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Factors Affecting U.S. Sorghum Yields

Curtis Ramsey
cramsey1094@gmail.com

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By

Curtis Ramsey

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Submitted in Partial Fulfillment of the Requirements for the
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RESEARCH PAPER APPROVAL

FACTORS AFFECTING U.S. SORGHUM YIELDS

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A Research Paper Submitted in Partial

Fulfillment of the Requirements

For the Degree of

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in the field of Agribusiness Economics

Approved by:

Dr. Dwight R. Sanders

Graduate School
Southern Illinois University Carbondale
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AN ABSTRACT OF THE RESEARCH PAPER OF

Curtis Ramsey, for the Master of Science degree in Agribusiness Economics, presented on May 2nd, 2018 at Southern Illinois University Carbondale.

TITLE: FACTORS AFFECTING U.S. SORGHUM YIELDS

MAJOR PROFESSOR: Dr. Dwight R. Sanders

Sorghum productivity is an interesting topic in U.S. agriculture. Sorghum continues to grow as an export for the U.S., but its' overall production is decreasing yearly. However, the average yield per acre of sorghum is on the rise. The various uses for sorghum make it an essential grain worldwide and in the U.S. The research acquired for this analysis is used to see exactly how influential weather variables are on sorghum yields. U.S. precipitation and climate conditions during the sorghum growing season will be key variables measured in the study, and the tests ran for this study will show what level of significance weather variables play on the decrease in U.S. sorghum production. Specifically, the average temperature of the northern and southern plains from May through September, and the average precipitation for the northern and southern plains are the independent variables used in the regression. Also, a secondary test on silage sorghum will be ran to see if it experiences the same effects as grain sorghum. The weather data was obtained by regional grouping of the major sorghum growing states along the sorghum belt from South Dakota down to southern Texas. A multiple regression analysis will be used to help exploit the elements of production that are most influential for the sinking sorghum production. Also, this study involves tests to see if there were any indirect effects from the price per bushel for sorghum and its' competing crops, such as soybeans, wheat, and corn. Lastly, this paper addresses issues with separate tests in order to help provide a specific analysis on how to improve the study and improve sorghum production.

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CHAPTER 1

INTRODUCTION

Sorghum is believed to have originated as an African grass where its' domestication took many different pathways to become the diverse plant that it is today. The original cultivation of the cereal has not been pinpointed to an exact geographic, but many developing studies and findings from botanists, archeologists, geographers, plant breeders, and scientists have helped shape spatial theories for its' early application. As sorghum underwent natural evolution in its' presumed source of northeast Africa, comprising Ethiopia, the Sudan, and East Africa, it spread to India during the first century AD. Then, Sorghum worked its way from India to China, Australia, and eventually to North America in the late 1750's (Doggett 1988). "The first known record of sorghum was from Ben Franklin in 1757 who wrote about its application in producing brooms. During this progression, sorghum diversified into five major races and thousands of separate genotypes. The five major races are separated into four cultivated species and one wild species. The four cultivated species include: Bicolor, Caudatum, Kafir, and Durra, and the wild species is Halepense. These five main species are broken down further into 10 intermediate groups, which are all combinations of the major races. Each species has distinct characteristics that set them apart from one another (Smith and Frederiksen, 2000).

A feature point that is emphasized for determining the species of sorghum is if the plant is categorized as cultivated or wild. According to Smith and Frederiksen (2000), editors of Sorghum: Origin, History, Technology, and Production, "a fundamental change in wild plants leading to identification of domestication in the archeological record is loss of the ability to self-seed, and thus human assistance is required for survival as a taxon" (Smith and Frederiksen, 108, 2). The human involvement of sorghum's domestication leads to plant structural changes. These changes cause the plant to evade dormancy, while removing the chemical and physical defense properties of the plant to increase its dependence on human cultivation processes. More specifically, sorghum changes from wild to a cultivated race depending on the presence or absence of an abscission zone at the rachis, panicle, or spikelet nodes of the plant (Helbaek, 1960). The first sorghum species studied was Halepense. This species does not enter the cultivation process, so it is categorized as wild. Halepense is the only major species that is considered a wild plant. It is a perennial plant that has been known as a native weed of southern Eurasia, east India, and all warm temperate areas of the world (Dahlberg 1995). These plants are very slender with narrow leaf blades with small clusters of flowers arranged on the main stem. This slender appearance is similar to the cultivated species' appearance, but the human involvement of the cultivated plants causes plants to have differentiated properties.

Cultivated sorghum species are the primary focus of this paper, because of the worldwide dependence of this plant. Sorghum covers areas in over 100 countries spread throughout the Americas, Africa, Asia, and the pacific. It is the fifth most important cereal crop in the world after wheat, maize, rice, and barely. Grain sorghum is the most abundant and useful type of sorghum in the world. The United States produces over 480 million bushels making it the world's largest producer of grain sorghum. It is key for food production and animal feed production. In China and Africa, dye is extracted from the leaf sheaths used on fabrics, wool, and hides. Traditionally, many countries incorporate sorghum into foodstuffs, for example porridge, unleavened bread, cookies, cakes, and various alcoholic and soft drinks. In the southern United States specifically, sorghum is used a sweet spice, applied to biscuits, corn bread, and pancakes

Also, there has been growing interest in the U.S. to use sweet grain sorghum in ethanol production (Coclea, 2014).

Grain sorghum can vary in shapes and sizes depending on the geographic location. They can be short or tall, contain tight-headed, circular panicles or open, hanging panicles. Also, the color differentiation of the sorghum come with certain properties. Red, orange, or bronze colored are the most fundamental, and are used in all aspects of the sorghum industry. Light colored sorghum are incorporated into the production of flour, while darker varieties are utilized for their antioxidants. Another type of sorghum focused on in the United States is forage sorghum. This variety can be anywhere from 8 to 15 feet tall and is mainly used as silage for feeding livestock. It also provides usefulness for pasture grazing, hay production, and green-chop. The most recently developed sorghum is biomass sorghum. The appearance of this type differs from all the others with an enormous stature reaching to 20 feet. These hybrids are developed to assist in the production of bioenergy. The final class of sorghum focused on in the U.S. is sweet sorghum. This specific class is specified by harvesting the plants' stalks rather than the actual grain. The stalks are crushed in order to extract syrup. This syrup can then be used as a healthy alternative sweetener for the production of rum and whisky products, as well as for biofuel and chemical production.

The main goal of this paper is to identify the variables that affect U.S. grain sorghum yields. Also, this study will help compare those results for the main states involved in sorghum production, as well as, compare the data with the other leading sorghum producing countries. Throughout the world, farmers and researchers are continuously trying to enhance their sorghum production in order to improve their yields, so it is vital to understand the characteristics influencing yield the most. A multiple regression model will examine the effects of precipitation and temperature on grain sorghum during the growing season from May through September along the sorghum belt. Also, this research attempts to see if and the change in price per bushel for sorghum, and its’ close substitutes and competing crops have any indirect effects on the actual yield per acre.

The information gathered from running these various tests will be valuable to farmers and researchers determined to increase sorghum yields for the United States and other sorghum focused countries. Also, it will highlight what conditions are favorable or unfavorable for certain types of sorghum. This will prove to be an important study, because not many studies have focused on showing how the hybrid sorghum seeds react to the different geographic locations, as well as see if crop price changes have any behavioral effects that cause farmers to reduce sorghum planting.

CHAPTER 2

REVIEW OF LITERATURE

In this study it is important to understand how sorghum were originally developed to become the versatile plant it is today. The present examinations of sorghum are from the foundation of a long series of variety tests conducted by the United States Department of Agriculture. They performed these experiments on field stations located on the Great Plains in 1915. The basis of these tests were to figure out the variation limits sorghum can undergo, and for classification purposes. Different form of sorghum was brought in from nearly all countries to run extensive comparison tests. From these tests, the USDA determined that there are no clear lines of demarcation between the various types of sorghum. The data derived from the conditions of the tests are supposed to accurately represent the behavior of sorghum in the northern, central, and southern locations where sorghum is being grown in the U.S. The measurements and examinations accurately described the growth process for these areas, but because the weather for some of these areas vary so much it was difficult to get exact figures pertaining to the natural behavior of sorghum. The main purpose of these tests was to pinpoint when sorghum should be planted in each region to reach maximum productivity. The data gathered from the early tests helped determine the classification of sorghum seed varieties, as well as providing tests from showing the best methods for growing sorghum in the separate U.S. regions (Vinall, 1936).

CHAPTER 3

DATA

The research gathered for this study includes the U.S. sorghum production per acre as the dependent variable Y. The study covers from 1976 to 2016. The explanatory variables being tested in this regression include: the average temperature and precipitation during the sorghum growing season (May-September) in the central and south region of the United States, specifically from South Dakota down to Texas. This will help determine if the weather conditions have played a major role in the decline of recent U.S. sorghum production. The information used to run this regression was collected from the National Oceanic and Atmospheric Administration (N.O.A.A). This database was used to get the average monthly temperature and precipitation from May through September in the two separate regions of the U.S. that sorghum is grown. Then, to find the overall average monthly temperatures of the total area of the sorghum belt, the two regions were averaged together. Additionally, N.O.A.A. was used to find the measurements for precipitation. The precipitation variables are described as the measure of aggregate rainfall in inches for May, June, July, August, and September. Like the method used for temperature, the precipitation was averaged from the two regions in the U.S. thin which sorghum is located.

The next test analyzed deals with the same dependent variable of total U.S. sorghum yields per acre with the same time frame of 1976 to 2016 providing a sample size of 41 years. The independent variables under analysis are the prices per bushel for sorghum, wheat, soybeans, and corn. The United States Department of Agriculture's (USDA) National Agriculture Statistics Service QuickStats program and USDA's Crop Production Historical Records provided the data for this report. The goal for this regression is to see if there was any indirect correlation between the yearly price changes for the crops under study have influence on the overall U.S. sorghum production. The last variable looked at is the total production of forage sorghum yields. Forage sorghum is a grassy product that is undried after harvest, and stored for livestock feed. Forage is typically measured in tons, so the measure for overall U.S. forage yield per acre.

Most of the data needed for this study was easily accessible, however there were some issues for providing specific state by state sorghum production comparisons. Also, detailed country to country comparisons were not available, because sorghum is largely grown in developing countries where there can be lapses in record keeping. Some of the countries do not provide thorough yearly reports of sorghum production, and the sorghum that is used in these countries differ from the hybrids being developed in the U.S. and other developed countries. The only other issue addressed in this research was when applying the specific regions for where sorghum is grown in the U.S. Sorghum is grown in the central and southern regions of the U.S., but does not totally cover both regions. The average temperature and precipitation accounted for two separate U.S. regions provided by USDA’s QuickStats to give the closest estimate of for the weather variables along the sorghum belt.

CHAPTER 4

METHODS

The ordinary least squares multiple linear regression (OLS) is the primary method used to evaluate each data set within the research. This method has become very popular within modern statistics. According to Abdi's article in 2007, *The Method of Least Squares,* this is first credited to most common estimators can placed within the foundation. Second, using squares makes OLS mathematically very manageable, because through the use of the Pythagorean theorem, the squared estimated quality and squared error can be added if the error is independent of the projected quantity. Third, the mathematical tools and algorithms involved in the least squares method have been well studied for a relatively long time (Abdi, 2007, 1). This method determines the significance of the relationship between the tested dependent and independent variables. The typical equation for a linear regression model looks like ($Y=a+bX = e$). "Y" represents the independent variables that is being tested, "X" is the independent variable (or variables), "a" is the intercept term, "b" is the regression coefficient on the variable X, and "e" is a residual error term.

The minimization of the sum of squares between observed and predicted variables is the premise behind the OLS method. The OLS method contains strong statistical characteristics, and these characteristics reach optimality when they meet five foundational criteria: "the data obtained constitute a random sample from a well-defined population, the population model is linear, the error has zero expected value, and the error is normally distributed and uncorrelated with the independent variables" (Abdi, 2007, 5). The criteria depend greatly on the assumption of homoscedasticity, which is the idea that all values for the dependent variables variation is the same around the regression line. Following these parameters, the research gathered for this study has been split into two separate equations in order to help with clarity and organization. The equations conveyed for this model include:

(1) U.S. Grain Sorghum Yield Per Acre = β_0 + β_1(May temperature) + β_2 (June Temperature) + β_3 (July temperature) + β_4(August Temperature) + β_5 (September Temperature) + β_6(May Precipitation) + β_7(June Precipitation) + β_8(July Precipitation) + β_9 (August Precipitation) + β_{10}(September Precipitation) + β_{11}(Trend) + ε

(2) U.S. Silage Sorghum Yield Per Acre = β_0 + β_1(May temperature) + β_2 (June Temperature) + β_3 (July temperature) + β_4(August Temperature) + β_5 (September Temperature) + β_6(May Precipitation) + β_7(June Precipitation) + β_8(July Precipitation) + β_9 (August Precipitation) + β_{10}(September Precipitation) + β_{11}(Trend) + ε

In both equations total U.S. sorghum production by yield per acre is the variable under observation with differentiated predicted variables. Grain sorghum is measured in bushels per acre and silage sorghum is measured in tons per acre. The first equation deals with the impact that weather variables for May, June, July, August, and September should have a negative correlation with U.S. sorghum production. When the temperature increases overall production should decrease. However, this is the opposite for precipitation. As precipitation increases sorghum production will increase. But, because weather varies so much these inferences may not show clear significance. Also, sorghum is a very adaptable crop, meaning it may react differently to these weather variables than traditional crops. Using a rational method, the predicted correlation for the total planted sorghum should show that if more sorghum is planted then there will be greater yield per acre. The second equation follows the same format as the first with the same independent variables, but the dependent variable is changed to silage sorghum yields per acre in tons. The addition of the yield per acre variables for each sorghum will show a surprising trend that overall production has decreased as yield per acre is increases. This can be the cause of many different unmeasurable variables. For example, technological improvements, better planting practices, soil fertility, and many more lead to this yield per acre increase. The last test ran in these studies was to see if there was any relationship between price changes of competing crops and sorghum yields per acre. However, because the price changes do not directly affect the yield per acre for sorghum, the tests were inconclusive. Price changes may affect the farmer's decision on what crops to plant, but does not influence the actual growing process of sorghum.

By applying the regression method to these equations, there are many different calculations used for explaining the effects that the exogenous variables have on the endogenous variable. The tasks focused on for this OLS regression are deriving the estimator, applying sensitivity to scales and units, standardization and elasticity testing, derive variances, probability distribution, hypothesis testing, and r-squared. These tools and methods are first used to formulate hypotheses for each variable in the analysis as shown in table 2. Once the hypotheses are established, the regression is conducted. Next, the significance that each exogenous variable has is determined by running a next we will conduct a t-test and then use t-statistic to determine significance or insignificance of a variable. The t-test depends on the degrees of freedom, sample size, and the t-test statistic given by the regression. Next, in order to find if all variables in the study have influence on the variation of sorghum production. More specifically, the f-test can be used to explain how the specific variables for each equation effect the dependent variable. Elasticity testing provides a more concentrated look at how each individual variable impacts sorghum. Ultimately, elasticities will be tested to determine the influence of each variable involved in sorghum yields. The hypothesis tests in focus for this regression are listed below in table 1.

Table 1: Hypothesis Tests

Null Hypothesis	Alternative Hypothesis
H_o: $\beta_{\text{MayTemp.}} = 0$	H_a: $\beta_{\text{MayTemp.}} \neq 0$
H_o: $\beta_{\text{MayPrecip .}} = 0$	H_a: $\beta_{\text{MayPrecip.}} \neq 0$
H_o: $\beta_{\text{JuneTemp.}} = 0$	H_a: $\beta_{\text{JuneTemp.}} \neq 0$
H_o: $\beta_{\text{JunePrecip .}} = 0$	H_a: $\beta_{\text{JunePrecip.}} \neq 0$
H_o: $\beta_{\text{JulyTemp.}} = 0$	H_a: $\beta_{\text{JulyTemp.}} \neq 0$
H_o: $\beta_{\text{JulyPrecip .}} = 0$	H_a: $\beta_{\text{JulyPrecip.}} \neq 0$
H_o: $\beta_{\text{AugustTemp .}} = 0$	H_a: $\beta_{\text{AugustTemp.}} \neq 0$
H_o: $\beta_{\text{AugustPrecip.}} = 0$	H_a: $\beta_{\text{AugustPrecip}} \neq 0$
H_o: $\beta_{\text{SeptemberTemp.}} = 0$	H_a: $\beta_{\text{SeptemberTemp}} \neq 0$
H_o: $\beta_{\text{SeptemberPrecip.}} = 0$	Ha: $\beta_{\text{SeptemberPrecip}} \neq 0$
H_o: $\beta_{\text{Trend}} = 0$	Ha: $\beta_{\text{Trend}} \neq 0$

CHAPTER 5

RESULTS

The regression results for testing the hypotheses above are included in table 2 of the appendix. To test the hypotheses for this research, the coefficients are summarized in accordance to the effect they have on U.S. sorghum yields per acre. Table 3 delves into the actual values of the coefficients in relation to the observed variable. The coefficients are expressed as: $\beta_{\text{MayPrecipitation}}$ = for every one-inch increase in may precipitation, there is an increase in yield of 3.58 bushels per acre. $\beta_{\text{JunePrecipitation}}$= for every inch increase in June precipitation, there in an increase in yield by 5.77 bushels per acre. $\beta_{\text{JulyPrecipitation}}$= for every inch increase in July precipitation, there is an increase in yield by 0.64 bushels per acre. $\beta_{\text{AugustPrecipitation}}$= for every inch increase in August precipitation, there is an increase in yield by 2.87 bushels per acre. . $\beta_{\text{SeptemberPrecipitation}}$= for every inch increase in September precipitation, there is a decrease in yield by 1.21 bushels per acre. $\beta_{\text{MayTemperature}}$ = for every degree increase in average May temperature, there is a decrease in yield by .77 bushels per acre. $\beta_{\text{JuneTemperature}}$= for every degree increase in average June temperature, there is an increase in yield by 1.02 bushels per acre. $\beta_{\text{JulyTemperature}}$= for every degree increase in average July temperature, there is a decrease in yield by 1.91 bushels per acre. $\beta_{\text{AugustTemperature}}$= for every degree increase in average August temperature, there is a decrease in yield by 1.27 bushels per acre. $\beta_{\text{SeptemberTemperature}}$= for every degree increase in average August temperature, there is an increase in yield by .68 bushels per acre. Lastly, β_{trend} = additional year of technological improvement there is an increase in yield by.32 bushels per acre.

In order to do the comparison of grain and silage sorghum, the next step in the regression process is to identify the coefficients relationship with the dependent variable for silage sorghum.

The coefficients are expressed as $\beta_{\text{MayPrecipitation}}$ = for every one-inch increase in may precipitation, there is an increase in yield of .59 tons per acre. $\beta_{\text{JunePrecipitation}}$= for every inch increase in June precipitation, there in an increase in yield by .45 tons per acre. $\beta_{\text{JulyPrecipitation}}$= for every inch increase in July precipitation, there is an increase in yield by .07 tons per acre. $\beta_{\text{AugustPrecipitation}}$= for every inch increase in August precipitation, there is an increase in yield by .47 tons per acre. $\beta_{\text{SeptemberPrecipitation}}$= for every inch increase in September precipitation, there is a decrease in yield by .28 tons per acre. $\beta_{\text{MayTemperature}}$ = for every degree increase in average May temperature, there is an increase in yield by .07 tons per acre. $\beta_{\text{JuneTemperature}}$= for every degree increase in average June temperature, there is a decrease in yield by .06 tons per acre. $\beta_{\text{JulyTemperature}}$= for every degree increase in average July temperature, there is a decrease in yield by .01 tons per acre. $\beta_{\text{AugustTemperature}}$= for every degree increase in average August temperature, there is a decrease in yield by .39 tons per acre. $\beta_{\text{SeptemberTemperature}}$= for every degree increase in average August temperature, there is an increase in yield by .09 tons per acre. Lastly, β_{trend} = additional unit of technological implementation there is an increase in yield by .09 tons per acre.

The next phase involves using the t-statistic to find the significance of each variable. The level of significance being used for this regression is .05, and the critical t value calculated from using a degree of freedom of 30 and a two-tailed test is -2.042 to 2.042. So, every t value that lies in between the critical t values of -2.042 and 2.042 fails to reject the hypothesis that the coefficient being tested has significance. Every t value that lies outside of the parameters is rejected meaning that there is significance between the variables. Every variable under test for the silage sorghum lies in between -2.042 and 2.042 indicating that none of the coefficients have serious significance on sorghums yield per ton. In the regression model using grain sorghum there are three variables that are rejected as seen in table 3. The variables rejected include: June precipitation, July temperature, and the technological trend. In the silage regression, there were two variables that had significance on yields: August temperature and the technological trend variable.

After finding the significance of the coefficients, the r-squared is the next descriptive tool observed to find the significance of all the variables within the regression. The r-squared for grain sorghum located in table 3 is .69 meaning that all variables represent 69% of variation in sorghum yields per acre. For the silage sorghum regression, the r-squared is only .67 indicating that all variables tested make up 67% of variation in silage sorghum yields. Along the same lines of the r-squared statistic, the f-statistic test is used to show the significance of all the data gathered and prove if the r-squared equals zero. In the first data set for the first model, the f-statistic is 5.91. The critical f value of 2.38 was found by using the degrees of freedom of (11,31), and locating those coordinates on the f-table. The first model proves the hypothesis wrong, because the r-squared is not equal to 0 concluding that 69% of the model can be represented by the variation of all variables. Running the same test for the second model, the calculated f-statistic is 5.36. This is still greater than the critical f value of 2.38 proving that the r-squared is not 0, and that 67% of the data can be exemplified by all coefficients being tested in the data set.

CHAPTER 6

DISCUSSION

This analysis shows the various effects that weather variables have on the yield per acre for both grain sorghum and silage sorghum. The data set covers a span of 41 years from 1976 to 2016 to show the progression that sorghum is experiencing in the sorghum belt of the United States. The two dependent variables of yield per acre in bushels for grain sorghum and yield per acre in tons for silage sorghum helps show what kind of effect the 11 independent variables have on each type of sorghum. From the use of the ordinary least squares multiple regression, we were able to determine that grain sorghum is much more influenced by outside factors than silage sorghum. In the grain sorghum model, June precipitation, July temperature, and the trend value have significant influence on the yield per acre for grain sorghum, while there were only two significant independent factors that affect silage sorghum: august temperature and the technological trend value. Some issues were discovered in the process of gathering the data for this research. There has been very little progression of sorghum research in the U.S. Also, there are some restrictions in sorghum’s historical data, because it is primarily recorded on a nationwide basis. So, it is difficult to get precise weather data for the entire area where sorghum is planted. All in all, these findings provide helpful information for sorghum farmers to adjust their practices in accordance with the optimal times for growing both types of sorghum.

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APPENDICES

APPENDIX

Table 2: 1976-2016, United States Sorghum Yield Data

Year	*Silage Acres Planted*	*Grain Acres Planted*	*Yield Per Acre Silage (Tons)*	*Yield Per Acre Grain (Bushels)*
1976	793	14,466	9.2	49.1
1977	839	13,797	10.9	56.6
1978	724	13,410	10.9	54.5
1979	764	12,901	11.8	62.6
1980	734	12,513	9.5	46.3
1981	786	13,677	12	64
1982	603	14,137	12.3	59.1
1983	639	10,001	10.3	48.7
1984	609	15,355	10.6	56.4
1985	534	16,782	12.3	66.8
1986	499	13,862	11.8	67.7
1987	429	10,531	12.4	69.4
1988	518	9,042	10.1	63.8
1989	541	11,103	10.4	55.4
1990	527	9,089	10.2	63.1
1991	483	9,870	10	59.3
1992	453	12,050	12.1	72.6
1993	351	8,916	11.2	59.9
1994	362	8,882	11.9	72.7
1995	413	8,253	10.3	55.6
1996	423	11,811	11.8	67.3
1997	412	9,158	13.1	69.2
1998	308	7,723	11.4	67.3
1999	320	8,544	11.6	69.7
2000	278	7,726	10.5	60.9
2001	352	8,579	11	59.9
2002	408	7,125	9.6	50.6
2003	343	7,798	10.4	52.7

2004	352	6,517	13.6	69.6
2005	311	5,736	13.6	68.5
2006	347	4,937	13.3	56.1
2007	392	6,792	13.4	73.2
2008	412	7,312	13.9	65.1
2009	255	5,502	14.5	69.4
2010	272	4,806	12.5	71.9
2011	226	3,945	10.4	54
2012	353	4,995	11.9	49.6
2013	380	6,585	14.3	59.6
2014	315	6,401	13.1	67.6
2015	306	7,851	14.6	76
2016	298	6,163	14	77.9

Table 3: Model Summary for Grain Sorghum

Model Summary				
Model	**R**	**R^2**	**Adjusted R^2**	**Standard Error of the Estimate**
1	.830	.69	.57	5.32

Table 4: Coefficients Summary for Grain Sorghum

Coefficients Summary						
Model		**Estimated Coefficient**	**Coefficients Standard Error**	**Prob.**	**t-Statistic**	**Hypothesis Test Outcomes**
1	Constant (Average Yield)	111.767	69.988	.121	1.597	
	May Temperature	0.775	0.568	0.183	1.363	Fail to Reject
	May Precipitation	3.581	1.887	0.068	1.898	Fail to Reject
	June Temperature	1.024	0.688	0.147	1.489	Fail to Reject
	June Precipitation	5.778	2.753	0.045	2.099	Reject
	July Temperature	-1.913	0.843	0.031	-2.267	Reject
	July Precipitation	0.643	1.732	0.713	0.371	Fail to Reject
	August Temperature	-1.270	0.686	0.075	-1.850	Fail to Reject
	August Precipitation	2.870	1.754	0.113	1.363	Fail to Reject
	September Temperature	.684	0.361	0.068	1.895	Fail to Reject
	September Precipitation	-1.218	1.645	0.465	-0.741	Fail to Reject
	Trend	0.324	.080	0.000	4.028	Reject

Table 5: Model Summary for Silage Sorghum

Model Summary				
Model	**R**	**R^2**	**Adjusted R^2**	**Standard Error of the Estimate**
2	.811	.67	.55	1.00

Table 6: Coefficients Summary of Silage Sorghum

Coefficients Summary						
Model		**Estimated Coefficient**	**Coefficients Standard Error**	**Prob.**	**t-Statistic**	**Hypothesis Test Outcomes**
2	Constant (Average Yield/ Tons)	30.035	13.191	0.030	2.277	
	May Temperature	0.073	0.107	0.501	0.682	Fail to Reject
	May Precipitation	0.587	0.356	0.110	1.650	Fail to Reject
	June Temperature	-0.064	0.130	0.625	-0.494	Fail to Reject
	June Precipitation	0.452	0.519	0.391	0.871	Fail to Reject
	July Temperature	-0.000	0.159	0.997	-0.004	Fail to Reject
	July Precipitation	0.070	0.326	0.831	0.215	Fail to Reject
	August Temperature	-0.387	0.129	0.006	-2.991	Reject
	August Precipitation	0.474	0.331	0.162	1.435	Fail to Reject
	September Temperature	0.090	0.068	0.197	1.320	Fail to Reject
	September Precipitation	0.284	0.356	0.367	0.917	Fail to Reject
	Trend	0.096	0.015	0.000	6.307	Reject

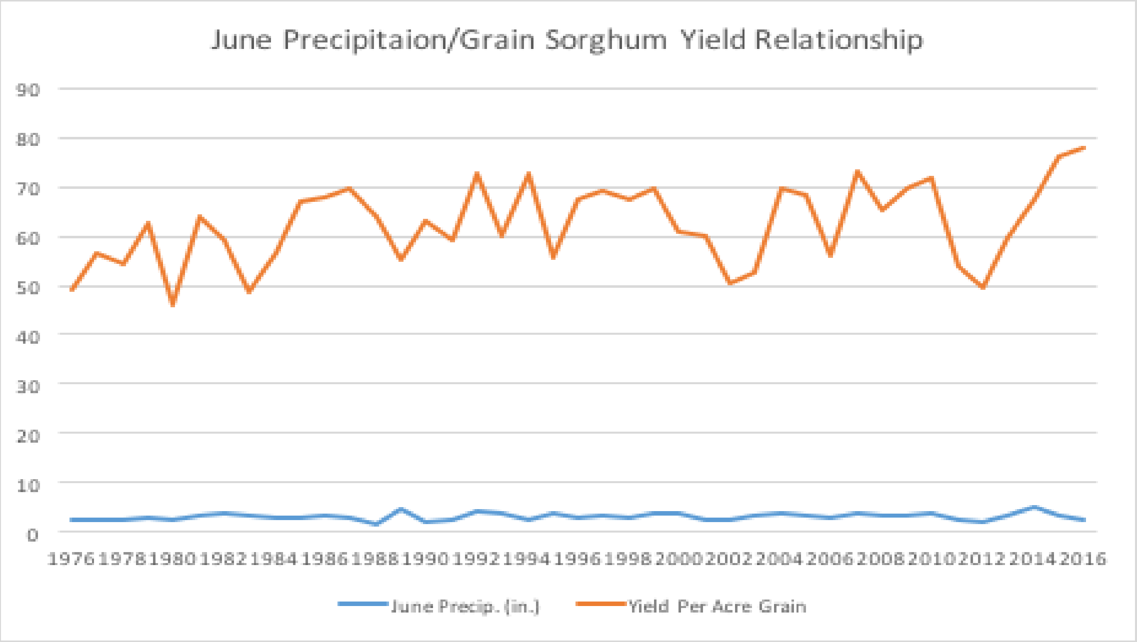

Figure 1

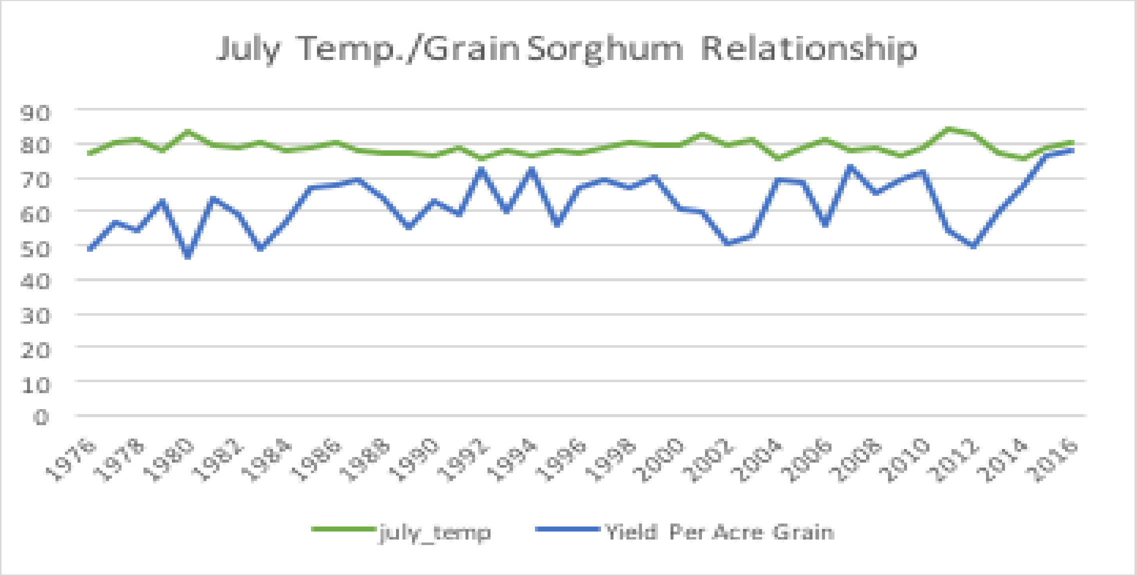

Figure 2

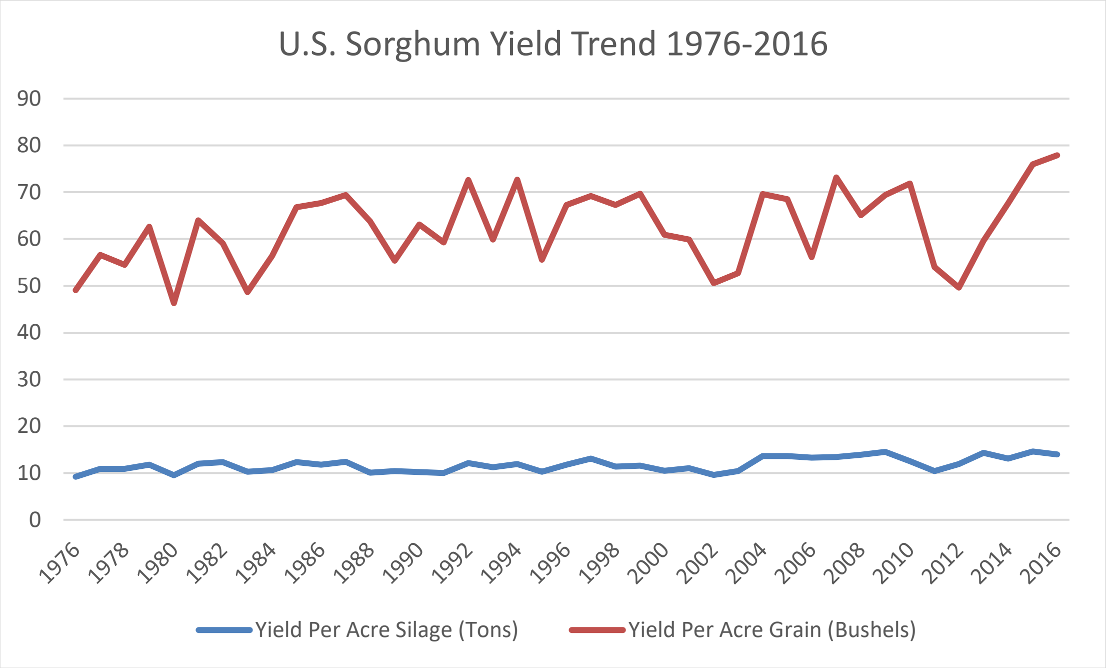

Figure 3

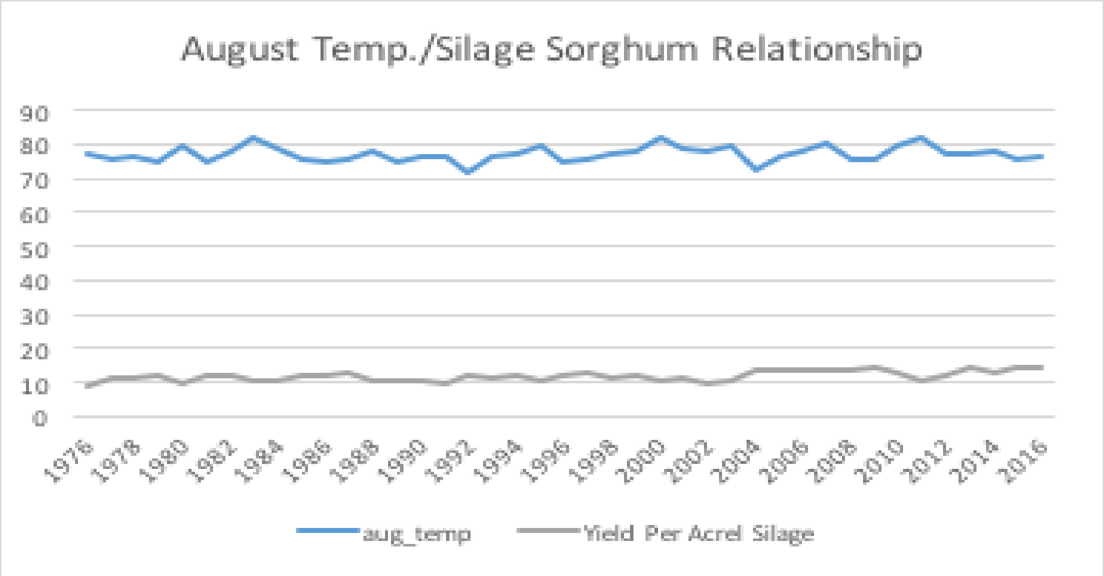

Figure 4

VITA

Graduate School
Southern Illinois University

Curtis A. Ramsey

Cramsey1094@gmail.com

Southern Illinois University Carbondale

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Major Professor: Dr. Dwight R. Sanders