An Empirical Investigation of a Framework for Assessing the Impact of Climate Change on Crop Yields

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Climate change and economic variables can have an adverse impact on crop production and yield locally and globally, resulting in the vulnerability of agriculture. This research responded to a call to empirically examine the impact of climatic and economic variables on crop yield (Ojumu, Ojumu, and Joonas, 2020). Our study examined the yield of corn, cotton, soybean, and peanut in Alabama for the 1960–2015 period, in light of these factors. Ordinary Least Square (OLS) regression analysis was used to estimate the crop yield, as a function of the independent variables of minimum temperature, maximum temperature, precipitation, technology, and fertilizer use. Results revealed a significant effect of climate on the yield of soybean, peanut, and corn. Technology was significantly related to the yield of all the crops in the study. Findings suggested that while a good understanding of climate trends is important, technology is a key input that will assist agricultural producers improve their adaptive capacities to climate variations.

Keywords: Climate Change, Temperature, Vulnerability, Agricultural Yields, Statistical Modeling, Alabama

1. Introduction

Current research informs us that natural resources such as water and forests are less vulnerable to climate change than agriculture, which forms the focus of several authors (e.g., Lotten et al. 2015, Russell, 2007, Tao et al., 2011.). Proactive strategies could be enabled by shedding light on agricultural vulnerability to climate change to feed the world's population. Climate variability has been heightened in vast areas comprising the world's "food basket", and threatening the world's food security (Intergovernmental Panel on Climate Change IPCC, 2007; Schmidhuber and Tubiello, 2007), spurring policy responses (e.g., DAFF, 2005, 2006; Nelson et al., 2007). Agriculture is sensitive to changes in water supply. Crops and regions can be differently affected by temperature and rainfall changes. Trapped Infrared radiation from the surface of the earth – or the greenhouse effect – is caused by carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), and chlorofluorocarbons (CFCs). The greenhouse effect is exacerbated by human activity related primarily to industrialization. The resulting increase in infrared radiation has caused changes in

air temperature, rainfall, sea level, and polar glacial melting, generally called climate change (IPCC, 2007).

A theoretical model examining the role of changes in selected climatic variables, inputs, and technology on crop yield, and explaining farmers' productive efficiency and adaptive capacity to such changes, accompanied by required mitigation strategies, was also proposed. The present study is in response to a call for empirical investigation of a theoretical model proposed by Ojumu, Ojumu, and Joonas (2020).

2. Literature Review and Theoretical Model

An integrated literature review of "models of climate change, simulated climate change empirical studies at the global and country levels, and historical climate change empirical models at the global, country and state levels" was presented in at least one study (Ojumu, Ojumu, and Joonas, 2020). The theoretical framework for the present study was based on extant empirical work (e.g., Yingjie et al., 2008, Ajetomobi and Abiodun, 2010, Kucharik and Serbin, 2008, Lobell et al., 2007, Changnon and Hollinger, 2003, Hu and Buyanovsky 2003). These authors estimated crop yield as a function of minimum temperature, maximum temperature, precipitation and selected agricultural inputs.

A longitudinal research covering different regions in China modeled the differential role of climate warming, agricultural inputs, and planting area on crop yield and stages of grain production. This research also suggested that the effects of climate warming on grain production in affected regions improved with altered fertilizer inputs, better seeds, and the use of irrigation (Yingjie et al., 2008). Another longitudinal study in Nigeria modeled differential the impact of temperature, rainfall, and technological change, and geographical location on cowpea yield. Further, in face of climate change, farmers were found to be effectively adapting with new agricultural practices (Ajetomobi and Abiodun, 2010).

In the U.S., a research regressed yield of corn and soybean on changes in temperature (range and mean) as well as precipitation. This research also evidenced a decrease in corn and soybean yields with increasing maximum temperature, balanced with increased yield from increasing rainfall. Reduced temperatures and higher rainfall during summer were found to enhance yield (Kucharik and Serbin, 2008). A study based on twelve Californian crops modeled yield on concurrent climatic conditions such as precipitation and range of temperature. According to this model, for most crops, as few as two to three factors accounted for over 67% of variance in yield (Lobell et al., 2007).

In Missouri, a longitudinal study modeled the impact of temperature, temperature range, and rainfall distribution on corn yields. Predictors for high yield included lower precipitation and higher temperature during cop planting, higher precipitation and higher temperature during the growth period. The opposite was found to be true in the case of low yield (Hu and Buyanovsky, 2003). Another longitudinal study compared field tests with yield-weather models based on the role of varying levels of added rainfall during the growing season, on corn yields in central Illinois. This study indicated that yield-weather models were not accurate in predicting yield for a wetter climate. (Changnon and Hollinger, 2003).

This study focus is on Alabama and it covered the four major crops: cotton, corn, peanut and soybean, using historical secondary data for the crop yields and data and

the selected climatic variables for the 1960-2015 period. This period was chosen because of the availability of consistent time-series data on the dependent variable and the independent variables.

2.1 The Estimated Model

Following Ojumu, Ojumu, and Joonas (2020), the estimated model is stated as:

$$Y_t = \alpha_0 + \alpha_1Tmax_t - \alpha_2Tmin_t \pm \alpha_3PRE_t + \alpha_4Fert_t + \alpha_5TECH_t + u \dots\dots\dots 1$$

Y = Yield per acre in bushel or pound per acre

α_i = Regressor coefficients (i = 1,...,5)

t = 1960-2015

Tmin_t = Average annual minimum temperature in degrees Celsius

Tmax_t = Average annual maximum temperature in degrees Celsius

PRE_t = Average annual precipitation in millimeters

Fert_t = Fertilizer used in tons/acre

TECH_t = Technology (time used as proxy)

u = Error term

The hypotheses and expected signs of Regressor coefficients, as in Ojumu, Ojumu, and Joonas (2020), are shown below in Table 1.

Table 1 Hypotheses and Expected Signs of Regressor Coefficients

Coefficient	Expected Signs	Impact on Yield/Acre
α_1	+	Promotes yield
α_2	-	Suppresses yield
α_3	$\pm$	Promotes or suppresses yield
α_4	+	Promotes yield
α_5	+	Promotes yield

3. Methodology

3.1 Data Collection and Source

Desk research was conducted to collect data on annual yields of for crops - corn, cotton, soybean, and peanut - for Alabama, the source being the National Agricultural Statistics Service Database for 45 years covering 1960-2005. Data from Blackland Research and Extension Center, Texas were collected in reference to daily precipitation, daily maximum temperature and daily minimum temperature for the same period. For this period, daily totals were used to arrive at annual average maximum and minimum temperatures, and daily totals of precipitation were used to arrive at annual average precipitation.

3.2 Specification and Operationalization of Variables

The dependent variable is crop yield in pounds per acre or bushels per acre, as prescribed by USDA-National Agricultural Statistics Service NASS yield in total production per harvested acre. Independent variables include climatic variables, fertilizer used and technology. Climatic variables comprising minimum temperature, average annual minimum temperature, average annual minimum temperature, average annual maximum temperature, and precipitation were determined as given in the literature (National Oceanic and Atmospheric Administration’s National Weather

Service NOAA NWS, 2009). Fertilizer for cotton, corn, soybean, and peanut was estimated based on the literature (Ojumu, Ojumu, and Joonas, 2020). Technology, comprising adaptive interventions such as machinery and equipment, improved seeds, better management practices, was expressed in terms of time (Ajetomobi and Abiodun, 2010; Chavas and Johnson, 1982; Kouka and Engle, 1998).

3.3 Data Analysis

Trend and correlation analyses were used to arrive as climatic time-series data and crop yield. LIMDEP version 8.0 was used for OLS multiple regression analysis. Crop yield for cotton, corn, soybean, and peanut was regressed on five factors - minimum temperature, maximum temperature, precipitation, fertilizer used, and technology. We evaluated the relationship between dependent and independent variables, and the change in yield explained by independent variables was based on coefficients of determination (Ojumu, Ojumu and Joonas, 2020).

4. Results and Discussion

This section discusses the GIS outputs; the changes in trends of the climatic variables: minimum temperature, maximum temperature, and precipitation with the changes in yield; correlation analysis; and the results of the OLS multiple regression.

4.1 GIS Outputs

GIS-generated crop maps in figure 1(A, B, C and D) show the geographic concentration of the four major crops in the state of Alabama in 2015, specifically the counties in which each crop is grown. Corn production is concentrated in the north and south, with Jackson, Lawrence, Madison, Colbert and Lauderdale, counties as the major producers. Also, cotton production is concentrated in the north and south with Limestone, Madison, Lawrence, Lauderdale, Houston and Colbert counties as the largest producers. Peanut production is concentrated in the south with Houston, Baldwin, Geneva, Henry, and Escambia counties as the major producers. Soybean production is concentrated in the north with Jackson, Madison, Limestone, DeKalb, and Cherokee counties as the major producers.

A: The Distribution of Corn in 2015 B: The Distribution of Cotton in 2015

Figure 1 Maps of Alabama Showing Crop Distributions in 2015

C: The Distribution of Peanut in 2015 D: The Distribution of Soybean in 2015

4.2 Trend Analysis

The trend from 1960-2015, which shows that peanut yield and minimum temperature appear to move in the same direction, suggests that both are positively related (A). A sufficiently high minimum temperature promotes the yield of peanut as seen in A where the peaks of minimum temperature in 1965, 1972, 1975, 1982, 1985, 1991, 1995, and 2005 seem to correspond to the peak of yield per acre for peanut. The minimum temperature for 1982 was 12.9°C with peanut yield of 2,950 pounds per acre, an increase of 235 pounds from the previous year. It was observed that there were more valleys than peaks for the period under study.

Maximum temperature (B) is seen to move in an opposite direction with peanut yield. A high maximum temperature suppresses while a low maximum temperature increases peanut yields. The years when the maximum temperature peaked are the same years when the yield decreased relative to the previous year. Maximum temperature peaked in 1962 (25.3°C), 1967 (25.1°C), 1972 (25.8°C), 1974 (25.9°C), 1978 (24.6°C), 1990 (27°C), and 2000 (26.7°C) with these years recording reduced yields per acre of 975, 1340, 1870, 2360, 2640, 1510, 1490 pounds per acre, respectively, relative to their preceding years. The peaks of maximum temperature correspond to the valleys of peanut yield and vice versa.

On the other hand, precipitation (mm) shows a positive correlation with peanut yield as both variables move in the same direction. The years with the highest peaks of precipitation are also the peak years for peanut yield. Precipitation peaked in the years 1964 (129.8mm), 1971 (107.3mm), 1979 (89mm), 1982 (101.3mm), 1985 (91.1mm), 1992 (105.4mm), and 2003 (105.2mm) with corresponding peaks of yields of 1251, 2070, 2785, 2950, 2950, 2505, and 2750 pounds per acre, respectively.

It is noteworthy that in 1964 when precipitation was highest, the peanut yield was 1,251 pounds per acre whereas in 1979, precipitation peaked at 89mm with a resultant yield of 2,785 pounds per acre. This may be due to the distribution pattern and timing of precipitation in 1964 and then, technology improvement could be the major reason why there was a higher yield per acre in 1979 despite the fact that precipitation was lower than that of 1964.

For soybean, the trends of minimum and maximum temperatures (D and E) are similar to those of peanut. It can be seen that the years when the minimum temperature was high between 12 and 13.5°C, the high yields of soybean were recorded whereas high maximum temperatures between 25 and 27°C resulted in low yields of soybean. In addition, years of low precipitation (F) led to very low yields, and high precipitation resulted in higher yields.

Similarly, cotton (G, H, and I) and corn (J, K and L) exhibit the same yield trends with minimum temperature, maximum temperature and precipitation, in the same way as peanut and soybean for the 1960-2015 period. The harvested acres (M) for the four crops have been on a gradual decline from 1960-2005 except for soybean which reached a peak of 2,150,000 acres in 1979 with a sharp decline thereafter. In spite of the decline in harvested acres, the yields per acre of these crops show an increasing trend. This increase in yield is attributed to technology, a proxy for the adaptive capacity of the farmers.

Soybean acreage in Alabama began to expand rapidly in the early 1960s with harvested acreage increasing from 135,000 acres in 1960 and reaching a peak of 2,150,000 acres in 1979. The growth of the US soybean processing industry, which produced soy oil and soybean meal, was a major cause of the increase in soybean acreage. Harvested acreage has decreased since 1979, with only 295,000 acres harvested in 1993, and has remained below 200,000 acres since 2000.

Cotton production declined throughout much of the twentieth century as a result of federal legislation (Cotton Control Act of 1934 which limited the number of bales a farmer could produce and the Soil Bank Program of 1956, which paid farmers to take land out of production), natural causes (boll weevil infestation), and crop diversification (Phillips and Roberts, 2008). Between 1960 and 1990 cotton acreage dropped by 482,000 acres. Concurrently, yield per acre was on the increase, signifying the improvement and adoption of more scientific methods of farming. Cotton almost disappeared from south Alabama in the 1970s and 1980s, due primarily to crop diversification. A new peanut allotment program was adopted in 1977 and revised in 1996 as an incentive to grow peanuts, and as a result of this program, harvested acreage for cotton was below half a million acres annually. In the 1990s, cotton picked up again with the harvested acreage averaging over 500,000 acres annually, but presently less than 300,000 acres are being cultivated. The acreage devoted to cotton (545,000 acres) in 2005 was almost equal to that of peanuts, corn, and soybeans combined.

Peanut harvested acreage has not recorded any dramatic changes over the years. The rise in the peanut's popularity was timely. Bolstered by new agricultural crop diversification strategies, the invention of labor-saving equipment that made planting, cultivating, harvesting, shelling, and cleaning peanuts easier and more efficient, and the discovery of its many uses, the peanut became a viable cash crop for southern farmers, who began growing peanuts on a significant scale (Dixon, 2009). From 1960-2005, the harvested acreage ranged between 176,000 acres in 1967 and 277,000 acres in 1991. The trend has gradually been on the decline. For most of the years, harvested acreage was below 200,000 acres. This was a result of the federal peanut program, administered by USDA, which was designed to support producers' incomes while ensuring an ample supply of domestically produced peanuts. The program served as a control in the domestic supply of peanuts and

guaranteed producers a minimum price for their crops. A national quota was placed on the number of pounds that could be sold for domestic consumption, and restrictions were on imports. The idea of the marketing quota programs was to limit sales to a certain quantity (quota) to keep prices higher and more stable than they would have been in a free market system. The program was abolished in 2002.

Corn harvested acreage declined from 1,705,000 acres in 1960 to 545,000 acres in 1972 and picked up again, reaching a peak of 800,000 in 1976 and steadily declining to 200,000 acres in 2005 which represents about 88% reduction in acreage. Many factors were responsible for these yield increases: better hybrids, more efficient use of fertilizers, better pest management (weeds, insects, and diseases), and better management overall.

For the four crops, trend in yield per acre (N) from 1960-2005 has been increasing with cotton and corn having the most significant increases in yield per acre. In 1960, cotton acreage was 860,000 with yield of 396 lbs. per acre. With subsequent annual reduction in acreage, the yield has been increasing, reaching a peak of 795 pounds per acre in 1985 with 329,000 harvested acres, and in 2005 the yield was 747 pounds per acre with 385,000 harvested acres. From 1960 -2005, the reduction in acreage was about 55% while yield per acre for the same period rose by about 89%.

Corn yield per acre increased from 26 bushels per acre from a total of 1,705,000 harvested acres in 1960 to 119 bushels per acre from 200,000 harvested acres in 2005. The harvested acres in 2005 represents 88% reduction in acreage from 1960 with an increase in yield per acre of about 358%. As discussed previously, the role of technology in this acreage reduction and yield increase cannot be overemphasized. Technology has been a key resilient tool for most countries and regions of the world helping to mitigate climate impacts.

A: Peanut Yield and Minimum Temperature B: Peanut Yield and Maximum Temperature

Figure 2 Trend Analysis Charts

C: Peanut Yield and Precipitation D: Soybean Yield and Minimum Temperature

E: Soybean Yield and Maximum Temperature F: Soybean Yield and Precipitation

G: Cotton Yield and Minimum Temperature H: Cotton Yield and Maximum Temperature

I: Cotton Yield and Precipitation J: Corn Yield and Minimum Temperature

K: Corn yield and Maximum Temperature L: Corn Yield and Precipitation

M: Harvested Acres of Corn, Cotton, Peanut and Soybean N: Yield per acre of Corn, Cotton, Peanut and Soybean

4.3 Correlation Analysis

The correlation between the yield of each of the four crops and minimum temperature, maximum temperature and precipitation was determined using the correlation matrix in Table 2 below. This analysis was used to test the strength of relationship between crop yield and each of the climatic variables. The analysis of the correlation matrix indicates that few of the observed relationships were very strong. The strongest relationship was between soybean yield and precipitation with a significance level of 5% ($r = 0.361$) indicating that as precipitation increased, soybean yield increased. Minimum temperature was positively correlated with corn yield ($r = 0.015$), cotton yield ($r = 0.88$), peanut yield ($r = 0.172$), and soybean yield ($r = 0.258$), although the relationship was not statistically significant. These results indicate that as minimum temperature increases, the yields of these crops are likely to increase.

Maximum temperature was positively correlated with corn yield ($r = 0.209$) and cotton yield ($r = 0.147$) and negatively correlated with peanut yield ($r = -0.61$) and soybean yield ($r = -0.19$), although the relationship was not statistically significant in both cases. These results indicate that an increase in maximum temperature may increase the yield of corn and cotton while peanut and soybean yields may decrease. Precipitation was positively correlated with all the crops: corn yield ($r = 0.77$), cotton yield ($r = 0.108$), peanut yield ($r = 0.064$), and soybean having the strongest correlation ($r = 0.361$). The relationship with soybean was statistically significant. These results indicate that an increase in precipitation will likely result in increased yields for all the crops.

Table 2 *Correlation Matrix*

	corn yield	cotton yield	peanut yield	soybean yield	TMIN	TMAX	PREC
<i>corn yield</i>	1.000						
<i>cotton yield</i>	0.794	1.000					
<i>peanut yield</i>	0.583	0.630	1.000				
<i>soybean yield</i>	0.573	0.588	0.382	1.000			
<i>TMIN</i>	0.015	0.088	0.172	0.258	1.000		
<i>TMAX</i>	0.209	0.147	-0.061	-0.190	-0.329	1.000	
<i>PREC</i>	0.077	0.108	0.064	0.361**	0.348	-0.359	1.000

*Sample size = 46** Correlation is Significant at the .05 Level (Two-Tail) r = Correlation Coefficient*

4.4 Ordinary Least Square Regression Model

The Ordinary Least Square regression model (OLS), a more refined tool than the trend and correlation analyses, was used to estimate the strength of the estimated model. The results for soybean show that minimum temperature and technology are statistically significant at ten and one percent levels respectively, and both explanatory variables have positive effects on soybean yield (Table 3). These results imply that a 1°C rise in minimum temperature would lead to an increase of 1.425 bushels per acre of soybean. The result also shows that as production technologies increase, the yield also increases. Fertilizer used is statistically significant at five

percent, but did not have the expected positive sign. The regressor coefficient for precipitation was not significant, although it had the expected positive sign.

The R-squared value for this regression is 0.46 implying that 46% of the variation in yield can be explained by the independent variables. For peanut, the regression result (Table 4) shows that minimum temperature and technology are statistically significant at five and one percent levels. They both have positive effects on peanut yield as expected while maximum temperature is statistically significant at 10 percent with the expected negative impact on peanut yield. Maximum temperature has the largest impact suggesting a decrease in yield of 201.893 pounds per acre if the maximum temperature increased by 1°C. Fertilizer used was not significant but it had the expected positive sign while precipitation was negative and insignificant contrary to expectations. The R-squared value is 0.47 implying that the independent variables explain 47% of the variation in yield.

Table 3 Model Result for Soybean

Variable	Coefficient	t-value
Tmax	-2.076*	-1.969
Tmin	1.425*	1.902
Prec	0.60	1.337
Fert	-0.205**	-2.374
Tech	0.181***	3.837
Constant	51.178	1.781
F	6.440***	
R ²	0.45	

*** Statistical Significance at 1% **Statistical Significance at 5% *Statistical Significance at 10%

$$Y_t = 51.178 - 2.076 * T_{max_t} + 1.425 * T_{min_t} + 0.6PRE_t - 0.205 ** Fert_t + 0.181 *** TECH_t$$

Table 4 Model Result for Peanut

Variable	Coefficient	t-value
Tmax	-201.893*	-1.731
Tmin	194.149**	2.159
Prec	-0.847	-0.164
Fert	141.611	0.500
Tech	31.193***	5.282
Constant	3841.380	1.187
F	7.230***	
R ²	0.470	

*** Statistical Significance at 1% **Statistical Significance at 5% *Statistical Significance at 10%

$$Y_t = 3841.380 - 201.893 * T_{max_t} + 194.149 ** T_{min_t} - 0.847 PRE_t + 141.611 Fert_t + 31.193 *** TECH_t$$

For cotton, the results (Table 5) show that only technology has a statistically significant effect on the yield of cotton at one percent level.

This implies that as the level of technology improves over time, the yield of cotton will increase by 7.578 pounds per acre. Minimum temperature and precipitation were not significant, although they had the expected signs. Also, fertilizer used was not significant and did not have the expected positive sign. The R-squared value is 0.54 and it shows that the explanatory variables explain 54% of the variation in cotton yield.

Table 5 Model Result for Cotton

Variable	Coefficient	t-value
Tmax	4.847	0.178
Tmin	29.442	1.489
Prec	1.398	1.197
Fert	-1.634	-0.369
Tech	7.578***	5.346
Constant	-238.506	-0.328
F	9.500	
R ²	0.540	

*** Statistical Significance at 1%

$$Y_t = -238.506 + 4.847T_{max_t} + 29.422T_{min_t} + 1.398PRE_t - 1.634Fert_t + 7.578***TECH_t$$

For corn, the results (Table 6) suggest that minimum temperature, fertilizer used, and technology have significant and positive effects on corn yield with minimum temperature having the largest impact showing that if minimum temperature increases by 1°C, corn yield will increase by 4.48 bushels per acre. Maximum temperature and precipitation both had the expected negative and positive signs respectively but were not significant. The independent variables explain 84% of the variation in corn yield.

The role of technology in promoting crop yield is very crucial as the above results show. Technology, for the four crops was statistically significant at the 1% level.

Table 6 Model Result for Corn

Variable	Coefficient	t-value
Tmax	-1.333	-0.459
Tmin	4.480**	2.042
Prec	0.177	1.384
Fert	0.881**	2.638
Tech	2.451***	8.976
Constant	-45.133	-0.568
F	41.640***	
R ²	0.840	

*** Statistical significance at 1% **Statistical significance at 5%

$$Y_t = -45.133 - 1.333T_{max_t} + 4.480**T_{min_t} + 4.505PRE_t + 0.881**Fert_t + 2.451***TECH_t$$

5. Discussion

The overall objective of this study was to examine the effects of climatic variables such as minimum temperature, maximum temperature and precipitation, technology and fertilizer used on the yields of the four major crops in Alabama. The four crops are: cotton, corn, peanut and soybean and the study period was 1960-2005 because of the availability of consistent time-series data on climatic and economic variables. The specific objectives were to: i) assess the strength of the relationship between crop yield and selected climatic variables such as minimum temperature, maximum temperature, precipitation, and variables such as fertilizer used and technology, and ii) assess farmers' adaptive capacity to such changes in Alabama.

The trend analysis showed that the crop yields were positively related to minimum temperature, with the peaks and valleys of minimum temperature coinciding with those for the crop yields. These findings suggest that high minimum temperature most likely promotes yield.

Maximum temperature and crop yield were opposite mirror images, with the peaks of maximum temperature coinciding with yield valleys. The negative relationship indicates that high maximum temperature most likely suppresses yield. Precipitation was positively related to yield for the four crops, with the peaks and valleys coinciding with those for the crop yields. This suggests that precipitation most likely promotes crop yield. For the 1960-2005 study period, maximum temperature showed an increasing trend, in contrast to decreasing trends for minimum temperature and precipitation. However, crop yield generally recorded an increasing trend during the study period.

The correlation analysis showed that the yields for the four crops were positively related to minimum temperature and precipitation but they were not significant, except for soybean which had a statistically significant correlation with precipitation. These findings are consistent with those by Goldblum (2009), which showed that soybean yield had a positive correlation with precipitation in Illinois. Cotton and corn had positive correlations with maximum temperature but the correlations with peanut and soybean were negative. In both cases, the relationship was not statistically significant.

The major OLS regression results were that minimum temperature had a positive and statistically significant relationship with the yield for soybean, peanut and corn, with the highest impact on peanut. The latter finding suggested a 194.149 pounds per acre increase in yield if the minimum temperature increased by 1°C and soybean yield would increase by 4.48 bushels per acre. These findings are consistent with those by Harrison (2010) which showed an increase in corn production with increase in minimum temperature. However, there is a contrast with the findings of Lobell et al. (2007) and Peng et al. (2004) in that high minimum temperature was found to suppress hay and rice yields. Maximum temperature had a negative and statistically significant effect on soybean and peanut yields. The effect of maximum temperature on peanut was larger than that on soybean. The results suggested a decrease in peanut yield of 201.893 pounds per acre if the maximum temperature increased by 1°C and soybean yield would decrease by 2.076 bushels per acre. These findings are consistent with those by Travasso et al. (2009), Kucharik and Serbin (2008), Lobell and Field (2007) which showed a reduction in corn yield as a result of increased temperature, with the expected negative sign for corn yield.

Fertilizer used was statistically significant for corn and soybean but with opposite effects. The relationship was positive for corn, suggesting an increase of 0.88 bushels per acre with an increase of 1 ton per acre of fertilizer applied. However, a decrease of 0.247 bushels per acre would occur for soybean, probably as a result of the low fertilizer requirements of soybean since it naturally enriches the soil through nitrogen fixation. These findings are consistent with those by Yingjie et al. (2008) where fertilizer inputs had positive effects on corn production in Northeast China, in spite of a warming climate trend. On the contrary, the findings by Schlenker and Lobell (2010) indicated that South Africa and Zimbabwe, the highest users of fertilizers in Sub-Saharan Africa, had the largest projected yield losses, suggesting that well-fertilized modern seed varieties are more susceptible to heat related losses.

