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Evaluation of the Relationship and Impact of Climatic Factors on West Tennessee Corn and Soybean Yields from 1955 to 2013

William Michael Vestal[1*], Rachna Tewari[1], Barbara Darroch[1] and Joey Mehlhorn[1]

[1]University of Tennessee at Martin, Martin, Tennessee, USA.

Authors' contributions

This work was carried out in collaboration between all authors. Author WMV designed the study, managed the literature review, collected required data, performed the statistical analysis and wrote the first draft of the manuscript. Author RT participated in the design of the study, managed the literature review and reviewed all drafts of the manuscript. Author BD reviewed all statistical analyses and all drafts of the manuscript. Author JM reviewed all drafts of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

This study was designed to determine if a relationship existed between corn (*Zea mays*) and soybean (*Glycine max*) yields and climate factors in West Tennessee from 1955 to 2013. Yield data was obtained from National Agricultural Statistics Service (NASS) annual crop surveys for the twenty one counties in United States Department of Agriculture (USDA) West Tennessee and Delta Districts. Climate data was obtained from National Climatic Data Center (NCDC). Only climate data from April through October was used in calculations to more accurately reflect corn and soybean growing seasons. Correlations, linear regressions, and multiple regressions were developed to compare crop yields with climate factors for the year as well as three phases of the crop production process (planting, growing, and harvesting). Significant relationships were found to

*Corresponding author: E-mail: wmv20@msstate.edu;

exist between corn yield and minimum temperature (*r* = 0.32; *P* = .01), precipitation (*r* = 0.29; *P* = .26), Palmer Z-Index (*r* = 0.26; *P* = .47), and one month Standardized Precipitation Index (*r* = 0.26; *P* = .049). Significant relationships were found between soybean yield and maximum temperature (*r* = -0.32; *P* = .01), precipitation (*r* = 0.43; *P* < 0.001), Palmer Drought Severity Index (*r* = 0.28; *P* = .03), Palmer Z-Index (*r* = 0.43; *P* < .001), and one month Standardized Precipitation Index (*r* = 0.46; *p* < .001). The study found that yields were dependent on multiple climatic factors due to the abundance of significant multiple regression models compared to linear regression models. However, West Tennessee corn and soybean yields were not statistically influenced by average temperature or climate factors during the planting stage of production. Overall, growing season temperature and precipitation factors were important and will continue to impact corn and soybean yields in West Tennessee.

Keywords: Corn; soybean; climate; agriculture; crop; temperature; precipitation; climate variability.

1. INTRODUCTION

Agriculture is the largest economic industry in the United States, as well as in the state of Tennessee. Tennessee is a diverse agricultural state with the Mississippi Delta in the West, rolling hills in the middle, and Appalachian Mountains in the East. The diversity of the landscape allows several agricultural commodities to be produced. Tennessee's top agriculture commodities include beef cattle, grains, oilseeds, poultry, and forage (Table 1).

Crop production is an important part of Tennessee agriculture, especially in the western portion of the state. Corn (*Zea mays*), cotton (*Gossypium hirsutum*), soybeans (*Glycine max*), and wheat (*Triticum aestivum*) are the top crop commodities grown in Tennessee (Table 2). According to the 2012 United States Department of Agriculture's (USDA) Census [1], Tennessee ranked 17th in the nation in the production of corn for grain and soybeans for beans.

The majority of Tennessee's corn is produced in West Tennessee. In 2013, of the 890,000 acres of corn planted in Tennessee, 870,000 acres were harvested for grain and silage (Table 2). West Tennessee accounted for 65% (578,000 acres) of the total acres of corn planted and 67% (550,000 acres) of the total acres of corn harvested in Tennessee. A total of 1.28 million bushels of corn was produced in Tennessee. West Tennessee accounted for 66% (84.2 million bushels) of Tennessee's total production. West Tennessee's yield (153 bushels per acre) was slightly below the state yield average (156 bushels per acre) for 2013 [2].

Like corn, the majority of Tennessee's soybean production is found in West Tennessee. Of the 1.56 million acres of soybeans planted in Tennessee in 2013 (Table 2), 75% (1.16 million acres) were planted in West Tennessee. Seventy four percent (1.13 million acres) of the 1.52 million acres of soybeans harvested in Tennessee was produced in West Tennessee.

Table 1. Tennessee farms and market value of agriculture products in 2012 [1]

Item	Farms	Sales ($1,000)
Total	68,050	3,611,037
Grains, oilseeds, dry beans, and dry peas	5,691	1,301,303
Cattle and calves	32,852	735,511
Poultry and eggs	3,889	552,015
Nursery, greenhouse, floriculture, and sod	1,149	294,740
Cotton and cottonseed	546	253,428
Milk from cows	469	145,445
Tobacco	934	108,224
Vegetables, melons, potatoes, and sweet potatoes	1,273	72,885
Hogs and pigs	812	48,245
Other crops and hay	12,119	46,215
Horses, ponies, mules, burros, and donkeys	3,737	21,326
Sheep, goats, wool, mohair, and milk	3,502	8,906

Table 2. Tennessee crop acreage from 2004 to 2013 [3]

	Corn		Cotton		Soybeans		Wheat	
Year	**Planted**	**Harvested**	**Planted**	**Harvested**	**Planted**	**Harvested**	**Planted**	**Harvested**
2013	890[†]	870	250	233	1,560	1,557	640	575
2012	1,040	1,010	380	377	1,260	1,230	405	330
2011	790	773	495	490	1,290	1,260	400	305
2010	710	685	390	387	1,450	1,410	225	155
2009	670	640	300	280	1,570	1,530	410	325
2008	690	690	285	280	1,490	1,460	650	530
2007	860	845	515	510	1,080	1,010	420	260
2006	550	547	700	695	1,160	1,130	280	190
2005	650	645	640	635	1,130	1,110	240	150
2004	680	670	530	525	1,210	1,180	400	280

[†] = Measured in 1,000 acres

West Tennessee produced 73% (51.2 million bushels) of Tennessee's 69.9 million bushels of soybeans harvested in 2013. The average soybean yield of the state (46 bushels per acre) was slightly higher than the average yield in West Tennessee (45 bushels per acre) [4].

Agriculture is a risky industry subject to several uncontrollable factors. One of the most uncontrollable factors affecting agriculture is climate. Because climate factors directly impact agriculture outputs, it is critical to understand the effects climate variability can have on agricultural production. Several studies [5-8] have been conducted to determine the effects of climate variability on crop yields. Crop yield variability will have impacts in local and global markets as well as human welfare [5]. It is critical to determine the impact of climate variability on crop production, which may alter the capacity of agricultural producers to meet the growing demand at local, regional, and national levels.

Historical observations and mathematical models project rising global temperatures due to increased carbon dioxide (CO_2) concentrations in the atmosphere. Models project that the average temperature in the central United States could rise over 1℃ in upcoming decades [9]. The increase in the average temperature will extend the growing season by extending the frost free period. Crops can be planted earlier to take advantage of more abundant precipitation in the spring [6]. However, global climate variability is expected to create longer rain free periods in the southeastern portion of the United States. In light of the above, timing and amount of precipitation will be critical to agricultural production in the future [10].

Changes in temperature and precipitation are projected to occur in Tennessee in the upcoming decades [11]. Average temperature is predicted to rise 2℃ to 6℃ per year due to increased CO_2 concentrations. It is estimated that if climate variability continues at its current rate, the mean annual temperature in Tennessee will increase by 3.5℃ per year. However, precipitation will continue to be unpredictable. Changes in Tennessee's precipitation could range between a 3% decrease to a 15% increase per year. