000	772	820,000
2004	550,000	540,000	724	814,000
2005	550,000	545,000	747	848,000

Table 2.4 U.S. Cotton Production

Year	Planted Acres (Thousand)	Harvested Acres (Thousand)	Yield (Pounds/Acre)	Total Production (Thousand Bales)
1986	9,933	8,357	547	9,525
1987	10,259	9,894	702	14,475
1988	12,325	11,759	615	15,077
1989	10,210	9,166	602	11,504
1990	12,117	11,505	632	15,147
1991	13,802	12,716	650	17,216
1992	12,977	10,863	694	15,710
1993	13,248	12,594	601	15,764
1994	13,552	13,156	705	19,324
1995	16,717	15,796	533	17,532
1996	14,395	12,632	700	18,414
1997	13,648	13,157	666	18,245
1998	13,064	10,449	619	13,476
1999	14,584	13,138	595	16,294
2000	15,347	12,884	626	16,799
2001	15,499	13,560	694	19,602
2002	13,714	12,174	652	16,530
2003	13,301	11,826	723	17,823
2004	13,409	12,809	843	22,505
2005	13,975	13,534	825	23,260

Hay

More acres of hay are harvested in Alabama each year than any other commodity. There are few larger commercial producers of hay, and the majority of hay is produced and harvested by cattle and horse producers for their own use. Hay has often been overlooked as a major crop in Alabama, even though hay production is essential to Alabama's multimillion-dollar cattle and horse industries. In addition, there is a large demand for hay from the construction and landscaping industry. The Alabama Department of Environmental Management (ADEM) now requires land left idle for more than 13 days to be reseeded by grass for erosion control, and hay mulch is needed to cover newly seeded and fertilized lands (Collins, 2005).

Alabama hay production from 1986-2005 is found in Table 2.5. U.S. hay production from 1986-2005 is found in Table 2.6. On average 756,750 acres of hay are harvested and 1,675,200 tons of hay are produced during the 20 year period. The average yield per acre for 1986-2005 is 2 tons, which is approximately 27% less than the U.S. average yield per acre for the same time period.

Table 2.5 Alabama Hay Production

Year	Harvested Acres	Yield (Tons/Acre)	Total Production (Tons)
1986	700,000	1.6	1,120,000
1987	700,000	2.1	1,470,000
1988	750,000	2	1,500,000
1989	700,000	2.2	1,540,000
1990	750,000	1.5	1,125,000
1991	780,000	2.1	1,638,000
1992	710,000	2.1	1,491,000
1993	720,000	2	1,440,000
1994	730,000	2.7	1,971,000
1995	720,000	2.1	1,512,000
1996	730,000	2.4	1,752,000
1997	770,000	2.25	1,733,000
1998	750,000	2.1	1,575,000
1999	800,000	2.3	1,840,000
2000	720,000	1.8	1,296,000
2001	920,000	2.6	2,392,000
2002	825,000	2.2	1,815,000
2003	780,000	2.6	2,028,000
2004	850,000	2.7	2,295,000
2005	730,000	2.7	1,971,000

Table 2.6 U.S. Hay Production

Year	Harvested Acres (Thousand)	Yield (Tons/Acre)	Total Production (Thousand Tons)
1986	62,334	2.49	155,385
1987	60,133	2.45	147,457
1988	64,771	1.94	125,736
1989	62,722	2.31	144,706
1990	61,030	2.4	146,212
1991	61,834	2.46	152,073
1992	58,903	2.49	146,903
1993	59,689	2.46	146,699
1994	58,815	2.55	150,136
1995	59,764	2.58	154,239
1996	61,169	2.45	149,779
1997	61,084	2.5	152,536
1998	60,006	2.52	151,387
1999	63,181	2.53	159,582
2000	60,355	2.54	153,603
2001	63,516	2.46	156,416
2002	63,942	2.34	149,467
2003	63,371	2.48	157,390
2004	61,944	2.55	158,122
2005	61,637	2.44	150,461

Peanuts

Climate and soil requirements for peanuts limit production to only a few states in the U.S., making it a relatively minor crop. In the Southeast peanuts are produced in Georgia, Alabama, Florida, and South Carolina. Farms that grow cotton, soybeans, corn, and wheat will typically grow peanuts on a 3 to 4 year rotation. The most common crop alternative for peanuts is cotton. During the 1996 Farm Act peanuts were only grown on about 12,000 farms in the U.S. and peanut revenues made up only one percent of the total U.S. crop production revenue, averaging $1 billion a year. During 1999-2000 about 60 percent of the U.S. peanut production occurred in the Southeast, and during 2000-2002 peanuts accounted for over 20 percent of total crop value in Alabama and Georgia (Dohlman et al., 2004).

Peanuts were regulated by marketing quota systems, which limited the amount of peanuts that could be sold for food use in the U.S. domestic market. Under the 1996 Farm Act peanuts produced over the quota level were exported or sold for oil and peanut meal in the lower value crush markets. Producers with quota rights received a government-established loan rate of $610 per ton which gave growers strong incentive to attempt to produce the maximum amount of peanut production allocated to them. The loan rate of $132 per ton was given to peanut producers without quota rights (Dohlman et al., 2004).

The 2002 Farm Act ended the peanut price support system. This dramatic change in policy resulted in two general observations that can be seen in both the U.S. and AL peanut production tables. First, there is a steep decrease in the planted acreage from 2001 to 2002. Planted acreage then sees an increase each year after 2002. Second, peanut producers took advantage of planting flexibility by shifting peanut production to higher yielding areas. This shift can be attributed to the high level of crop revenue the peanuts provide. Even though peanut acres only make up a fifth of cropland on peanut growing farms, peanuts account for 30 % of the crop revenue (Dohlman et al., 2004).

Alabama ranks third in peanut production in the United States, preceded by Georgia and Texas, generating more than $100 million per year for the Alabama economy. During 1986-2005 Alabama peanut production made up approximately 12.26% of the total peanut production in the United States. The top peanut producing counties in Alabama are Houston, Baldwin, Henry, and Geneva (Dixon, 2009). Alabama peanut production from 1986-2005 is found in Table 2.7. U.S. peanut production from 1986-2005 is found in Table 2.8. On average 215,550 acres of peanuts are harvested and 482,198,000 pounds of peanuts are produced during the 20 year period. The average yield per acre for 1986-2005 is 2,241 pounds, which is approximately 13% less than the U.S. average yield per acre for the same time period.

Table 2.7 Alabama Peanut Production

Year	Planted Acres	Harvested Acres	Yield (Pounds/Acre)	Total Production (Pounds)
1986	n/a	219,000	2,260	494,940,000
1987	n/a	220,000	2,115	465,300,000
1988	n/a	236,000	2,380	561,680,000
1989	n/a	239,000	2,250	537,750,000
1990	n/a	256,000	1,510	386,560,000
1991	n/a	277,000	2,305	638,485,000
1992	n/a	236,000	2,505	591,180,000
1993	n/a	239,000	1,980	473,220,000
1994	223,000	222,000	2,010	446,220,000
1995	213,000	212,000	2,280	483,360,000
1996	192,000	191,000	2,355	449,805,000
1997	194,000	193,000	1,930	372,490,000
1998	198,000	197,000	2,195	432,415,000
1999	207,000	206,000	2,175	448,050,000
2000	190,000	182,000	1,490	271,180,000
2001	200,000	199,000	2,675	532,325,000
2002	185,000	180,000	2,110	379,800,000
2003	190,000	185,000	2,750	508,750,000
2004	200,000	199,000	2,800	557,200,000
2005	225,000	223,000	2,750	613,250,000

Table 2.8 U.S. Peanut Production

Year	Planted Acres (Thousand)	Harvested Acres (Thousand)	Yield (Pounds/Acre)	Total Production (Thousand Pounds)
1986	1,564.7	1,535.2	2,408	3,697,085
1987	1,567.4	1,547.4	2,337	3,616,010
1988	1,657.4	1,628.4	2,445	3,980,917
1989	1,665.2	1,644.7	2,426	3,989,995
1990	1,846.0	1,815.5	1,985	3,603,650
1991	2,039.2	2,015.7	2,444	4,926,570
1992	1,686.6	1,669.1	2,567	4,284,416
1993	1,733.5	1,689.8	2,008	3,392,415
1994	1,641.0	1,618.5	2,624	4,247,455
1995	1,537.5	1,517.0	2,282	3,461,475
1996	1,401.5	1,380.0	2,653	3,661,205
1997	1,434.0	1,413.8	2,503	3,539,380
1998	1,521.0	1,467.0	2,702	3,963,440
1999	1,534.5	1,436.0	2,667	3,829,490
2000	1,536.8	1,336.0	2,444	3,265,505
2001	1,541.2	1,411.9	3,029	4,276,704
2002	1,353.0	1,291.7	2,571	3,321,040
2003	1,344.0	1,312.0	3,159	4,144,150
2004	1,430.0	1,394.0	3,076	4,288,200
2005	1,657.0	1,629.0	2,989	4,869,860

Soybeans

Soybeans account for about 90% of oilseed production in the U.S., and soybean oil accounts for 55-65% of U.S. vegetable oils and animal fats consumed. Nationally, soybean acreage has increased in recent years due to planting flexibility, narrow-rowed seeding practices, increased corn-soybean crop rotations, and the adoption of herbicide-tolerant varieties. Soybean yields per acre can be higher for areas that have a more concentrated planting practice (USDAc, 2008). Planted acres in Alabama have seen a decreasing trend since 1986, Table 2.11 illustrates soybean production in Alabama from 1986-2005. U.S. soybean production from 1986-2005 is found in Table 2.12. On average 315,750 acres of soybeans are harvested and 7,665,250 bushels of soybeans are produced during the 20 year period. The average yield per acre for 1986-2005 is 26 bushels, which is approximately 28.6% less than the U.S. average yield per acre for the same time period.

Table 2.9 Alabama Soybean Production

Year	Planted Acres	Harvested Acres	Yield (Bushels/Acre)	Total Production (Bushels)
1986	650,000	610,000	23	14,030,000
1987	600,000	580,000	18	10,440,000
1988	590,000	570,000	25	14,250,000
1989	600,000	570,000	21	11,970,000
1990	470,000	440,000	17	7,480,000
1991	360,000	350,000	23	8,050,000
1992	290,000	270,000	29	7,830,000
1993	310,000	295,000	24	7,080,000
1994	310,000	295,000	31	9,145,000
1995	240,000	225,000	24	5,400,000
1996	320,000	305,000	34	10,370,000
1997	350,000	340,000	25	8,500,000
1998	340,000	320,000	22	7,040,000
1999	240,000	200,000	16	3,200,000
2000	190,000	160,000	18	2,880,000
2001	140,000	135,000	35	4,725,000
2002	170,000	155,000	24	3,720,000
2003	170,000	160,000	36	5,760,000
2004	210,000	190,000	35	6,650,000
2005	150,000	145,000	33	4,785,000

Table 2.10 U.S. Soybean Production

Year	Planted Acres (Thousand)	Harvested Acres (Thousand)	Yield (Bushels/Acre)	Total Production (Thousand Bushels)
1986	60,405	58,312	33.3	1,942,558
1987	58,180	57,172	33.9	1,937,722
1988	58,840	57,373	27.0	1,548,841
1989	60,820	59,538	32.3	1,923,666
1990	57,795	56,512	34.1	1,925,947
1991	59,180	58,011	34.2	1,986,539
1992	59,180	58,233	37.6	2,190,354
1993	60,085	57,307	32.6	1,869,718
1994	61,620	60,809	41.4	2,514,869
1995	62,495	61,544	35.3	2,174,254
1996	64,195	63,349	37.6	2,380,274
1997	70,005	69,110	38.9	2,688,750
1998	72,025	70,441	38.9	2,741,014
1999	73,730	72,446	36.6	2,653,758
2000	74,266	72,408	38.1	2,757,810
2001	74,075	72,975	39.6	2,890,682
2002	73,963	72,497	38.0	2,756,147
2003	73,404	72,476	33.9	2,453,845
2004	75,208	73,958	42.2	3,123,790
2005	72,032	71,251	43.1	3,068,342

III. LITERATURE REVIEW

The evaluation of fluctuations in crop production in the United States has become increasingly important in recent years (Luttrell and Gilbert, 1976). If crop production in the U.S. experiences low yields for even a few successive years, a decrease in the quality of produce available and an increase in the cost of produce will be seen. Many factors shift crop yields and production from year to year, but the most important factor is commonly agreed to be weather fluctuations. The evaluation of patterns associated with crop yields is important when determining agricultural policy. This evaluation includes national accumulation of crop reserves needed to maintain satiability during low crop yielding years (Luttrell and Gilbert, 1976). This chapter reviews published literature on crop production response to climate change which is applicable to drought and possibly could be used to estimate drought's impacts on crop yield.

Mendelsohn et al. (1994) use agricultural land prices to measure the economic impact of climate. They used the *Ricardian* approach to examine the impact of climate and other economic factors on farmland values and revenues in the U.S. for 1978 and 1992. Nearly 3,000 counties in the U.S. were used as cross-sectional data in this study. The *Ricardian* approach was compared to the traditional production-function approach for estimating economic impacts of climate change. By varying input variables such as precipitation, temperature, and carbon dioxide levels these traditional studies rely on underlying production functions to predict environmental damage caused by global warming. Mendelsohn et al. criticizes production-function studies for having inherent bias and overestimated results for the impact of global warming on reduced crop yields, even though their estimates rely on calibrated crop yield models. Important traditional production-function studies referred to by Mendelsohn et al. include Callaway et al. (1982), W. Decker et al. (1986), Adams et al. (1988, 1990), Adams (1989), D. Rind et al. (1990), and Rosenzweig and Perry (1994).

The bias discussed is referred to as the "dumb-farmer scenario" and implies farmers will not adjust their practices in response to changing environmental or economic conditions. Overestimations are said to be caused by the failure of production-function models to allow for complete adjustments such as new crop production decisions, major technology advancements, or conversion of agricultural land to other land uses. Mendelsohn et al. address this bias in their model by replacing the dependent variable from crop yields with the net value of farmland. The *Ricardian* approach allows for direct measurement of the effects climate change has on different crops, while also allowing for the indirect effects to be measured. Adjustments in farmland value take into account land user's management decisions for both changes in nutrient inputs as well as crop selections. They also include urban measurements to account for urban development that might have replaced agricultural lands. Weather variables include January, April, July, and October temperature and precipitation averages. Soil factors for erosion, soil type, moisture capacity, and permeability are also included.

Mendelsohn et al. find that climate change has high degrees of nonlinear effects on agriculture. These effects are found to vary season to season. Also, the effect of climate change on farmland value was found to be dramatically different than the effect of climate change on farmland revenue. The impact of global warming was found to have a dramatic negative impact of farmland values. Different results were found for the climate impact on farmland revenue. The revenue model suggested global warming actually had a positive effect on crop revenue.