Precipitation had the expected positive sign for the four crops, except peanut and was not statistically significant. Molua and Lambi (2007), Deressa and Hassan (2009), Kurukulasuriya and Mendelsohn (2008) and Gwimbi (2009) indicated yield losses due to decreased precipitation. However, increased precipitation reduced cowpea yield in the northern states of Nigeria (Ajetomobi and Abiodun, 2010) and corn and red kidney bean production in Cayo and Orange Walk districts in Belize (Harrison, 2010). For the four crops, technology was positive and statistically significant at the one percent level, suggesting that, as the level of technology improves over time, say, within a year, the yields for soybean, peanut, cotton and corn would likely increase by 0.282 bushels per acre, 31.193 pounds per acre, 7.578 pounds per acre, and 2.451 bushels per acre respectively. The findings by Ajetomobi and Abiodun (2010), Cai et al. (2009), Deressa and Hassan (2009), and Lobell and Field (2007) were that increase in yield or yield loss reduction in crop production occurred as a result of the adoption of appropriate technology.

The results of this study suggest that, farmer's adaptive capacity, through the use of technology significantly promotes yields for the four crops. Farmer's adaptive capacity is assumed in economic models (Ajetomobi and Abiodun, 2010) to be a composite variable which reflects judicious investments by farmers in the use of better machinery and equipment, improved seeds, water conservation, and other better crop management practices. Such investments counter and mitigate the adverse impact of climate change on crop yield. It can be inferred from the statistical significance of technology from the regression results that only farmers who can afford such investments in technology will increase their adaptive capacity to minimize the adverse effects of climate change on crop yield. Such farmers have access to suitable soils, land resources, key agricultural inputs, and benefit from economies of scale. In contrast, those farmers who cannot afford such investments and who lack such strategic access are most likely to suffer from their limited adaptive capacity, and are, therefore, particularly vulnerable to climate change. Lotten et al. (2015) tried to compute a composite index to measure how agriculture can adapt to climate change. The study concluded that representing agricultural vulnerability in a single composite index might be insufficient to guide climate adaptation.

6. Conclusion

Since changes in climatic variables, fertilizer inputs, and technology, can suppress or promote crop yield, it is important to understand these relationships in order to be

able to implement appropriate adaptive technology. There is a need to ensure that agricultural policy planners and other policy-makers at all levels integrate climate change risks, and build public support for climate policies that will enable farmers to further enhance their adaptive capacity. It is equally critical that the research findings on the impact of climate change on Alabama crop production, and agriculture in general, are integrated into outreach education and extension to benefit all farmers irrespective of country or region where the farmer is located. The study by Lotten et al. (2015) concluded that representing agricultural vulnerability in a single composite index might be insufficient to guide climate adaptation. This study shows that there is need to adapt different strategies to mitigate climate impacts on different crops and the related environmental variables.

Our study responded to a call (Ojumu, Ojumu, and Joonas, 2020) to empirically test a theoretical framework measuring the role of climatic variables, technology, and fertilizer used, on the yield of four major crops in Alabama. An important research contribution of our study is that it sheds light on this theoretical framework. Yields of soybean, peanut, and corn were significantly affected by climate variables. Yields of all four crops in the study – soybean, peanut, corn, and corn - were significantly impacted by technology. Our research highlights the importance of intervention through appropriate technology for enhanced crop yields. The results of our study are relevant to stakeholders in the agricultural fields, such as consumers, farmers, planners, policy-makers, agricultural marketers, as well as educators. Future studies need to focus on achieving greater generalizability of our findings, by obtaining crops data from other geographical areas. Another extension of our research would be to examine the longitudinal effects of climate change, and to unmask other factors that veil the impacts of climate variations on crop yields.

7. References

1. Ajetomobi, J., & Abiodun, A. (2010). Climate Change Impacts on Cowpea Productivity in Nigeria. *African Journal of Food, Agriculture, Nutrition and Development*, 10(3).
2. Cai, X., Wang, D., & Laurent, R. (2009). Impact of climate change on crop yield: A case study of rainfed corn in central Illinois. *Journal of Applied Meteorology and Climatology*, 48(9), 1868-1881.
3. Changnon, S., & Hollinger, S. (2003). Problems in estimating impacts of future climate change on midwestern corn yields. *Climatic Change*, 58, 109-118.
4. Chavas, J., & Johnson, S. R. (1982). Supply dynamics: The case of U.S. broilers and turkeys. *American Journal of Agricultural Economics*, 64, 558-564
5. DAFF. (2005). Information handbook: Exceptional circumstances assistance. Australian Government Department of Agriculture, Fisheries and Forestry. <http://www.affa.gov.au/content/publications.cfm?ObjectID=D43AC96E-FEB9-42A0-9A6BBCD98FA5A401>
6. DAFF. (2006). National agriculture and climate change action plan 2006-2009. *Department of Agriculture, Fisheries and Forestry, Canberra*.
7. Deressa, T., & Hassan, R. (2009). Economic impact of climate change on crop production in Ethiopia: Evidence from cross-section measures. *Journal of African Economies*, 18, 529-554.

8. Dixon, R. (2009). Peanut production in Alabama. Encyclopedia of Alabama. <http://www.encyclopediaofalabama.org/article/h-2016>.
9. Goldblum, D. (2009). Sensitivity of corn and soybean yield in Illinois to air temperature and precipitation: The potential impact of future climate change. *Physical Geography*, 30, 27-42.
10. Gwimbi, P. (2009). Cotton farmers' vulnerability to climate change in Gokwe District (Zimbabwe): Impact and influencing factors. *JAMBA: Journal of Disaster Risk Studies*, 2(2).
11. Harrison, A. (2010). *An assessment of climate change on grain production in Belize*. Unpublished thesis, Tuskegee University.
12. Hu, Q., & Buyanovsky, G. (2003). Climate effects on corn yield in Missouri. *Journal of Applied Meteorology*, 42, 1626-1635.
13. Intergovernmental Panel on Climate Change, IPCC. (2007). Climate change: Impacts, adaptation and vulnerability, contribution of working group ii to the fourth assessment report of the intergovernmental panel on climate change. Cambridge, UK: Cambridge University Press.
14. Kouka, P., & Engle, C. (1998). An estimation of supply in the catfish industry. *Journal of Applied Aquaculture*, 8(3)
15. Kucharik, C., & Serbin, S. (2008). Impacts of recent climate change on Wisconsin corn and soybean yield trends. *Environmental Research Letters*, 3, 034003.
16. Kurukulasuriya, P., & Mendelsohn, R., (2008). A Ricardian analysis of the impact of climate change on African cropland. *African Journal of Agricultural and Resource Economics*, 2.
17. Lobell, D., Cahill, K., & Field, C. (2007). Historical effects of temperature and precipitation on California crop yields. *Climatic Change*, 81, 187-203.
18. Lobell, D., & Field, C. (2007). Global scale climate-crop yield relationships and the impacts of recent warming. *Environmental Research Letters* 2, 014002.
19. Lotten, W., Åsa, D., & Nesen, T.S., (2015). Assessment of composite index methods for agricultural vulnerability to climate change. *Journal of Environmental Management Volume*, 156(1), 70-80.
20. Molua, E., & Lambi, C. (2007). The economic impact of climate change on agriculture in Cameroon. *World Bank Policy Research Working Paper* 4364.
21. National Oceanic and Atmospheric Administration's National Weather Service. (2009). *National weather service glossary*. <http://www.nws.noaa.gov/glossary/>
22. Nelson R., Kokic, P., & Meinke, H. (2007). From rainfall to farm incomes—transforming advice for Australian drought policy. II. Forecasting farm incomes. *Australian Journal of Agricultural Research*, 58(10), 1004-1012
23. Ojumu, O., Ojumu, M., & Joonas, K. (2020). A Theoretical Framework for Assessing the Impact of Climate Change on Crop Yields. *AIMS International Journal of Management*, 14(2), 65-87
24. Peng, S., Huang, J., Sheehy, J., Laza, R., Visperas, R., & Zhong, X. (2004). Rice yields decline with higher night temperature from global warming. *PNAS* 101, 9971-9975.
25. Phillips, K., & Roberts, J. (2008). Cotton. Encyclopedia of Alabama. <http://www.encyclopediaofalabama.org/face/Article.jsp?id=h-1491>

26. Russell, N. (2007, April). The agricultural impact of global climate change: How can developing-country farmers cope? *Geotimes, Earth, Energy and Environmental News*.
27. Schlenker, W., & Lobell, D. (2010). Robust negative impacts of climate change on African agriculture. *Environmental Research Letters*, 5, 014010.
28. Schmidhuber, J., & Tubiello, F. (2007). Global food security under climate change. *Proceedings of the National Academy of Sciences of the USA*, PNAS 104(50), 19703-19708.
29. Travasso, M., Magrin, G., Rodriguez, G., Solman, S., & Nunez, M. (2009). Climate change impacts on regional maize yields and possible adaptation measures in Argentina. *International Journal of Global Warming*, 1, 201-213.
30. Tao, S., Xu, Y., Liu, K., Pan, J., & Gou, S. (2011). Research progress in agricultural vulnerability to climate change. *Collection of Advances in Climate Change Research*, 2(4), 203-210.
<https://doi.org/10.3724/SP.J.1248.2011.00203>.
31. Yingjie, L., Erda, L., Liu, Y., & Lin, E. (2008). Impact of climate warming in the past 20 years on agriculture in different regions of China. *Advances in Climate Change Research*, Article ID: 1673-1719, Suppl. 0051-55

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