Cline (1996) comments on Mendelsohn et al. (1994) stating that even though their study provided an important service for analysis of global warming impacts for the U.S., their study also understated the damaging impacts. He explains three reasons for the underestimation. First Cline questions the conceptual framework behind applying cross-sectional analysis to future climate (global-warming) impacts based on current land values. He calls their approach ingenious for trying to capture farmer responses to changing climate, but also critiques the investigation for not recognizing other methods of the production-function approaches such as those in the studies by Easterling et al. (1993) and Rozenzweig et al. (1993). Cline (1996) further questions the meaningfulness of the results of Mendelsohn et al. in comparison with direct estimates from the improved production-function models listed above. Second, Mendelsohn et al. assumed implicitly that the price of irrigated water was infinitely elastic. The problem that arises from the partial-equilibrium model or *Ricardian* approach with respect to water availability for irrigation is also discussed by Cline. He quickly points out that experts are speculating on water scarcity in the U.S. and this will increase in years to come. Finally, to measure global warming effects in the U.S. Mendelsohn et al. used the global mean for precipitation and warming effects. Cline states that there is evidence suggesting actual damages in the U.S. would be more severe than global data implies and that regional data would be more appropriate.

Schlenker and Roberts (2006) examine the reduced-form relationship between daily weather records and county level corn yields in eastern United States for 1950-2004. Their study combines broad aggregate weather measures used in reduced-form regressions and detailed nonlinear weather interaction used in crop-simulation models to estimate weather effects on corn yields. Schlenker and Roberts' detailed set of daily weather records and corn yields from almost 2,000 U.S. counties allow them to accurately estimate nonlinear impacts of weather on yields. Equation (3.1) below is the model proposed by Schlenker and Roberts to identify the appropriate temperature bounds as well as utilize a large data set. Yield growth is a nonlinear function of heat $g(h)$, so that the log yield y_{it}, in county i and year t is

$$(3.1) \qquad y_{it} = \int_{\underline{h}}^{\overline{h}} g(h)\phi_{it}(h)dh + z_{it}\delta + c_i + \varepsilon_{it}$$

Where $\phi_{it}(h)$= the time distribution of temperatures over the season in each county
$\underline{h}$ and $\overline{h}$= the lower and upper bounds of temperature observed
z_{it} = other factors, such as precipitation and technological change
c_i= a time-invariant county-fixed effect

In their study, growing degree days (GDDs) are incorporated to measure the effects of temperature. They define degree days as the sum of truncated degrees of a given day that occur between the lower and upper bounds of temperature. Degree days are then summed over the entire growing season producing the GDDs. Schlenker and Roberts explain their flexible functional form allows them to observe possible negative effects of extreme heat above the upper temperature threshold on yield. Their model also treats time as being dimensionless, implying that temperature is perfectly substitutable over time.

Equation (3.2) is given by Schlenker and Roberts to discretize the integral over heat by using 1ºC intervals ranging from -5 ºC to 50 ºC. The 1º heat interval $(h, h+1)$ becomes $\phi_{it}(h+1) - \phi_{it}(h)$ and replaces $\phi_{it}(h)$ from Equation (1.1).They also approximate the nonlinear function $g(h)$ by using a *m*th order Chebyshev Polynomial $T_j(\ )$ for *j* = 1,..., m, and evaluate the interval at midpoints.

$$(3.2) \qquad Y_{it} = \sum_{j=1}^{m} \beta_j \underbrace{\sum_{h=-5}^{49} T_j(h+0.5)\left[\phi_{it}(h+1) - \phi_{it}(h)\right]}_{x_{it,j}} + z_{it} + c_i + \varepsilon_{it}$$

Where $x_{ji,t}$ = the exogenous variable obtained by summing the *j*th order Chebyshev Polynomial evaluated at each temperature interval midpoint multiplied by the time spent in each temperature interval

Schlenker and Roberts found that yield increases as temperatures increase from 12 ºC to 25 ºC and then quickly becomes negative for temperatures that exceed 30 ºC. They found a significant nonlinear relationship between temperature and corn yields, with an R^2 of 0.76 for the regression that included year and county fixed effects.

Schlenker et al. (2006) estimate potential impacts of global warming on farmland values for U.S. counties east of the 100th meridian. Mendelsohn et al.'s (1994) *Ricardian* approach was used for the bases of their model. The study area, east of the 100th meridian, represents the boundary where agricultural production is possible without the use of irrigation. This was done to eliminate discrepancies between previous studies. Schlenker et al.'s model is unique in the way it links climatic, soil, and socioeconomic factors to farmland values.

The growing season months April through September were selected to represent U.S. crop response to ambient weather conditions. Precipitation monthly averages for

April-September were collected for the 30 years proceeding each census year. Degree days were chosen to represent the effects of temperature on plant growth. Schlenker et al. explain that much agronomic literature represents plant growth as being linear within a certain range. They use temperatures between 8 and 32ºC for the linear range, and temperatures of 34ºC to represent the harmful effects of temperature on crop growth. Schlenker et al. experimented with both linear and quadratic specifications for the degree days with base 34ºC, and found the square root to be the best fit. Explaining that the square root function best approximated the dramatic negative effects high temperatures have on plant growth. They also found the soil K factor to be significant at the 10% level in three of the five regression runs. Soil K factor represents erodibility of top soil, which can be harmful to the productivity of agricultural lands. Linking climatic, soil, and socioeconomic to farmland values resulted in robust estimates that remained robust even after various specification tests.

Isik and Devadoss (2006) used historical data on crop yields and climatic variables to develop an econometric model of stochastic production functions. Their analysis focused on the impacts of climate change on crop yields and yield variability. They quantify the impacts of climate variables on the mean, variance, and covariance for wheat, barley, potatoes, and sugar beet yields in Idaho. Also, the estimated production function parameters and their elasticities are used to show the projected long-term temperature and precipitation on Idaho agricultural yields. Isik and Devadoss use the Just-Pope (1978) production function, equation (3.3), to represent crop yields.

$$(3.3) \quad y_{it} = f(x_{it};\beta) + \omega_{it} h(x_{it};\delta)^{1/2}$$

Where y_{it} = crop yield for region *i* and year *t*
x_{it} = weather variables for region *i* and year *t*
ω_{it} = the stochastic term with mean zero and variance σ_{ω}^{2}
β and δ = the production function parameters to be estimated

The effects of the independent weather variables on mean crop yield is given by the estimation of expected crop yield ($f(x_{it};\beta)$). The effect of the independent weather variables on the variance of yields is given by the estimation of $h(x_{it};\delta)$. Isik and Devadoss use weather variables that include a constant, precipitation, temperature, and a trend. They choose the Just-Pope function because it does not impose a *priori* restriction of the risk effects of these inputs, and provided accommodation to both increasing and decreasing risk effects on production outputs. Isik and Devadoss looked toward Saha et al. (1997) for an estimation of the Just-Pope production function, equation (3.4), interpreted as estimation with heteroscedastic errors.

$$(3.4) \qquad y_{it} = f(x_{it};\beta) + u_{it}$$

Where $u_{it} = \omega_{it} h(x_{it};\delta)^{1/2}$
Var(u_{it}) = $\sigma_{\omega}^{2} h(x_{it};\delta)$

In order to ensure positive out-variance Isik and Devadoss assumed that the exponential form for the variance of crop yield was Var(u_{it})=exp(δx_{it}) with σ_{ω}^{2}=1 (i.e. ω_{it} ~*N*(0,1)).

According to Saha et al., the Just-Pope production function has been widely used in applied economics. Just and Pope proposed a theoretical model that allowed the effects of inputs on the stochastic component of production to be analyzed separately from the deterministic component, and offer two alternative methods of estimating the stochastic production function. Just and Pope's 1978 article examines a maximum likelihood (ML) procedure for estimating the stochastic production function and their 1979 article provided a production function estimation by feasible generalized least squares (FGLS) under heteroscedastic disturbances. Saha et al. (1997) compares the Just-Pope production function estimated by FGLS, which is the traditional estimation method, to the ML estimator. Their main objective is to investigate the small-sample properties of FGLS and ML estimators in heteroscedastic error models. They found that the maximum likelihood approach was more effective for estimation. In order to take into account region-specific effects the log-likelihood function for panel data estimation was given by equation (3.5), where N is the number of observations.

$$(3.5) \qquad \ln L = -\frac{1}{2}\left[N * \ln(2\pi) + \sum_{i=1}^{N} \frac{\left(y_{it} - f(x_{it};\beta)\right)^2}{\exp(x_{it}\delta)} + \sum_{i=1}^{n} \delta x_{it} \right]$$

Isik and Devadoss (2006), under the assumption $\omega_{it} \sim N(0,1)$, use the maximization of equation (3.2) to estimate the parameters of β and δ . They estimated both a linear and quadratic to represent the relationship between the mean of Idaho crop yields and the weather variables, but only use the linear functional form for estimation of the relationship between the variance and covariance of crop yield and the weather variables. Their econometric model found varying effects of temperature and precipitation on wheat, barley, potatoes, and sugar beet yields. The effect of climate on the mean of yields was found to be modest. For most of the crops the variance and covariance of yield was significantly reduced by climate change.

A study done by Luttrell and Gilbert (1976), investigated whether or not weather changes have random effects on crop yields. According to Luttrell and Gilbert the belief in weather cycles dates back to the Old Testament and since then several studies have been done to evaluate if crop yields are random, cyclical, or bunchy. These studies include Jevons (1884), Jevons (1909), Moore (1923), Fulmer (1972), and Lin et al. (1963). Luttrell and Gilbert used United States crop yield data from 1866-1932 for wheat, corn, rye, barley, and oats, and crop yield data from 1933-1974 for wheat, corn, rye, barley, oats, and cotton. According to Luttrell and Gilbert the empirical results of the 1866-1932 tests primarily reflect the influences of weather on crop yields, based on the natural fertility of the land. They found little evidence of positive autocorrelation, or bunchiness for crop yields during this time period. The test results for 1933-1974 also found no evidence of bunchiness. They did however find some evidence of positive autocorrelation indicating that the trend of yields was misspecified by regressing the natural log of yield. They attributed crop yields variation from trend to increased technology, such as hybrid crops and fertilizer, and government policy. One main finding of their statistical evaluation of crop yields was that they found little evidence for nonrandom, cyclical, or bunchy yields in either the national average yields or the weighted average for major agricultural producing areas in the United States. Another important finding was that government acreage control programs created major changes in cotton production. According to Luttrell and Gilbert acreage removed from production during years of government policy were probably less fertile than the acreage that remained in production. They found that years prior to acreage restriction, cotton yields were below trend, and years during acreage restriction were above trend.

IV. DATA AND METHODS

This analysis used panel data to evaluate the effects of weather variables on average crop yields for Alabama during the years 1986-2005. This study used the statistical analysis software SAS 9.1. Data for corn, cotton, hay, peanuts, and soybeans were collected at the county level. Average crop yields for each commodity from 1986-2005 were collected from the United States Department of Agriculture's (USDA) National Agriculture Statistic Serves (NASS) Quick Stats website (http://www.nass.usda.gov/QuickStats/) and can be found in the Appendix. Weather variables including precipitation, minimum and maximum temperature, wind speed, solar radiation, and relative humidity were collected from Texas A&M Blackland Laboratory . Descriptive statistics for yield and weather variables are found in Table 4.1.

Table 4.1 Descriptive Statistics of the Data Used in the Estimation

	N	Mean	Minimum	Maximum	Std. Dev
Corn Data					
Corn Yield Bushels Per Acre	960	79.41	9.34	178.00	27.95
Growing Degree Days (50-86ºF) in Thousands	960	4.24	3.47	4.89	0.25
Temperature Stress Degree Days	960	262.41	17.03	763.61	114.26
Coefficient of Variation for Precipitation	960	2.86	1.99	5.77	0.47
Average Precipication (mm)	960	3.85	1.37	9.02	1.20
Average Daily Solar Radiation (MJ m-2d-1)	960	21.82	19.01	24.44	0.93
Average Wind Speed (m/sec)	960	2.79	2.28	3.87	0.30
Average Relative Humidity	960	68.51	58.25	77.07	3.84
Cotton Data					
Cotton Yield Hundred Pounds Per Acre	620	5.97	1.72	12.72	1.75
Growing Degree Days (60-86ºF) in Thousands	620	2.60	2.03	3.13	0.19
Temperature Stress Degree Days	620	266.87	31.08	645.12	111.52
Coefficient of Variation for Precipitation	620	2.85	1.99	5.43	0.48
Average Precipication (mm)	620	3.92	1.37	9.02	1.25
Average Daily Solar Radiation (MJ m-2d-1)	620	21.84	19.30	23.95	0.95
Average Wind Speed (m/sec)	620	2.83	2.28	3.87	0.32
Average Relative Humidity	620	68.33	58.25	76.52	3.80
Hay Data					
Hay Yield Tons Per Acre	1340	2.23	0.80	3.89	0.52
Growing Degree Days (40-86ºF) in Thousands	1340	5.97	5.14	6.71	0.27
Temperature Stress Degree Days	1340	256.55	17.03	763.61	114.72
Coefficient of Variation for Precipitation	1340	2.85	1.99	5.77	0.46
Average Precipication (mm)	1340	3.83	1.37	9.02	1.16
Average Daily Solar Radiation (MJ m-2d-1)	1340	21.87	19.01	24.44	0.93
Average Wind Speed (m/sec)	1340	2.80	2.28	3.87	0.29
Average Relative Humidity	1340	68.01	57.59	77.07	4.02
Peanut Data					
Peanut Yield Thousand Pounds Per Acre	240	2.26	1.13	4.08	0.44
Growing Degree Days (56-86ºF) in Thousands	240	3.32	2.85	3.76	0.15
Temperature Stress Degree Days	240	291.37	67.58	645.12	116.00
Coefficient of Variation for Precipitation	240	2.84	2.00	5.43	0.51
Average Precipication (mm)	240	4.04	1.86	7.38	1.28
Average Daily Solar Radiation (MJ m-2d-1)	240	22.00	19.50	23.88	0.89
Average Wind Speed (m/sec)	240	2.57	2.32	2.98	0.18
Average Relative Humidity	240	70.87	64.81	77.07	2.49
Soybean Data					
Soybean Yield Bushels Per Acre	440	25.54	6.00	46.54	7.74
Growing Degree Days (50-86ºF) in Thousands	440	4.13	3.47	4.89	0.25
Temperature Stress Degree Days	440	236.42	17.03	645.12	104.92
Coefficient of Variation for Precipitation	440	2.82	1.99	4.88	0.43
Average Precipication (mm)	440	3.83	1.37	7.87	1.12
Average Daily Solar Radiation (MJ m-2d-1)	440	21.47	19.30	23.95	0.87
Average Wind Speed (m/sec)	440	2.86	2.28	3.33	0.26
Average Relative Humidity	440	68.16	58.25	75.86	4.00

Weather Variables

The total effect environmental conditions have on plant yield can only be observed after the crops are harvested. Plant stress results from a number of factors and often is not visually noticeable. Soil moisture, atmospheric conditions, nutrients, diseases, insects, and weeds all interact on a daily basis to create numerous different kinds of crop stress (Shaw et al., 2009). Disease, insect, and weed control, nutrient application are all environmental factors that are under control of management practices. These factors are not considered by this study, and are held constant under the *ceteris paribus* assumption. This study will focus on the environmental factors that cannot be controlled (i.e. soil moisture and atmospheric conditions), and their relationship with crop yield.

Moisture stress occurs when soil moisture and atmospheric conditions become unbalanced. Soil moisture is determined by both the amount of precipitation and soil characteristics. Atmospheric conditions can be defined as the combination of air temperature, the amount of energy available (solar radiation), dryness of the air (humidity), and movement of evaporation from plant surfaces (wind) (Shaw et al., 2009). The following sections explain how each weather variable is measured and how each is posited to affect crop yields.

Temperature (Growing Degree Days)

In agriculture it is important to find a way to measure the impact of temperature on crop development, and also the potentially negative effect of weeds and insects on crop yields. Agricultural producers use a concept called growing degree-days (GDD) to measure the impacts of air temperature on plant growth, development, and maturity.

GDD is based on the idea that plants have a minimum temperature at which plant growth will start to occur, and a maximum temperature at which growth will shut down. Each crop and variety has its own minimum developmental threshold temperature (T_{base}) (Fraisse et al., 2007, 2009). Table 4.2 lists T_{base} for selected crops and insects provided by the University of Florida's Institute of Food and Agricultural Sciences Extension.

Table 4.2 Base Temperatures for Selected Crops and Insects

Crop	**Base Temperature**
Corn, Sorghum, Rice, Soybeans, Tomato	50 ºF
Cotton	60 ºF
Peanuts	56 ºF
Potato, Sunflower	45 ºF
Wheat, Barley, Rye, Oats, Flaxseed, Lettuce, Asparagus	40 ºF

Insect	**Base Temperature**
Alfalfa Weevil	48 ºF
Black Cutworm, European Corn Borer	50 ºF
Corn Rootworm	44 ºF
Green Cloerworm	52 ºF

GDD is calculated for each 24-hour day during plant development. The accumulation of GDD throughout a growing season can provide useful information on how daily air temperatures and plant development are related. Equation (4.1) illustrates the standard calculation for GDD.

$$(4.1)\ \text{GDD} = \left(\frac{T_{MAX} + T_{MIN}}{2}\right) - T_{base}$$

Where T_{MAX} = the daily maximum reported temperature
T_{MIN} = the daily minimum reported temperature
T_{base} = the crop specific minimum temperature required for growth

The standard way of calculating GDD can be modified in several ways. One of the most common modifications for agricultural studies, shown in equation (4.2), is to set the daily minimum temperature (T_{MIN}) equal to T_{base} if $T_{MIN} < T_{base}$.

$$(4.2)\ \text{GDD} = \left(\frac{T_{MAX} + T_{base}}{2}\right) - T_{base}$$

Where T_{MAX} = the daily maximum reported temperature
T_{base} = the crop specific minimum temperature required for growth

Equation (4.2) can also be modified to consider the maximum temperature at which plant growth will start to shut down is known as the upper developmental threshold (T_{cutoff}). The upper cutoff is commonly assumed to be equal to 86 ºF. Equation (4.3) illustrates the upper developmental threshold modification for GDD by setting the daily maximum temperature (T_{MAX}) equal to T_{cutoff} if $T_{MAX} > T_{cutoff}$.

$$(4.3)\ \text{GDD'} = \left(\frac{T_{cutoff} + T_{base}}{2}\right) - T_{base}$$

Where T_{cutoff} = the upper developmental threshold temperature (86 ºF)
T_{base} = the crop specific minimum temperature required for growth

(Fraisse et al., 2007, 2009).

This study uses the modified equation (4.3) to calculate the GDD for corn, cotton, hay, peanuts, potatoes, and soybeans for each county in Alabama for the years 1986-2005. Each crop's GDD represents the range between the minimum temperature and maximum temperature at which growth occurs, and should represent the positive linear effects of temperature on yield. However, if a crop is experiencing stress, high temperatures even within the range of each crop GDD could have a negative effect.

Temperatures experienced over the upper developmental threshold (T_{cutoff}) have a negative effect on yield. The accumulation of degree days above T_{cutoff} are known as temperature stress degree days (TSDD). Calculation of the TSDD is represented by equation (4.4).

(4.4) TSDD = GDD – GDD′

Where GDD = growing degree days without an upper developmental threshold
GDD′= growing degree days with an upper developmental threshold

(Danneberger and Street, 1985, Walker and Hatfiled, 1979)

Crops have different GDD accumulations based on their specific T_{base}. In this study each county has the same TSDD accumulation for each crop, because T_{cutoff} is assumed to be the same for all crops. Even though TSDD is calculated beyond the point were plants are negatively effected by heat, there is a point where the incremental damage from further exposure to temperatures over T_{cutoff} is dramatically reduced. To capture this affect the square root of TSDD has been placed in the model, as applied by Schlenker et al, 2006.

Precipitation

Crop moisture stress originates from a deficiency of precipitation over a period of time. The occurrence, and severity, of moisture stress is unique to each crop and crop variety. The timing of precipitation is as important to crop yield as the amount of precipitation received in an area. Effectiveness of precipitation for crop production comes from a direct relationship between rainfall intensity and the occurrence of precipitation during principle development stages (NDMC, 2006). The studies of Schlenker et al.

(2006) and Isik and Devadoss (2006) both use the average precipitation over the growing season to measure the effects of precipitation on yield. However, precipitation is a dynamic process, and the uses of data collected at traditional ground based weather stations have a major problem with accuracy. As rainfall moves through an area, its form and intensity can change dramatically. The data may only be accurate for the actual amount of rain for that particular weather station and a small area around the weather station. Not only the amount of rain, but the occurrence of rain is in question. Precipitation acquired at weather stations may not have been received by agricultural lands, and vice versa (Jensen and Pedersen, 2005).

The data used in this study come from one weather station for each county to measure atmospheric conditions. In order to account for measurement errors in the precipitation amounts and frequency, the coefficient of variation (CV) was used to measure precipitation. Because crop moisture stress originates from a deficiency of precipitation over a period of time, it is important to look at the variability of precipitation over time as a function of the amount of precipitation received. CV is the standard deviation divided by the mean (Jensen and Pedersen, 2005). For this study the CV of precipitation was calculated by dividing the standard deviation of average precipitation for each county in each year by the average precipitation for each county in each year. The CV for precipitation can be considered a measurement of risk and has a negative relationship with yield. As the coefficient of variation increases, risk for planting crops also increases. Variables for the average precipitation from each station as well as averaged precipitation squared were included in the model to capture both the positive and negative effects of precipitation.

Erosion

Soil moisture is determined by both the amount of precipitation and soil characteristics. One way to characterize soil is by its erosion properties. Erosion is an important factor when looking at agricultural yields for an area. The four soil properties that determine the erodibility of soil are; particle size, structure, organic content, and permeability. Based on the four properties, soil's potential for erosion by water can be interpreted by a number known as the K factor (IWR-MSU, 2002). County level soil data is collected and managed by the USDA Natural Resource Conservation Service. The Soil Survey Geographic (SSURGO) database can be found at the USDA Soil Data portal (http://soildatamart.nrcs.usda.gov/). K factor is the soil erodibility factor. Medium textured soils, such as the silt loam, are moderately susceptible to detachment. K factor values of 0.25 to 0.4 produce moderate runoff. Values of 0.4 or greater are highly erodible (IWR-MSU, 2002). The average K factor for each county in Alabama, collected from SSURGO is shown in Table 4.3. In this study the K factor was used as an interactive variable with average precipitation.

Table 4.3 Alabama K Factors by County

County Name	K Factor	County Name	K Factor	County Name	K Factor
Autauga	0.21	Dallas	0.26	Marion	0.30
Baldwin	0.21	De Kalb	0.26	Marshall	0.26
Barbour	0.19	Elmore	0.24	Mobile	0.17
Bibb	0.27	Escambia	0.22	Monroe	0.26
Blount	0.29	Etowah	0.31	Montgomery	0.30
Bullock	0.22	Fayette	0.30	Morgan	0.30
Butler	0.23	Franklin	0.25	Perry	0.28
Calhoun	0.31	Geneva	0.20	Pickens	0.30
Chambers	0.28	Greene	0.28	Pike	0.21
Cherokee	0.33	Hale	0.28	Randolph	0.25
Chilton	0.27	Henry	0.16	Russell	0.23
Choctaw	0.27	Houston	0.17	Shelby	0.33
Clarke	0.24	Jackson	0.27	St. Clair	0.33
Clay	0.26	Jefferson	0.32	Sumter	0.29
Cleburne	0.30	Lamar	0.29	Talladega	0.30
Coffee	0.19	Lauderdale	0.35	Tallapoosa	0.25
Colbert	0.30	Lawrence	0.31	Tuscaloosa	0.30
Conecuh	0.20	Lee	0.24	Walker	0.28
Coosa	0.27	Limestone	0.37	Washington	0.26
Covington	0.18	Lowndes	0.28	Wilcox	0.29
Crenshaw	0.21	Macon	0.22	Winston	0.28
Cullman	0.28	Madison	0.33		
Dale	0.16	Marengo	0.28		

Evapotranspiration Variables

Evapotranspiration can be defined as water lost from the surface of plants into the atmosphere (USGS, 2009). There are six factors that affect transpiration rates from plants: the type of plant, soil-moisture available, temperature, relative humidity, radiation, and wind. Evapotranspiration is part of how plants “breathe”. Like people plants have to breathe to stay alive. Some types of plants transpire less than others and need less water to stay alive. Also if soil-moisture isn’t available plants whither and transpire less. High temperatures also increase evapotranspiration rates. When relative humidity is high in the air surrounding the plant evapotranspiration will happen less quickly. Humidity in the air allows for plants to keep moisture in their leaves. One thing to point out is that 10% of all moisture in the air is due to moisture lost during the plant transpiration process (USGS, 2009). High levels or humidity could indicate higher rates of plant transpiration. A plant's photosynthesis and transpiration is also affected by the amount of radiation intercepted by the plant. Leaf area development throughout the growing season determines the amount of radiation intercepted by the crop (NeSmith, 1997). Solar radiation is necessary for plant development until a certain level. After that level of radiation is received by the plant radiation can have a negative impact of growth and development. High levels of solar radiation can increase the evapotranspiration process and create plant stress.

Not so obvious are the effects of wind on crop yield production. Wind plays a critical role in the growth and development of crops in many ways. Fast winds can significantly reduce crop yield. The most damaging effect wind has on plants is breakage, or greensnap. Wind can also cause abrasions and tear leaves. Root or stem lodging can also occur due to high winds. A secondary physical effect wind plays in crop growth is increased transpiration and crop water use. However there are some positive effects of wind. The shaking of crops caused by wind can increase the plants mechanical strength and root to shoot ratio. These stronger plants have thicker and wider leaves, and may be less affected by moisture stress (Elmore, et al. 2005).

Weather Dummy Variables

A dummy variable for years with extreme drought was created to help capture the effects of drought on yield. The "tree-ring" reconstruction of the Palmer Drought Severity Index (PDSI) was used to select drought years for Alabama. This reconstruction was done for North America for all years before and including 2003 and can be found on the National Climatic Data Center (NCDC) website (http://www.ncdc.noaa.gov/cgi-bin/paleo/pd04plot.pl). Each composite image of the summer months June-August was examined for 1986-2003. The years 1986, 1988, 1998, 2000, and 2002 were selected as drought years. These years all had negative PDSI values which indicate dry conditions. For years 2004 and 2005 the USDA U.S. Drought Monitor Archives were used (http://drought.unl.edu/dm/archive.html). Drought conditions were not found in either year.

Also a dummy variable was created to capture hurricane damage to crops in southern Alabama. Because hurricanes make landfall on the Gulf Coast and then lose strength as they move inland only southern counties were selected to represent damaging hurricane winds and rains. Counties selected included Autauga County and Elmore County as well as all counties located in the Gulf, Costal Plain, and Prairie climate divisions. The years 1995, 2004, and 2005 were selected to illustrate damages done by Hurricane Opal, Ivan, and Katrina. Hurricane Opal made landfall on October 4th 1995. In 1995 the harvesting of corn began in late July, by October there was little corn for Opal to damage. Cotton, Peanuts, and Soybeans harvest began in September, and when Opal arrived in Alabama they were all vulnerable to her heavy rains and high winds. Cotton was severly damaged (Hudson, 1995). Hurricane Ivan arrived in Alabama on September 16th, 2004. Ivan's effect on crop production was a critical concern of the USDA's State Statistical Office. They increased the monthly crop report surveys in September, November, and again in December to asses the impacts of Ivan. The crop production effects for Alabama were similar to that of Opal. Cotton suffered the most of all

Alabama's row crops. Un-harvested fields of corn also suffered minimal to severe damage. Peanut and soybean fields had little to no damage (Vanderberry, 2004). The very next year on August 29th, 2005 Hurricane Katrina hit Alabama's crop production hard. Katrina's extreme winds and heavy rains damaged cotton and corn fields similarly to Ivan (Schnepf and Chite, 2005). A dummy variable for Opal, Ivan, and Katrina was created for Corn and Cotton.

Policy Dummy Variables

It is important when looking at crop yield to take into account government legislation affecting agricultural programs. These programs can make major changes to agriculture policy, and in return change the planting and land use decisions of agricultural producers. This study looks at the Federal Agriculture Improvement and Reform Act of 1996, and the Farm Security and Rural Investment Act of 2002. By creating a separate dummy variable for each policy this study hopes to capture any significant effects either policy may have had on Alabama crop production during the years of 1996-2005.

The Federal Agriculture Improvement and Reform Act of 1996 made significant changes in U.S. agricultural policies. Signed into law in April of 1996, the Act was designed to guide agricultural programs from 1996-2002. Title I of the 1996 Act, known as the Agricultural Market Transition Act (AMTA), provided the most significant change to long-standing U.S. agricultural policies. Farmers who participated in any of the 1991-1995 programs for wheat, feed grains, cotton, or rice were given a series of predetermined annual contract payments as long as they adhered to a Production Flexibility Contract (PFC); drastically changing the approach used for making direct payments to farmers. The 1996 Act also eliminated target prices, deficiency payments, and production adjustment programs. Most importantly the AMTA lifted restrictions on the use of cropland enrolled in commodity programs allowing for more flexibility in farmers planting decisions. However some programs involving fruits and vegetables were excluded (Nelson, 1996).

The AMTA continued to base nonrecourse commodity loan rates on a moving average of recent past market prices, setting maximum commodity loan rates equal to 1995 levels. Marking loan provisions for wheat, feed grains, oilseeds, rice, and upland cotton were made available to producers if market prices fell below commodity loan rates. The 1996 Act also modified the price support program for quota peanuts. It held the nonrecourse loan rates for quota peanuts constant for 1996 through 2002 at $610 per ton, and the cost-of-production estimates were no longer used as the basis for support. The loan rate for additional peanuts ensured the Commodity Credit Corporation (CCC) no losses from the sale or disposal of additional peanuts (Nelson, 1996).

By 2002 U.S. agricultural producers witnessed depressed prices for all major agricultural commodities and frail outlooks for short-term price recovery. Record government payment in recent years also contributed to the passage of the Farm Security and Rural Investment Act of 2002. The Farm Act of 2002 had a six year lifespan from 2002-2007 and was similar to the Farm Act of 1996. The market loan program continued with slightly higher rates than the Farm Act of 1996, and provisions for fixed annual payments were continued at similar rates. It also retained planting flexibility by allowing for updating base acreages. One new program introduced by the Farm Act 2002 was the counter-cyclical program (CCP) which established direct payment to producers for supplemental and disaster payments (Tiller et al., 2009). The Farm Act of 2002 also ended the marketing quota program for peanuts. Peanut quota owners were given a buyout payment and made peanut producers eligible for crop commodity programs (Dohlman et al., 2004).

Models

One of the main objectives of this study is to expand independent weather variables used by previous studies to improve regression results explaining crop yield response to moisture stress. In order to test this hypothesis both an unrestricted model and a restricted model were tested. Included in the unrestricted model were additional independent weather variables, weather dummy variables, and policy dummy variables. This analysis used the framework from Isik and Devadoss (2006), Schlenker et al. (2006), and Peiris and McNicol (1996) to form five unrestricted models to illustrate crop yield response to drought in Alabama. How each previous study contributed to the formation of the models is explained below, and a review of each of these studies can be found in the previous chapter.

Isik and Devadoss (2006) performed both a linear and quadratic regression to find the impact of precipitation and temperature on average crop yields. Their use of crop yields as the dependent variable was applied for this study. This study used a semi-logarithmic model, and the natural log of crop yield per acre was used as the dependent variable. Schlenker et al. (2006) examined the impact of global warming on U.S. Agriculture by regressing county level data for U.S. counties located east of the 100th Meridian. They used growing degree days (GDD), and GDD squared, square root of stress degree days, average precipitation, and average precipitation squared as the weather variables in their model. The five independent weather variables (Schlenker et al., 2006) were used as a guideline for this study, and are nested in the five crop models. Also used as a guideline for this study was from Schlenker et al. was the inclusion of soil property K factor. Peiris and McNicol (1996) also expanded weather variables further to include solar radiation, wind speed, and relative humidity in their model. These additional weather variables can also be found in the five crop models: equation (4.5) is the corn model, equation (4.6) is the cotton model, equation (4.7) is the hay model, equation (4.8) is the peanut model, and equation (4.9) is the soybean model. The restricted models for corn, cotton, hay, peanuts, and soybeans including only the five independent weather variables presented by Schlenker et al. are given by equations (4.10) through (4.14) respectively. Variables for each model and their definitions are listed in Table 4.4.

Table 4.4 Indepentent Variables and Definitions

Variable	Definitions
Y	Crop Yield Per Acre
GDDcorn	Corn Growing Degree Days (50-86 ºF) in Thousands
$GDDcorn^2$	Corn GDD (50-86 ºF) Squared
GDDcotton	Cotton Growing Degree Days (60-86 ºF) in Thousands
$GDDcotton^2$	Cotton GDD (60-86 ºF) Squared
GDDhay	Hay Growing Degree Days (40-86 ºF) in Thousands
$GDDhay^2$	Hay GDD (40-86 ºF) Squared
GDDpeanut	Peanut Growing Degree Days (56-86 ºF) in Thousands
$GDDpeanut^2$	Peanut GDD (56-86 ºF) Squared
GDDsoy	Soybean Growing Degree Days (50-86 ºF) in Thousands
$GDDsoy^2$	Soybean GDD (50-86 ºF) Squared
SqrtTSDD	Square Root of Temperature Stress Degree Days
Precip	Average Precipitation in mm
$Precip^2$	Average Precipitation Squared
CVprecip	Coefficient of Variation for Precipitation
Rad	Average Solar Radiation
Humidity	Average Relative Humidity
Wind	Average Wind Speed
K*precip	K Factor and Average Precipitation Interaction
Drought	Drought Dummy for Years 86, 88, 98, 00, & 02
Hurricane	Hurrican Dummy for Years 95, 04, & 06
Time	Time Intercept
Policy96	Farm Act 1996 Dummy
Policy02	Farm Act 2002 Dummy

$$\ln y_{it} = a_{it} + b_{it}\,\text{Time} + c_{it}\,\text{GDDcorn} + d_{it}\,\text{GDDcorn}^2 + e_{it}\,\text{SqrtTSDD} + f_{it}\,\text{Precip} + g_{it}\,\text{Precip}^2 + h_{it}\,\text{CVprecip} + i_{it}\,\text{Rad} + j_{it}\,\text{Wind} + k_{it}\,\text{Humidity} + l_{it}\,\text{K*precip} + m_{it}\,\text{Drought} + n_{it}\,\text{Hurricane} + o_{it}\,\text{Policy96} + p_{it}\,\text{Policy02} + \mu_{it} \tag{4.5}$$

$$\ln y_{it} = a_{it} + b_{it}\,\text{Time} + c_{it}\,\text{GDDcotton} + d_{it}\,\text{GDDcotton}^2 + e_{it}\,\text{SqrtTSDD} + f_{it}\,\text{Precip} + g_{it}\,\text{Precip}^2 + h_{it}\,\text{CVprecip} + i_{it}\,\text{Rad} + j_{it}\,\text{Wind} + k_{it}\,\text{Humidity} + l_{it}\,\text{K*precip} + m_{it}\,\text{Drought} + n_{it}\,\text{Hurricane} + o_{it}\,\text{Policy96} + p_{it}\,\text{Policy02} + \mu_{it} \tag{4.6}$$

(4.7) $ln y_{it} = a_{it} + b_{it}\,\text{Time} + c_{it}\,\text{GDDhay} + d_{it}\,\text{GDDhay}^2 + e_{it}\,\text{SqrtTSDD} + f_{it}\,\text{Precip} + g_{it}\,\text{Precip}^2 + h_{it}\,\text{CVprecip} + i_{it}\,\text{Rad} + j_{it}\,\text{Wind} + k_{it}\,\text{Humidity} + l_{it}\,\text{K*precip} + m_{it}\,\text{Drought} + n_{it}\,\text{Policy96} + o_{it}\,\text{Policy02} + \mu_{it}$

(4.8) $ln y_{it} = a_{it} + b_{it}\,\text{Time} + c_{it}\,\text{GDDpeanut} + d_{it}\,\text{GDDpeanut}^2 + e_{it}\,\text{SqrtTSDD} + f_{it}\,\text{Precip} + g_{it}\,\text{Precip}^2 + h_{it}\,\text{CVprecip} + i_{it}\,\text{Rad} + j_{it}\,\text{Wind} + k_{it}\,\text{Humidity} + l_{it}\,\text{K*precip} + m_{it}\,\text{Drought} + n_{it}\,\text{Policy96} + o_{it}\,\text{Policy02} + \mu_{it}$

(4.9) $ln y_{it} = a_{it} + b_{it}\,\text{Time} + c_{it}\,\text{GDDsoy} + d_{it}\,\text{GDDsoy}^2 + e_{it}\,\text{SqrtTSDD} + f_{it}\,\text{Precip} + g_{it}\,\text{Precip}^2 + h_{it}\,\text{CVprecip} + i_{it}\,\text{Rad} + j_{it}\,\text{Wind} + k_{it}\,\text{Humidity} + l_{it}\,\text{K*precip} + m_{it}\,\text{Drought} + n_{it}\,\text{Policy96} + o_{it}\,\text{Policy02} + \mu_{it}$

(4.10) $ln y_{it} = a_{it} + b_{it}\,\text{Time} + c_{it}\,\text{GDDcorn} + d_{it}\,\text{GDDcorn}^2 + e_{it}\,\text{SqrtTSDD} + f_{it}\,\text{Precip} + g_{it}\,\text{Precip}^2 + \mu_{it}$

(4.11) $ln y_{it} = a_{it} + b_{it}\,\text{Time} + c_{it}\,\text{GDDcotton} + d_{it}\,\text{GDDcotton}^2 + e_{it}\,\text{SqrtTSDD} + f_{it}\,\text{Precip} + g_{it}\,\text{Precip}^2 + \mu_{it}$

(4.12) $ln y_{it} = a_{it} + b_{it}\,\text{Time} + c_{it}\,\text{GDDhay} + d_{it}\,\text{GDDhay}^2 + e_{it}\,\text{SqrtTSDD} + f_{it}\,\text{Precip} + g_{it}\,\text{Precip}^2 + \mu_{it}$

$$(4.13)\quad \mathit{ln}\mathrm{y}_{it} = \mathrm{a}_{it} + \mathrm{b}_{it}\,\mathrm{Time} + \mathrm{c}_{it}\,\mathrm{GDDpeanut} + \mathrm{d}_{it}\,\mathrm{GDDpeanut}^2 + \mathrm{e}_{it}\,\mathrm{SqrtTSDD} + \mathrm{f}_{it}\,\mathrm{Precip} + \mathrm{g}_{it}\,\mathrm{Precip}^2 + \mu_{it}$$

$$(4.14)\quad \mathit{ln}\mathrm{y}_{it} = \mathrm{a}_{it} + \mathrm{b}_{it}\,\mathrm{Time} + \mathrm{c}_{it}\,\mathrm{GDDsoy} + \mathrm{d}_{it}\,\mathrm{GDDsoy}^2 + \mathrm{e}_{it}\,\mathrm{SqrtTSDD} + \mathrm{f}_{it}\,\mathrm{Precip} + \mathrm{g}_{it}\,\mathrm{Precip}^2 + \mu_{it}$$

V. RESULTS

Average crop yields for each commodity from 1986-2005 were collected from the United States Department of Agriculture's NASS website. We then excluded the counties that had more than three years of missing yield data for each commodity. The yield and weather data was combined for each county that remained. The multiple imputation (MI) procedure was chosen to estimate the incomplete cases. In SAS a substantial number of statistical analysis procedures exclude observations with any variables that have missing values (SAS, 2000). For Proc Panel to work correctly a complete and balanced panel data set is required. The Proc MI procedure draws a random sample of the missing values from its distribution, and results in a valid statistical inference that reflects the uncertainty due to the missing values. First the missing data are filled in *m* times to generate *m* complete data sets. Then the *m* complete data sets are analyzed using standard statistical analyses. Finally the results from the *m* complete data sets are combined to produce the results. MI does not attempt to estimate the missing values through simulation (SAS, 2000). For data sets where there are incomplete observations the multiple imputation is a well-established technique for estimation (Carpenter et al., 2006). Multiple imputation reduces the bias that may occur in studies that delete incomplete data, by allowing researchers to complete the missing values. In recent years there has been increased literature on multiple imputation and how researchers should deal with missing data (Penn, 2007). These studies include Schafer, 1997; Vriens and Melton, 2002; Schafer and

Graham, 2002; Raghunathan, 2004; Little and Rubin, 2002; Carpenter et al, 2005; and Penn, 2007. Once each of the commodity data were complete, models for each crop and their weather variables were selected.

This study used panel data to examine group effects and time effects by using the fixed effects model. Each model was then run in SAS 9.1 using Proc Panel. The models were first run using a random effects model. The Hausman *m* statistic for all models was statistically significant at the 5% or 1% level indicating that random effects were not present. In order to include dummy variables the one way model was selected and the intercepts across counties in Alabama were examined. In order to capture time effects, an annual time variable was created within the model. Group differences in the intercepts are examined by the one-way fixed least squares dummy variable model (LSDV). The fixed effect model creates as many dummy variables as the number of cross sections, and then drops the last dummy for a reference point. LSDV can be problematic when there are a large number of cross sections in the panel data set. Another option for fixed effects models with large number or cross sections is the within effects model, which does not use dummy variables and provides identical parameter estimates of the LSDV model. However the within effects model no intercept, has small MSE and incorrect standard errors and R2 values (Park, 2008).

The PANEL procedure in SAS was chosen because it uses the LSDV model and allows users to fit the within effects model and still reports correct MSE, SEE, R2, and standard errors for the LSDV1 model without the creation of dummy variables for each cross section. Also, this procedure uses the F test for the fixed group effects. In order to accomplish this, the data must be sorted by variables to appear in the ID statement of the

PANEL procedure (Park, 2008). For this study the data were sorted by county and the intercept for each model is the last county with crop yield for that commodity. The intercept for the corn model is Wilcox County, the cotton model is Tuscaloosa County, the hay model is Winston County, the peanut model is Russell County, and the soybean model is Talladega County.

An F test was then used to test the significance of the additional variance explained by the unrestricted model. The restricted model (Model 1) has k_1 independent variables with variance explained by R_1^2. The unrestricted model (Model 2) has $k_1 + k_2$ independent variables with variance explained by R_2^2. The F test statistic shown in equation (5.1) can be compared to the critical values of the F distribution with k_2 and $n - (k_1 + k_2) - 1$ degrees of freedom, where n is the number of observations:

$$(5.1) \qquad F = \frac{(R_2^2 - R_1^2)/k_2}{(1 - R_2^2)/(n - (k_1 + k_2) - 1)}$$

The null hypothesis for this test statistic is that all the coefficients for the additional independent variables included in the unrestricted model are zero. The alternative hypothesis is that at least one of the additional independent variables is non-zero. For this study the hypotheses for the corn and cotton models are as follows:

$\mathbf{H}_O$: h_{it} *CVprecip* = i_{it} *Rad* = j_{it} *Wind* = k_{it} *Humidity* = l_{it} *K*precip* = m_{it} *Drought* = n_{it} *Hurricane* = o_{it} *Policy96* = p_{it} *Policy02* = 0

$\mathbf{H}_A$: h_{it} *CVprecip* ≠ 0 or i_{it} *Rad* ≠ 0 or j_{it} *Wind* ≠ 0 or k_{it} *Humidity* ≠ 0 or l_{it} *K*precip* ≠ 0 or m_{it} *Drought* ≠ 0 or n_{it} *Hurricane* ≠ 0 or o_{it} *Policy96* ≠ 0 or p_{it} *Policy02* ≠ 0

The hypotheses for the hay, peanut, and soybean models are as follows:

$\mathbf{H}_O : h_{it}\, CVprecip = i_{it}\, Rad = j_{it}\, Wind = k_{it}\, Humidity = l_{it}\, K{*}precip = m_{it}\, Drought =$
$n_{it}\, Policy96 = o_{it}\, Policy02 = 0$

$\mathbf{H}_A : h_{it}\, CVprecip \neq 0$ or $i_{it}\, Rad \neq 0$ or $j_{it}\, Wind \neq 0$ or $k_{it}\, Humidity \neq 0$ or $l_{it}\, K{*}precip \neq 0$
or $m_{it}\, Drought \neq 0$ or $n_{it}\, Policy96 \neq 0$ or $o_{it}\, Policy02 \neq 0$

The results generated by the previously described models, for both the restricted model and the unrestricted model are reported below. The results for the F test are also evaluated.

Corn Model Results

Table 5.1 Results for Corn Model

Variable	Restricted Model Coeff. Estimates (Std. Err.)	Unrestricted Model Coeff. Estimates (Std. Err.)
Intercept	0.855 (2.264)	4.343 (2.184) **
Time	0.023 (0.002) ***	0.001 (0.003)
GDD (50-86 °F)	1.528 (1.072)	0.952 (0.677)
GDD^2 (50-86 °F)	-0.143 (0.127)	-0.073 (0.081)
SqrtTSDD	-0.061 (0.004) ***	-0.041 (0.005) ***
Precip	0.089 (0.045) *	0.159 (0.056) ***
Precip^2	-0.007 (0.005)	-0.010 (0.004) **
CVprecip		-0.072 (0.023) ***
Rad		-0.026 (0.030)
Humidity		-0.023 (0.010) **
Wind		0.013 (0.145)
K*precip		-0.255 (0.122) **
Drought		-0.371 (0.038) ***
Hurricane		0.057 (0.020) ***
Policy96		0.163 (0.028) ***
Policy02		0.325 (0.032) ***
Observations	960	960
R^2	0.551	0.673

The astrisks indicate a 1%, 5%, and 10% significance different from zero by ***, **, *, respectively.

In the two models, k_2= 9 and $n - (k_1 + k_2) - 1$= 896. Using equation (5.1) and the R^2 values from Table (5.1) the empirical F value was calculated to be F = 37.009. For the corn model the empirical F value exceeds the critical value of F = 2.339, assigned at the 1% level. We reject the null hypothesis, and find the unrestricted model for corn is a better fit than the restricted model.

The Time variable was found to be positive and significant at the 1% level in the restricted model, but in the unrestricted corn model the Time variable is no longer significant. This could indicated that increasing yield trends from 1986-2005 are captured by other variables not included in the restricted model such as government policy. The SqrtTSDD is negative and significant at the 1% level indicating that an increased stress degree day during the growing season reduces corn yields. Precipitation is found to be positive and significant at the 1% level and $Precip^2$ is negative and significant at the 5% level. More informing however is that the variable CVprecip is negative and significant at the 1% level. As the variation of precipitation increases moisture stress will increase, causing yield to reduce. Also humidity is found to be negative and significant at the 5% level. Because humidity slows down evapotranspiration this result seems odd. However humidity can be related to cloud cover, and reduced sunlight may have a negative effect on yield. The K*precip variable is negative and significant at the 5% level. This shows that the interaction of soil erodibility and precipitation reduces crop yield, most likely due to higher runoff and nutrient loss.

During drought years corn yield reduction is significant at the 1% level. Another interesting result to notice is the hurricane dummy. As explained in the previous chapter some corn damage was seen after all three hurricanes. However this model found that the hurricane dummy was positive and significant at the 1% level. This positive effect of hurricanes could be attributed to the increased precipitation late in the season. Also in the unrestricted model both the policy dummy variables, Policy96 and Policy02 are positive and significant at the 1% level. The 1996 Farm Act lead to a large acreage shift to corn as a result of increased planting flexibility and high prices that favored planting corn.

Cotton Model Results

Table 5.2 Results for Cotton Model

Variable	Restricted Model Coeff. Estimates (Std. Err.)			Unrestricted Model Coeff. Estimates (Std. Err.)		
Intercept	1.718	(1.510)		13.359	(2.217)	***
Time	0.007	(0.002)	***	0.000	(0.004)	
GDD (60-86 ºF)	3.669	(1.163)	***	3.877	(1.030)	***
GDD^2 (60-86 ºF)	-0.630	(0.225)	***	-0.681	(0.193)	***
SqrtTSDD	-0.047	(0.004)	***	-0.037	(0.008)	***
Precip	0.098	(0.049)	**	-0.031	(0.081)	
$Precip^2$	-0.008	(0.005)		0.001	(0.006)	
CVprecip				-0.098	(0.026)	***
Rad				-0.226	(0.042)	***
Humidity				-0.082	(0.018)	***
Wind				-0.482	(0.142)	***
K*precip				0.171	(0.113)	
Drought				-0.077	(0.028)	***
Hurricane				-0.129	(0.049)	***
Policy96				0.017	(0.043)	
Policy02				0.131	(0.058)	**
Observations	620			620		
R^2	0.434			0.507		

The astrisks indicate a 1%, 5%, and 10% significance different from zero by ***, **, *, respectively.

In the two models, $k_2 = 9$ and $n - (k_1 + k_2) - 1 = 573$. Using equation (5.1) and the R^2 values from Table (5.2) the empirical F value was calculated to be F = 9.470. For the cotton model the empirical F value exceeds the critical value of F = 2.339, assigned at the 1% level. We reject the null hypothesis, and find the unrestricted model for cotton is a better fit than the restricted model.

The Time variable in the unrestricted cotton model saw similar results as the corn model. Also the SqrtTSDD was negative and significant at the 1% level. In contrast with the corn model, the cotton model GDD was positive and significant at the 1% level GDD^2 was negative and significant at the 1% level. The significance of all three temperature weather variables in the cotton model suggests that cotton yield is more sensitive to temperature than precipitation. CVprecip was negative and significant at the 1% level. Also in the cotton model it is interesting to note that all three of the evapotranpiration variables radiation, humidity, and wind speed were negative and significant at the 1% level.

As expected the drought and hurricane dummy variables were negative and significant at the 1% level. However the Policy variables are not as easy to interpret with cotton. Because the Farm Act of 1996 directly changed policy on cotton you would expect to see significance there. The Farm Act of 2002 was passed at a critical time for U.S. cotton producers. Cotton prices were 60% lower than they had been prior to the Farm Act of 1996. Due to low cotton prices, total government payment for assistance to cotton producers exceeded $15.5 billion during 1998-2003 (Tiller and Brown). Because the Farm Act of 2002 increased the financial situations of cotton growers in Alabama as well as ended the quota peanut program it is not shocking that the Policy02 variable would be positive and significant at the 5% level. If the Policy02 dummy is removed from the cotton model the R^2 increases to 0.522, shown in Table (5.3).

Table 5.3 Second Unrestricted Cotton Model

Variable	Coeff. Estimates (Std. Err.)
Intercept	13.863 (2.086) ***
GDD (60-86 ºF)	3.433 (1.008) ***
GDD^2 (60-86 ºF)	-0.594 (0.188) ***
SqrtTSDD	-0.033 (0.008) ***
Precip	0.004 (0.074)
$Precip^2$	-0.004 (0.005)
CVprecip	-0.080 (0.023) ***
Rad	-0.244 (0.043) ***
Humidity	-0.085 (0.017) ***
Wind	-0.314 (0.137) **
K*precip	0.167 (0.113)
Drought	-0.071 (0.031) **
Hurricane	-0.243 (0.044) ***
Time	0.017 (0.003) ***
Policy96	-0.130 (0.035) ***
Observations	620
R^2	0.522

The astrisks indicate a 1%, 5%, and 10% significance different from zero by ***, **, *, respectively.

This second unrestricted cotton model is still a better fit than the restricted model with an F value calculated to be F =13.78. Also all variables other than Policy96 have the same effects at the same significant level as the unrestricted model in Table (5.2). This suggests that the second model is a more complete representation of cotton yields during 1986-2005. The cotton model that included Policy 02 was overestimating the effects of that farm act and failed to capture the effects of Policy96. In the second cotton model the Farm Act 1996 dummy variable is negative and significant at the 1% level. After the Farm Act of 1996, Alabama saw a reduced cotton acreage reduction due to more attractive corn and soybean prices in comparison with cotton prices. These lower cotton prices in combination with lifted acreage restrictions may have lead to cotton being planted on less fertile land resulting in lower yields (USDA 1997). This study finds that cotton yield per acre was reduced due to government policy, and our results are similar to the findings of Luttrell and Gilbert (2001).

Hay Model Results

Table 5.4 Results for Hay Model

	Restricted Model	Unrestricted Model
Variable	Coeff. Estimates (Std. Err.)	Coeff. Estimates (Std. Err.)
Intercept	-4.816 (2.152) **	-0.249 (1.985)
Time	0.012 (0.001) ***	0.009 (0.002) ***
GDD (40-86 ºF)	1.649 (0.724) **	1.271 (0.566) **
GDD^2 (40-86 ºF)	-0.128 (0.061) **	-0.096 (0.049) **
SqrtTSDD	-0.023 (0.002) ***	-0.017 (0.002) ***
Precip	0.216 (0.026) ***	0.311 (0.040) ***
Precip^2	-0.021 (0.003) ***	-0.024 (0.004) ***
CVprecip		-0.027 (0.013) **
Rad		-0.062 (0.021) ***
Humidity		-0.028 (0.007) ***
Wind		-0.100 (0.102)
K*precip		-0.293 (0.124) **
Drought		-0.088 (0.018) ***
Policy96		0.003 (0.016)
Policy02		0.040 (0.023) **
Observations	1340	1340
R^2	0.486	0.521

The astrisks indicate a 1%, 5%, and 10% significance different from zero by ***, **, *, respectively.

In the two models, k_2= 8 and $n-(k_1+k_2)-1$= 1258. Using equation (5.1) and the R^2 values from Table (5.4) the empirical F value was calculated to be F = 11.417. For the hay model the empirical F value exceeds the critical value of F = 2.339, assigned at the 1% level. We reject the null hypothesis, and find the unrestricted model for hay is a better fit than the restricted model.

Weather variables are unique to hay production because hay is cut several times during the growing season. In the unrestricted model we see that all variables except for the Intercept, Wind, and Policy96 are statistically significant. GDD is positive and significant at the 5% level, Precip and Policy02 are positive and significant at the 1% level. All three of the evapotraspitation variables are negative and significant at the 1% level. It is important to notice the CVprecip, Precip², and K*precip are all negative and significant at the 1% level. Similar to other crops as CVprecip and K*precip increases yield will decrease. Interesting to note too much rain can also play a large role when discussing hay production. If it rains or is too humid after hay is cut, the hay cannot dry enough to be bailed. Hay left cut for too long can rot which would reduce yield per acre.

Peanut Model Results

Table 5.5 Results for Peanut Model

Variable	Restricted Model Coeff. Estimates (Std. Err.)			Unrestricted Model Coeff. Estimates (Std. Err.)		
Intercept	3.552	(3.397)		8.258	(2.618)	***
Time	0.003	(0.002)		-0.002	(0.004)	
GDD (56-86 ºF)	1.944	(2.052)		2.590	(1.595)	
GDD² (56-86 ºF)	-0.236	(0.310)		-0.339	(0.233)	
SqrtTSDD	-0.018	(0.004)	***	-0.019	(0.006)	***
Precip	0.236	(0.056)	***	0.196	(0.109)	*
Precip²	-0.022	(0.006)	***	-0.022	(0.010)	**
CVprecip				-0.004	(0.017)	
Rad				-0.087	(0.024)	***
Humidity				-0.044	(0.009)	***
Wind				-0.249	(0.169)	
K*precip				0.135	(0.354)	
Drought				-0.021	(0.022)	
Policy96				-0.003	(0.033)	
Policy02				0.121	(0.047)	***
Observations	240			240		
R²	0.462			0.494		

The astrisks indicate a 1%, 5%, and 10% significance different from zero by ***, **, *, respectively.

In the two models, $k_2 = 8$ and $n - (k_1 + k_2) - 1 = 213$. Using equation (5.1) and the R^2 values from Table (5.5) the empirical F value was calculated to be F = 1.701. For the peanut model the empirical F value exceeds the critical value of F = 1.612, assigned at the 10% level. We reject the null hypothesis, and find the unrestricted model for peanut is a better fit than the restricted model.

Peanuts go through a rapid vegetative growth stage where adequate moisture is available. Precipitation is very important early in the growing season due to this vegetative growth. In the unrestricted model we see Precip is positive and significant at the 10% level. The $Precip^2$ is negative and significant at the 5% level. This may be because of heave rains over saturating peanuts in the ground. Also hurricane damage could play a role in the estimation of negative affects attributed to precipitation. Temperatures in the GDD range of 56-86 ºF shouldn't affect peanut yield because peanut flowers open and night and are self-fertilized before high afternoon temperatures can damage the flowers. However the SqrtTSDD is negative and significant at the 1% level due to vegetative stress that would occur. Rad and Humidity are negative and significant at the 1% level. Wind also doesn't affect peanut pollination because that is done internally inside the flower and flower stalk (Extension 2009).

The Policy02 was positive and significant at the 1% level. After the Farm Act of 2002 was passed peanut producers took advantage of planting flexibility by shifting peanut production to higher yielding areas. Also producers that may have not planted peanuts in previous years were now allowed to do so with the end of the peanut quota program.

Soybean Model Results

Table 5.6 Results for Soybean Model

Variable	Restricted Model Coeff. Estimates (Std. Err.)		Unrestricted Model Coeff. Estimates (Std. Err.)	
Intercept	5.628 (2.781)	**	13.232 (1.863)	***
Time	0.013 (0.002)	***	0.016 (0.004)	***
GDD (50-86 ºF)	-1.342 (1.346)		-1.651 (0.779)	**
GDD^2 (50-86 ºF)	0.184 (0.164)		0.200 (0.094)	**
SqrtTSDD	-0.048 (0.005)	***	-0.042 (0.005)	***
Precip	0.230 (0.062)	***	0.219 (0.079)	***
Precip^2	-0.021 (0.007)	***	-0.026 (0.006)	***
CVprecip			0.000 (0.035)	
Rad			-0.147 (0.033)	***
Humidity			-0.047 (0.012)	***
Wind			-0.115 (0.151)	
K*precip			0.181 (0.134)	
Drought			0.117 (0.024)	***
Policy96			-0.159 (0.033)	***
Policy02			0.061 (0.045)	
Observations	440		440	
R^2	0.506		0.566	

The astrisks indicate a 1%, 5%, and 10% significance different from zero by ***, **, *, respectively.

In the two models, $k_2 = 8$ and $n - (k_1 + k_2) - 1 = 403$. Using equation (5.1) and the R^2 values from Table (5.6) the empirical F value was calculated to be F = 7.075. For the soybean model the empirical F value exceeds the critical value of F = 2.356, assigned at the 1% level. We reject the null hypothesis, and find the unrestricted model for soybean is a better fit than the restricted model.

Soybeans are similar to peanuts in there growth and development. In this unrestricted model SqrtTSDD is negative and significant at the 1% level and Precip^2 is negative and significant at the 1% level. GDD is negative and significant at the 5% level and GDD^2 is positive and significant at the 5% level, indicating that soybeans are significantly affected by high temperatures. Also Precip is positive and significant at the

1% level. The same as the peanut model, the soybean model sees no significance with CVprecip , because both crops are considered somewhat drought tolerant and their roots extend deep into the soil. The drought dummy is positive and significant at the 1% level. Radiation and Humidity are both negative and significant at the 1% level as well. The Policy96 dummy is negative and significant at the 1% level. This decrease in yield per is similar to the effect of the Farm Act of 1996 on Cotton.

VI. CONCLUSION

This study identified a framework for analyzing crop yield response of major crops to climate fluctuations in Alabama. This analytical framework expanded the weather variables examined by previous studies to improve regression results for crop yield response to moisture stress. In order to test this hypothesis both an unrestricted model and a restricted model for corn, cotton, hay, peanuts, and soybeans were tested. Included in the unrestricted model were additional independent weather variables, weather dummy variables, and policy dummy variables. An F test was then used to test the significance of the additional variance explained by the unrestricted model. The unrestricted models for corn, cotton, hay, and soybeans were found to be a better fit than the restricted model, with empirical F values exceeding the critical F value, at the 1% level. The unrestricted peanut model was found to be a better fit that the restricted model, at the 10% level.

Because each drought year is unique in its climatic characteristics and impacts drought can devastate even very productive lands and can go undetected. To estimate the impacts of weather variables on crop yields this study econometrically use the additional weather variables CVprecip, Radiation, Humidity, Wind, K*precip, Hurricane, Drought, Policy96, and Policy02. All were found to be significant in at least one or all the models. The onset and end of a drought are difficult to determine and its impacts can not immediately be observed by eye or even ground data. It is easy to determine drought if plants are showing visible signs of distress. What is difficult to determining is how unobservable drought damage could be affecting crop yields. The crop yield study for corn, cotton, hay, peanuts, and soybeans for the years 1986 through 2005 found the impacts of unobservable weather variables (i.e. evapotranspiration and erosion) to significantly reduce crop yields.

Although drought is frequent in the United States there is no national policy to mitigate the impacts. The U.S. Department of Agriculture explains that the National Drought Policy Act was passed through Congress and thus creating the National Drought Policy Commission (NDPC) to advise on developing a comprehensive national policy to mitigate the impacts of drought to improve public awareness, and to achieve federal/nonfederal partnerships for better coordination and response to drought (Motha 2001). Motha explained that in the survey conducted for the final report, the NDPC found that 30 of the 50 states in the United States had drought plans, with most oriented toward relief rather than preparedness. This survey also revealed that in most states, drought responsibilities are normally located in the agencies that are responsible for the functions of agriculture, natural resources, water management, environment, or emergency management. Fewer than five states have independent, designated drought coordinators, while more than 20 states have drought task forces (Motha 2001).

Government legislation affecting agricultural programs has been passed in recent years to increase planting variability and establish more secure financial situations for agricultural producers. These agricultural programs give producers more control over production decisions based on their available land, inputs, and market prices. This study looked at the Federal Agriculture Improvement and Reform Act of 1996, and the Farm

Security and Rural Investment Act of 2002. Both programs were designed to allow producers more flexibility with their land. Additional land was brought into production that was previously idled due to restriction programs. Producers could now respond to signals from the market, which resulted in an economically more efficient agricultural production. This study found both Policy dummy variables to have significance in both the addition and reduction of yield per acre for all major commodities in Alabama: illustrating the important role government policy plays on agriculture.

Both the Federal Agriculture Improvement and Reform Act of 1996, and the Farm Security and Rural Investment Act of 2002 brought idle agricultural lands into production and allowed producers more flexibility in their farm management decisions. However flexible planting and price support programs don't protect producers from reduced yields caused by drought. Government incentives for better management practices and government subsidies for drought tolerant hybrid seed could reduce the impact of drought. Because drought impacts are not structural or localized, government development of drought contingency plans are hindered by many complications. Accurate, reliable, and timely estimates of the impacts of drought are becoming increasingly important as world demand for food and feed increases.

The impact of drought in the southeastern United States is likely to increase in magnitude as fresh water becomes increasingly scarce and as populations grow. Reliable and up to date information related to surface moisture conditions could be used to forecast crop yields, assess distressed areas for allocation of disaster relief funds, and could help resource managers and government officials plan ahead for difficult financial times. In the state of Alabama drought has cause serious problems for farming communities for the past several years and most recently in the summer of 2006. These conditions place farming communities in difficult financial situations which also substantially affects other economic sectors within the state.

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APPENDIX

The Data Used in Thesis

Alabama County Corn Yields 1986-2005

Year	Autauga	Baldwin	Barbour	Blount	Butler	Calhoun	Cherokee
1986	38.5	76.5	38.2	66.7	73.3	59.4	47.7
1987	47.7	91.1	77.0	86.9	74.1	90.0	71.0
1988	20.0	60.9	29.4	54.3	45.0	54.5	32.7
1989	62.5	103.3	65.4	85.0	73.5	106.3	73.3
1990	51.3	68.7	51.0	65.3	63.9	76.9	42.9
1991	90.0	93.0	85.2	96.3	87.5	84.4	65.5
1992	71.7	100.8	72.1	123.9	83.8	118.4	101.6
1993	29.4	78.9	51.4	57.1	62.8	64.0	56.1
1994	80.0	112.2	80.0	95.8	85.4	118.6	113.6
1995	50.0	96.0	77.0	61.0	88.0	58.0	52.0
1996	38.0	102.0	54.0	94.0	68.0	91.0	80.0
1997	75.0	99.0	88.0	94.0	77.0	90.0	73.0
1998	33.0	68.0	70.0	83.0	31.0	84.0	65.0
1999	76.0	112.0	110.0	119.0	85.0		107.0
2000	31.0	58.0		53.0	17.0		47.0
2001	71.0		99.0	127.0	66.0		119.0
2002	52.0	94.0	88.0	94.0	40.0	96.0	78.0
2003	120.0	120.0	115.0	128.0	178.0	117.0	132.0
2004	83.0	120.0	93.0	139.0		144.0	143.0
2005	103.0	124.0	114.0				135.0

Corn Yields Continued

Year	Coffee	Colbert	Conecuh	Covington	Crenshaw	Cullman	Dale
1986	42.7	59.7	62.1	45.0	50.0	62.5	33.8
1987	58.9	78.0	66.9	71.0	72.7	85.8	57.0
1988	42.9	55.0	35.3	22.1	46.9	41.2	25.5
1989	79.4	109.1	80.3	87.9	81.4	82.4	82.9
1990	34.2	51.5	64.4	47.8	62.1	55.8	80.5
1991	73.5	50.0	65.0	84.0	71.8	72.9	83.0
1992	93.3	103.3	97.6	83.3	85.3	116.4	71.3
1993	59.6	55.9	61.5	63.5	64.6	65.4	40.0
1994	87.9	121.6	88.7	89.8	90.2	112.6	60.3
1995	66.0	74.0	68.0	78.0	82.0	82.0	65.0
1996	74.0	82.0	70.0	75.0	84.0	97.0	62.0
1997	88.0	100.0	80.0	87.0	91.0	92.0	86.0
1998	42.0	79.0	57.0	32.0	52.0	78.0	40.0
1999	99.0	126.0	94.0	92.0	122.0	110.0	94.0
2000	38.0	99.0	21.0	25.0	18.0	60.0	18.0
2001		145.0				147.0	68.0
2002	88.0	118.0	53.0	76.0	50.0	93.0	54.0
2003	123.0	161.0	120.0	109.0		121.0	113.0
2004	111.0	138.0	97.0	122.0		130.0	90.0
2005	127.0	147.0	98.0	66.0		125.0	94.0

Corn Yields Continued

Year	Dallas	De Kalb	Elmore	Escambia	Etowah	Fayette	Geneva
1986	44.1	49.3	40.8	62.6	53.1	60.0	52.5
1987	60.7	79.8	51.3	91.1	56.7	78.1	67.8
1988	45.5	41.8	51.0	38.1	43.3	50.0	32.3
1989	71.5	90.0	100.0	88.3	88.9	78.6	55.6
1990	53.7	60.6	58.2	89.8	45.6	79.3	53.9
1991	65.4	85.6	88.2	93.0	85.0	78.8	66.7
1992	70.7	123.7	77.3	100.0	106.7	90.7	78.8
1993	41.4	53.8	43.3	70.1	52.4	58.8	48.4
1994	80.0	109.9	97.5	126.1	104.7	71.3	64.7
1995		65.0	46.0	96.0	60.0	83.0	
1996	70.0	92.0	41.0	101.0	83.0	83.0	70.0
1997	75.0	86.0	79.0	109.0	87.0	70.0	85.0
1998	66.0	74.0	36.0	50.0	77.0	54.0	40.0
1999	81.0	101.0	100.0	123.0	98.0	91.0	88.0
2000	48.0	80.0	33.0	38.0	43.0	30.0	53.0
2001	94.0	117.0	95.0			107.0	
2002	76.0	84.0	92.0	81.0	87.0	81.0	96.0
2003	105.0	100.0	117.0	127.0	114.0	104.0	108.0
2004	129.0	136.0	132.0	90.0	104.0	101.0	115.0
2005		129.0	113.0	86.0	132.0	91.0	108.0

Corn Yields Continued

Year	Greene	Hale	Henry	Houston	Jackson	Lamar	Lauderdale
1986	30.0	64.5	34.0	45.0	53.5	54.2	70.0
1987	45.5	82.7	65.8	72.2	65.5	62.5	77.9
1988	38.3	58.9	40.8	60.9	50.5	54.2	34.5
1989	64.0	81.7	86.8	74.5	79.5	87.1	79.3
1990	43.3	56.4	49.9	60.6	60.3	37.8	35.9
1991	74.2	78.4	87.0	91.5	82.9	90.0	54.5
1992	70.0	90.4	67.5	80.0	120.5	84.2	104.0
1993	40.0	49.2	46.8	44.5	54.7	52.9	54.7
1994	68.0	98.5	81.8	82.2	117.4	75.7	96.2
1995	62.0	54.0	63.0		92.0	74.0	95.0
1996		82.0	50.0	67.0	99.0	73.0	80.0
1997	86.0	81.0	91.0	97.0	79.0	59.0	76.0
1998		61.0	48.0	76.0	69.0	52.0	61.0
1999	97.0	121.0	89.0	86.0	98.0	81.0	100.0
2000	25.0	57.0		57.0	80.0	54.0	95.0
2001			88.0				128.0
2002	50.0	95.0	73.0	83.0	85.0	92.0	99.0
2003	84.0	107.0	129.0	127.0	121.0	104.0	145.0
2004	85.0		106.0	107.0	130.0		135.0
2005			112.0	118.0	124.0	83.0	112.0

Corn Yields Continued

Year	Lawrence	Limestone	Lowndes	Macon	Madison	Marengo	Marion
1986	75.0	69.3	56.3	42.2	63.3	54.5	52.3
1987	65.7	58.2	77.2	57.3	71.2	50.0	76.7
1988	31.1	30.3	40.0	30.0	45.9	53.8	47.6
1989	83.3	82.2	96.4	40.0	80.0	62.7	77.5
1990	44.3	41.2	51.3	23.3	49.3	31.1	41.4
1991	78.6	70.2	57.5	40.0	82.0	50.6	53.0
1992	109.2	119.1	64.7	61.3	98.9	64.0	92.0
1993	65.6	66.7	30.0	30.0	50.0	37.9	52.1
1994	110.9	93.9	75.0	58.8	116.7	75.4	95.4
1995	92.0	94.0	38.0		104.0	47.0	68.0
1996	82.0	90.0			93.0	81.0	74.0
1997	108.0	86.0	99.0	94.0	83.0	51.0	65.0
1998	68.0	71.0	34.0	55.0	68.0	57.0	57.0
1999	136.0	112.0	105.0	108.0	121.0	61.0	
2000	99.0	86.0	24.0	40.0	88.0	59.0	55.0
2001	138.0	146.0	84.0		118.0		106.0
2002	115.0	107.0	77.0	79.0	102.0	93.0	
2003	153.0	150.0		121.0	125.0	65.0	
2004	151.0	150.0			137.0		119.0
2005	136.0	139.0			143.0		100.0

Corn Yields Continued

Year	Marshall	Mobile	Monroe	Morgan	Pickens	Pike	Randolph
1986	61.4	77.8	71.0	53.3	55.0	36.2	47.5
1987	86.8	83.0	75.3	55.2	70.0	84.7	57.3
1988	42.3	35.4	45.2	37.1	35.0	69.5	56.3
1989	94.3	91.0	94.8	88.5	55.0	85.0	76.3
1990	64.7	92.9	87.0	60.6	39.1	61.8	43.3
1991	79.8	89.3	95.2	65.4	66.0	93.4	57.1
1992	109.7	89.8	85.2	109.4	71.4	88.1	86.7
1993	43.7	77.6	65.1	53.9	50.0	61.6	50.0
1994	99.5	118.5	89.6	95.3	66.5	97.7	71.4
1995	67.0		87.0	84.0	74.0	90.0	49.0
1996	80.0	95.0	92.0	83.0	55.0	85.0	66.0
1997	78.0	91.0	101.0	88.0	90.0	94.0	66.0
1998	64.0	58.0	54.0	51.0	27.0	74.0	63.0
1999	108.0	89.0	110.0	122.0	63.0	100.0	74.0
2000	70.0	68.0	25.0	78.0		38.0	45.0
2001	103.0	103.0		119.0		98.0	
2002	98.0	75.0	66.0	104.0	63.0	78.0	52.0
2003	116.0	107.0	120.0	126.0		119.0	
2004	113.0		105.0	117.0		116.0	
2005	108.0			128.0		106.0	

Corn Yields Continued

Year	Russell	Sumter	Talladega	Tuscaloosa	Washington	Wilcox
1986	35.0	40.0	72.2	60.0	73.3	50.0
1987	65.8	59.1	76.7	75.2	87.1	65.8
1988	21.4	61.5	65.5	58.9	22.7	40.7
1989	55.6	70.0	49.1	75.0	63.3	78.1
1990	66.9	45.0	37.2	53.7	64.5	82.6
1991	65.7	70.0	90.0	80.0	63.6	85.7
1992	65.0	79.1	88.5	87.4	81.9	79.1
1993	38.3	35.8	70.4	67.6	56.8	58.1
1994	95.0	95.8	97.8	90.9	91.4	90.6
1995	50.0	71.0	55.0	87.0	84.0	90.0
1996	58.0	67.0	95.0	82.0	75.0	61.0
1997	75.0	76.0	117.0	99.0	84.0	89.0
1998	40.0	26.0	65.0	60.0	38.0	40.0
1999	80.0	75.0	123.0	112.0	95.0	97.0
2000			29.0	35.0	23.0	53.0
2001	80.0	75.0		117.0	85.0	
2002	63.0	73.0	105.0	81.0	39.0	53.0
2003		76.0	111.0	120.0	117.0	95.0
2004			134.0	122.0	99.0	
2005		56.0	131.0	108.0	99.0	

Alabama County Cotton Yields 1986-2005

Year	Autauga	Baldwin	Barbour	Blount	Calhoun	Cherokee	Coffee
1986	667	640	508	417	792	253	348
1987	609	476	450	502	895	543	449
1988	579	471	539	437	608	519	420
1989	588	529	585	497	328	593	283
1990	531	605	483	408	300	564	336
1991	767	634	934	688	572	770	685
1992	720	907	830	609	630	691	584
1993	413	798	438	388	350	224	509
1994	620	888	688	713	953	816	539
1995	172	494		421	393	303	473
1996	653	889	723	826	825	852	608
1997	660	760	479			617	347
1998	430	478	567		710	748	333
1999	523	841	616	686	438	384	424
2000	355	571		540		458	248
2001	755	813	652	1047	872	843	524
2002	537	396	438	792	610	580	270
2003	873	722	783	890	907	790	624
2004	713	647	665		1094	900	395
2005	781	661	830		1010	847	706

Cotton Yields Continued

Year	Colbert	Conecuh	Covington	Cullman	Dale	Dallas
1986	491	240	546	584	345	612
1987	600	489	750	553	287	605
1988	448	523	661	463	208	621
1989	502	754	614	398	383	545
1990	434	375	541	411	419	512
1991	533	457	1015	609	600	730
1992	629	571	791	460	630	692
1993	396	580	651	338	490	573
1994	700	743	631	646	661	576
1995	215		507		522	181
1996	821	572	672	632	412	633
1997	528	483	688		410	550
1998	612	308	520	716	243	467
1999	427	560	674	682	451	607
2000	592	356	486	557	381	398
2001	722	637	780	920	600	626
2002	586	595	465	789	314	589
2003	833	738	781		664	788
2004	773	579	536	1024	462	669
2005	623	630	864		779	683

Cotton Yields Continued

Year	Elmore	Escambia	Etowah	Fayette	Geneva	Henry
1986	420	793	348	576	541	293
1987	616	659	449	537	507	470
1988	526	602	331	352	504	375
1989	589	601	291	637	425	419
1990	522	544	403	600	488	426
1991	655	686	494	533	656	779
1992	679	733	686	590	754	696
1993	501	724	233	419	642	454
1994	592	811	888	649	638	683
1995	210	463	339	453	499	509
1996	753	884	681	755	536	499
1997	670	853	577		687	425
1998	593	482	758	642	217	444
1999	576	725	408	411	443	443
2000	421	513	324	360	198	413
2001	879	753	781	700	674	581
2002	561	442	517		458	371
2003	837	858	706	589	693	658
2004	795	567	1178		436	517
2005	735	710	852		640	816

Cotton Yields Continued

Year	Houston	Lauderdale	Lawrence	Lee	Limestone	Macon
1986	404	478	509	398	554	532
1987	432	583	599	398	559	469
1988	490	356	457	433	436	465
1989	468	462	642	403	576	419
1990	402	361	435	362	372	429
1991	625	495	574	737	555	822
1992	706	681	756	534	801	645
1993	447	410	494	485	512	443
1994	619	792	804	715	865	572
1995	592	526	243	361	382	274
1996	427	847	833	739	907	785
1997	428	599	591	675	491	
1998	313	718	788	590	741	544
1999	422	342	438	591	548	626
2000	234	615	543	460	520	309
2001	518	713	703	730	814	785
2002	347	516	598	647	561	496
2003	619	922	773	800	834	764
2004	599	840	826	779	857	763
2005	712	726	701		790	725

Cotton Yields Continued

Year	Madison	Mobile	Monroe	Pike	Shelby	Tuscaloosa
1986	534	832	592	518	408	632
1987	571	790	872	480	576	706
1988	538	647	791	495	399	591
1989	755	1272	772	435	626	581
1990	595	602	628	534	523	671
1991	726	559	957	894	674	718
1992	844	661	902	626	687	713
1993	670	757	775	467	508	537
1994	957	872	928	686	792	735
1995	471	605	574	478	246	457
1996	871	886	924	567	718	775
1997	478	643	864	431		800
1998	711	467	593	383	724	641
1999	557	713	713	433	643	525
2000	758	736	451	213	459	458
2001	857	791	817	508	688	750
2002	624	530	386	331	516	
2003	844		805	723	756	934
2004	1080	703	593	503	795	848
2005	855	571	711	765	800	765

Alabama County Hay Yields 1986-2005

Year	Autauga	Baldwin	Barbour	Bibb	Blount	Bullock	Butler
1986	2.00	1.65	2.00	1.50	2.00	1.63	1.62
1987	2.80	2.56	2.91	2.02	2.21	2.00	2.00
1988	2.75	2.35	1.86	1.91	1.54	2.00	2.75
1989	2.83	2.54	2.00	1.75	2.00	2.18	2.22
1990	2.20	2.44	0.82	1.33	1.91	2.13	2.38
1991	2.54	2.00	2.41	2.05	2.21	2.70	2.35
1992	2.10	2.00	2.69	1.78	2.10	2.17	2.05
1993	2.02	2.16	2.19	2.13	2.00	2.05	2.13
1994	2.35	2.91	3.44	3.02	3.05	3.07	2.58
1995	1.30	2.70	1.70	1.80	2.20	1.80	3.60
1996	1.50	2.30	2.50	2.70	2.70	2.50	3.20
1997	2.20	2.20	2.60	2.60	2.40	2.30	2.70
1998	1.70	1.70	1.90	2.30	2.40	1.90	2.00
1999	2.10	2.70	2.90	2.60	2.80	2.30	2.80
2000	1.40	2.80	1.70	1.40	2.60	1.50	1.40
2001	2.90	2.90	3.20	2.40	2.90	2.90	2.70
2002	1.70	2.50	3.00	2.30	2.50	2.20	2.40
2003	3.30	2.50	3.20	2.40	2.90	2.20	3.50
2004	2.90	2.40	3.30	2.70	3.40	2.90	3.10
2005	2.10	2.80	3.60	2.40	2.80	2.70	2.50

Hay Yields Continued

Year	Calhoun	Chambers	Cherokee	Chilton	Choctaw	Clarke	Clay
1986	1.33	1.12	1.09	1.83	1.88	1.82	1.25
1987	1.60	2.14	1.80	1.68	2.29	3.23	1.67
1988	2.67	2.50	2.00	1.71	2.00	2.88	1.46
1989	1.78	1.80	2.50	1.60	2.29	3.43	2.00
1990	1.00	1.85	1.67	1.11	1.73	1.67	1.57
1991	2.07	2.00	2.13	2.34	2.00	1.67	1.81
1992	2.24	2.15	2.04	2.16	2.08	2.00	2.22
1993	1.95	2.11	2.12	2.19	2.03	1.80	2.24
1994	2.75	2.32	2.54	3.19	2.39	3.79	2.59
1995	2.00	1.40	2.00	1.60	2.20	2.20	1.70
1996	2.40	2.00	2.80	2.50	2.50	2.60	2.50
1997	2.20	2.00	2.30	2.60	2.30	2.40	2.30
1998	1.90	2.00	2.20	2.00	2.00	2.20	2.10
1999	2.50	2.00	2.40	2.30	2.20	2.40	2.20
2000	1.90	1.80	1.70	1.50	1.50	1.10	1.60
2001	2.80	2.60	2.60	3.00	2.00	3.00	2.50
2002	2.00	1.90	2.60	2.30	1.80	1.80	2.40
2003	2.70	2.30	3.10	2.50	2.90	3.30	2.30
2004	2.70	3.20	3.20	3.40	3.00	2.70	2.40
2005	2.80	2.60	2.20	2.40	2.90	2.30	2.80

Hay Yields Continued

Year	Cleburne	Coffee	Colbert	Conecuh	Coosa	Covington	Crenshaw
1986	1.20	1.25	1.50	1.64	1.45	1.67	1.49
1987	1.70	2.35	1.60	2.71	1.90	3.05	2.86
1988	1.50	3.00	1.78	2.00	2.00	2.36	2.83
1989	1.60	2.89	2.50	2.00	2.00	2.00	2.50
1990	1.25	1.71	1.89	1.63	2.17	0.80	1.40
1991	1.95	2.82	1.57	1.82	1.85	2.74	3.00
1992	2.09	2.17	1.79	2.28	2.20	2.56	2.28
1993	2.09	2.08	1.77	2.14	2.29	2.16	2.08
1994	2.50	3.08	2.34	2.96	2.78	3.70	3.11
1995	2.40	2.30	1.90	2.60	1.60	2.30	2.80
1996	2.40	3.30	2.20	3.20	1.90	3.20	2.00
1997	1.90	2.60	2.10	2.90	1.90	2.90	3.10
1998	2.00	2.50	1.80	2.20	1.70	2.30	2.50
1999	2.40	2.40	2.20	2.60	2.00	3.10	2.80
2000	1.60	1.50	2.30	1.70	1.30	1.90	2.00
2001	2.70	2.30	2.40	3.00	2.10	3.00	3.30
2002	2.40	2.60	2.10	2.40	1.80	2.30	2.40
2003	3.00	3.00	2.40	2.80	2.10	2.80	2.70
2004	2.30	2.70	2.40	2.70	2.50	2.70	3.20
2005	2.80	3.70	2.10	2.70	2.00	3.40	3.20

Hay Yields Continued

Year	Cullman	Dale	Dallas	De Kalb	Elmore	Escambia	Etowah
1986	1.82	1.30	1.94	1.42	1.93	1.66	1.18
1987	1.96	2.00	2.29	2.09	2.00	2.44	2.17
1988	1.62	1.47	2.88	1.74	2.00	2.00	1.75
1989	1.91	2.14	3.33	2.63	2.00	2.80	2.00
1990	1.31	1.09	2.17	1.58	1.47	2.33	1.07
1991	2.29	2.59	2.24	2.42	2.50	2.57	1.81
1992	2.17	2.13	2.17	2.38	2.17	2.67	2.20
1993	2.23	2.00	2.03	2.26	1.75	2.27	2.14
1994	3.03	3.06	2.48	2.83	2.58	3.13	2.45
1995	2.50	2.20	2.10	2.50	1.40	2.90	2.10
1996	2.70	3.40	3.30	2.70	2.30	2.10	2.60
1997	2.40	3.00	2.50	2.40	2.40	2.20	2.20
1998	2.40	2.00	2.30	2.40	2.30	2.40	2.40
1999	2.50	2.80	2.20	2.50	2.30	2.90	2.70
2000	2.20	1.10	1.00	2.40	1.50	1.70	1.70
2001	3.00	2.30	2.90	2.90	2.50	2.90	2.60
2002	2.60	2.50	2.20	2.30	2.10	2.00	2.90
2003	3.00	2.70	2.30	3.10	3.00	2.40	2.70
2004	3.30	2.80	2.50	3.00	3.20	2.50	3.20
2005	2.80	3.20	2.40	3.10	2.60	2.30	3.00

Hay Yields Continued

Year	Fayette	Franklin	Geneva	Greene	Hale	Henry	Houston
1986	1.64	1.53	1.33	1.56	1.50	1.40	1.38
1987	1.70	1.92	2.80	2.63	1.81	2.80	2.15
1988	2.00	2.45	2.00	2.00	2.25	1.63	2.00
1989	2.25	2.29	1.83	2.43	2.50	2.00	2.22
1990	1.64	1.26	1.43	1.11	1.00	1.20	1.00
1991	1.86	1.52	2.32	1.72	2.64	2.41	2.12
1992	1.89	1.85	2.58	1.80	2.13	2.31	2.28
1993	2.12	1.85	2.22	1.56	2.00	1.84	1.69
1994	2.97	2.58	2.63	3.05	2.12	2.50	2.62
1995	2.50	2.50	2.20	2.80	2.00	1.70	2.00
1996	2.50	2.10	2.40	2.10	2.10	1.90	1.80
1997	2.60	2.10	2.60	2.20	2.20	1.90	2.10
1998	2.40	2.10	2.50	1.90	2.20	2.00	2.20
1999	2.50	2.30	2.40	2.00	2.20	2.20	2.40
2000	1.60	2.30	1.00	1.30	1.60	1.10	1.00
2001	2.50	2.50	3.00	1.80	1.80	2.10	1.70
2002	2.20	2.50	2.20	1.90	2.00	2.50	2.50
2003	2.70	2.70	2.10	2.90	2.20	2.00	2.10
2004	2.60	2.80	2.50	2.20	2.30	2.80	2.10
2005	2.80	2.60	2.30	2.70	2.70	2.30	2.30

Hay Yields Continued

Year	Jackson	Jefferson	Lamar	Lauderdale	Lawrence	Lee	Limestone
1986	1.57	1.68	1.42	1.66	1.60	1.88	1.50
1987	1.61	1.78	1.70	1.58	1.82	2.71	1.71
1988	1.88	2.10	2.00	1.78	1.53	1.44	1.40
1989	1.55	1.63	2.25	2.06	1.94	2.14	1.40
1990	1.71	1.20	2.40	0.91	1.50	1.22	1.20
1991	2.07	1.89	1.73	1.50	1.93	2.53	1.57
1992	2.02	2.00	1.96	1.73	1.85	2.26	1.76
1993	2.01	2.08	2.00	1.62	1.81	2.04	1.64
1994	2.52	2.79	2.59	2.18	2.63	3.17	2.26
1995	2.20	2.10	2.30	1.90	2.20	2.10	1.60
1996	2.30	2.10	2.70	1.80	1.90	2.60	1.90
1997	2.20	2.20	2.30	1.80	1.90	2.70	1.80
1998	2.30	2.40	2.20	2.00	1.80	2.20	1.90
1999	2.50	2.60	2.10	1.90	2.00	2.70	1.50
2000	2.30	1.50	1.60	2.10	1.80	1.30	1.70
2001	2.80	2.10	2.80	2.00	2.50	3.20	2.20
2002	2.10	1.90	2.40	1.80	2.10	2.90	1.70
2003	2.30	2.20	2.50	2.00	2.30	2.90	2.30
2004	2.90	2.30	2.40	2.20	2.40	3.50	2.30
2005	2.70	2.80	3.10	2.30	2.60	3.20	2.20

Hay Yields Continued

Year	Lowndes	Macon	Madison	Marengo	Marion	Marshall	Mobile
1986	1.55	1.50	1.59	1.90	1.89	1.90	2.22
1987	2.33	2.13	1.76	2.00	1.73	2.31	2.82
1988	1.93	2.00	1.83	1.74	2.63	2.00	3.00
1989	1.86	2.00	2.40	2.53	2.20	2.75	2.00
1990	1.45	1.47	1.18	1.94	1.50	1.83	1.55
1991	1.90	2.66	2.00	1.75	1.63	1.89	2.91
1992	1.81	2.14	1.69	2.16	2.11	2.30	2.70
1993	1.77	1.76	1.70	1.88	1.95	2.25	2.63
1994	2.19	2.54	2.35	2.29	2.53	2.89	3.77
1995	2.00	1.40	2.10	2.10	2.60	2.40	2.10
1996	2.50	2.00	2.10	2.20	2.30	2.80	2.30
1997	2.10	2.20	1.70	1.80	2.10	2.40	2.40
1998	2.00	1.80	1.80	1.90	2.30	2.20	2.50
1999	2.90	1.70	1.80	1.60	1.80	2.70	2.10
2000	1.10	1.70	2.00	1.30	2.00	2.50	2.30
2001	3.50	3.40	2.00	2.10	2.80	2.70	2.30
2002	2.10	2.60	1.90	1.90	2.10	2.50	2.60
2003	2.20	3.00	2.30	2.00	2.60	3.00	2.90
2004	2.40	2.60	2.30	2.30	2.80	3.10	2.50
2005	3.10	3.00	2.40	2.40	2.40	3.00	3.30

Hay Yields Continued

Year	Monroe	Montgomery	Morgan	Perry	Pickens	Pike	Randolph
1986	1.95	1.44	1.65	1.91	1.60	1.55	1.21
1987	3.00	1.76	2.26	2.36	1.80	2.96	1.93
1988	3.60	1.52	2.36	2.08	1.81	2.00	3.13
1989	2.50	2.72	2.10	1.79	1.45	2.00	2.31
1990	1.14	0.82	1.42	1.00	1.05	2.32	2.00
1991	1.75	1.98	1.85	2.10	2.27	3.10	1.91
1992	2.22	2.01	1.91	1.62	2.22	3.46	1.88
1993	2.19	1.75	1.89	1.70	2.16	2.67	2.11
1994	2.67	2.21	2.42	2.13	2.72	3.76	2.69
1995	2.60	1.40	2.10	1.50	2.40	2.80	1.90
1996	2.80	1.80	2.40	2.10	2.80	3.30	2.10
1997	2.60	2.10	2.00	1.90	2.60	3.50	2.00
1998	1.70	1.60	2.10	2.00	2.10	2.50	2.10
1999	2.50	2.00	2.00	1.60	2.70	3.30	2.30
2000	2.00	1.10	2.00	1.50	1.30	1.90	1.90
2001	2.20	2.20	2.40	2.20	2.90	3.30	2.50
2002	2.40	1.50	2.00	1.50	2.10	2.60	2.30
2003	3.20	2.30	2.60	2.40	3.20	3.10	2.80
2004	2.50	2.20	2.40	2.20	3.30	3.60	2.50
2005	3.50	2.50	2.50	2.50	3.30	3.70	2.40

Hay Yields Continued

Year	Russell	Shelby	St. Clair	Sumter	Talladega	Tallapoosa	Tuscaloosa
1986	1.88	1.16	1.32	1.58	1.19	1.45	1.32
1987	2.29	1.62	2.20	2.00	1.89	2.43	2.70
1988	3.29	1.88	1.60	2.36	1.76	1.56	1.67
1989	3.00	2.27	2.50	2.75	1.83	1.75	3.15
1990	2.22	1.00	1.08	1.20	1.95	2.29	2.00
1991	2.86	1.77	1.71	2.22	2.02	2.14	2.27
1992	2.65	1.71	2.22	2.10	1.77	2.38	2.21
1993	2.13	1.89	2.25	1.95	1.91	2.44	2.12
1994	3.47	2.92	3.00	2.28	3.89	2.94	2.48
1995	2.10	1.40	2.20	2.60	1.50	1.60	1.60
1996	2.70	2.10	1.80	2.20	2.50	2.50	2.50
1997	2.90	2.00	2.30	2.20	2.20	2.60	2.00
1998	2.00	1.90	2.30	1.70	1.80	2.30	2.30
1999	3.30	2.00	2.00	2.40	1.80	2.60	2.00
2000	2.70	1.70	1.90	1.80	1.60	2.00	1.70
2001	3.20	2.60	2.60	1.70	2.70	3.20	2.10
2002	2.50	1.80	2.00	1.70	2.00	2.50	2.30
2003	2.60	2.10	3.10	2.20	2.20	2.50	2.70
2004	2.90	2.30	3.20	2.50	2.60	2.30	2.50
2005	2.90	2.70	3.30	2.00	2.50	2.50	2.90

Hay Yields Continued

Year	Walker	Washington	Wilcox	Winston
1986	1.43	2.01	1.64	1.67
1987	1.90	2.75	1.68	1.75
1988	1.00	1.82	2.95	2.00
1989	1.86	2.20	2.15	2.55
1990	1.50	1.11	1.94	1.78
1991	1.90	2.45	2.30	2.24
1992	2.16	2.13	2.26	2.13
1993	2.02	2.16	2.07	2.00
1994	2.56	3.02	2.86	2.78
1995	1.50	2.60	2.30	2.10
1996	2.00	2.60	2.40	2.20
1997	1.90	2.20	2.10	2.30
1998	1.80	2.40	2.40	1.90
1999	2.80	2.80	1.80	2.00
2000	1.40	1.60	1.30	1.90
2001	2.30	2.80	2.40	3.10
2002	2.40	2.60	2.00	2.30
2003	2.90	3.30	2.40	2.50
2004	2.60	2.50	2.50	2.40
2005	2.80	2.80	2.20	2.80

Alabama County Peanut Yields 1986-2005

Year	Barbour	Coffee	Conecuh	Covington	Crenshaw	Dale
1986	2515	2680	2105	2375	2645	2325
1987	1545	2285	2050	2430	2250	2105
1988	2135	2570	2160	2680	2315	2300
1989	2110	2120	2255	2585	2015	2265
1990	1150	1255	1295	1720	2255	1285
1991	2375	2340	2130	2525	2265	2400
1992	2660	2580	2160	2680	2445	2675
1993	1835	2250	2190	2360	2370	2030
1994	2250	1855	1830	2110	2100	2030
1995	2210	2205	2405	2565	2220	2315
1996	2710	2510	2305	2930	2850	2225
1997	2025	1760	2015	2290	1935	1695
1998	1805	2105	1840	2620	1960	2140
1999	2620	2125	2195	2470	2060	2190
2000	1390	1130	1325	1585	1660	1220
2001	2605	2350	2700	2700	2580	2570
2002	2420	2070	1500	2390	2410	1980
2003	2830	2585	2920	3000		2410
2004	2620	2430		2565		2420
2005	2810	2445		2805		2975

Peanut Yield Continued

Year	Escambia	Geneva	Henry	Houston	Pike	Russell
1986	2665	2485	1985	1895	2260	1940
1987	2665	2280	2050	2165	1855	1660
1988	2450	2480	2155	2570	2190	1520
1989	2045	2330	2275	2390	2040	2000
1990	2000	1770	1200	1685	1605	1585
1991	2330	2285	2390	2235	2155	2115
1992	2415	2390	2620	2410	2250	2645
1993	2475	2180	1425	2050	1850	1300
1994	2610	1755	2290	1935	1885	2360
1995	2715	1900	2445	2385	2350	1650
1996	2925	2275	2185	2100	2380	2990
1997	2940	1980	1900	1960	1885	2180
1998	2920	2130	2265	2265	2255	2675
1999	3165	1965	1890	2100	2305	2185
2000	2600	1355	1250	1525	1465	1725
2001	4075	2525	2570	2415	2720	2905
2002	1960	1995	1910	2055	2380	2485
2003	3335	2190	2620	2755	2955	
2004	3425	2380	2610	2530	2660	
2005	2965	2485	2685	2400	2640	

Alabama County Potato Yields 1986-2005

Year	Baldwin	Cullman	De Kalb	Jackson
1986	150.00	125.00	140.00	130.00
1987	135.00	170.00	156.00	150.00
1988	140.00	115.00	88.00	85.00
1989	245.00	180.00	174.00	155.00
1990	150.00	180.00	160.00	149.00
1991	120.00	146.00	141.00	133.00
1992	155.00	152.00	177.00	163.00
1993	157.00	123.00	83.00	96.00
1994	176.00	170.00	173.00	167.00
1995	161.00	197.00	168.00	170.00
1996	160.00	140.00	140.00	177.00
1997	172.00	156.00	148.00	160.00
1998	154.00	85.00	136.00	111.00
1999	172.00	140.00	178.00	250.00
2000	197.00	107.00	158.00	160.00
2001	163.00	150.00	161.00	164.00
2002	205.00	135.00	213.00	148.00
2003	143.00	267.00	234.00	182.00
2004	139.00	94.00	246.00	187.00
2005	114.00	113.00	160.00	189.00

Alabama County Soybean Yields 1986-2005

Year	Baldwin	Blount	Calhoun	Cherokee	Colbert	Cullman	Dallas	De Kalb
1986	25.60	26.50	24.00	17.90	23.00	21.00	18.50	18.00
1987	25.00	19.00	15.00	16.50	15.00	19.50	16.50	17.00
1988	27.70	25.10	23.30	26.70	21.20	25.00	24.10	25.00
1989	22.00	27.30	23.00	25.00	24.00	27.10	17.00	26.80
1990	19.00	16.80	18.20	15.70	12.60	14.70	12.60	21.90
1991	25.90	25.00	23.80	23.50	19.10	25.10	21.80	22.00
1992	30.00	35.00	35.70	28.10	32.10	34.10	23.60	32.80
1993	30.10	28.20	19.70	14.70	24.90	28.30	23.90	24.70
1994	28.60	43.50	39.00	36.40	34.80	43.10	26.10	37.10
1995	29.00	21.00	23.00	18.00		22.00	19.00	25.00
1996	35.00	37.00	35.00	36.00	30.00	40.00	29.00	36.00
1997	25.00	28.00	27.00	23.00		27.00	19.00	26.00
1998	22.00	20.00	25.00	22.00	31.00	27.00	18.00	20.00
1999	28.00	20.00	18.00	16.00	11.00	13.00	23.00	15.00
2000	20.00	20.00	15.00	17.00	9.00	16.00	12.00	25.00
2001	34.00	35.00	35.00	35.00		35.00		38.00
2002	27.00	27.00	21.00	24.00	28.00	31.00	20.00	19.00
2003	31.00		41.00	40.00		36.00		39.00
2004	31.00		39.00	40.00	35.00	42.00	32.00	39.00
2005			31.00	41.00	31.00	36.00		40.00

Soybean Yield Continued

Year	Escambia	Etowah	Fayette	Geneva	Houston	Jackson	Lauderdale
1986	27.50	18.50	22.00	19.50	16.70	25.00	21.80
1987	23.50	17.50	21.40	18.40	16.40	16.50	16.50
1988	29.00	25.90	22.30	29.30	29.60	27.10	17.70
1989	17.10	21.60	20.20	19.00	19.30	23.00	21.00
1990	17.40	16.20	21.20	12.50	10.10	20.60	13.60
1991	25.00	18.90	23.20	20.90	21.40	24.00	25.00
1992	33.40	32.10	27.90	26.70	25.00	27.70	30.50
1993	25.10	22.70	23.30	18.80	17.90	19.20	23.90
1994	31.00	34.60	32.50	28.90	27.20	31.90	27.20
1995		19.00	25.00			27.00	27.00
1996	36.00	36.00	33.00	24.00	26.00	34.00	36.00
1997	26.00	24.00	23.00	20.00	18.00	26.00	27.00
1998	33.00	20.00	23.00	23.00	17.00	19.00	27.00
1999	33.00	18.00	19.00	18.00	14.00	13.00	6.00
2000	13.00	18.00	12.00		15.00	26.00	9.00
2001		35.00				35.00	38.00
2002	33.00	25.00	22.00	26.00	32.00	21.00	25.00
2003	33.00	41.00	29.00	33.00	32.00	33.00	37.00
2004	33.00	41.00	37.00	36.00	29.00	34.00	31.00
2005		39.00		41.00	32.00	32.00	28.00

Soybean Yield Continued

Year	Lawrence	Limestone	Madison	Marion	Marshall	Morgan	Talladega
1986	20.60	25.00	29.00	28.00	20.50	22.00	25.00
1987	14.00	13.00	17.00	15.00	16.50	18.00	11.00
1988	18.30	23.10	24.20	21.30	20.50	23.50	26.20
1989	23.50	23.20	22.30	22.60	18.00	23.20	18.70
1990	12.60	15.70	22.00	18.80	14.60	20.90	20.90
1991	17.60	26.50	28.20	15.10	17.00	16.50	23.40
1992	31.50	29.90	31.00	29.20	29.40	30.70	24.50
1993	26.30	28.20	25.60	19.60	17.40	24.00	20.50
1994	28.70	32.60	36.30	30.70	35.40	27.90	30.70
1995	26.00	24.00	24.00	26.00	20.00	22.00	17.00
1996	37.00	36.00	37.00	34.00	35.00	37.00	37.00
1997	29.00	30.00	27.00	24.00	25.00	24.00	23.00
1998	25.00	22.00	22.00	29.00	18.00	21.00	21.00
1999	12.00	8.00	12.00	16.00	18.00	16.00	
2000	13.00	17.00	20.00	13.00	20.00	13.00	
2001	35.00	35.00	34.00		33.00	31.00	43.00
2002	27.00	25.00	23.00	21.00	26.00	22.00	21.00
2003	37.00	39.00	36.00	40.00	27.00	35.00	35.00
2004	36.00	40.00	35.00	38.00	30.00	33.00	37.00
2005	30.00	31.00	31.00	33.00	31.00	33.00	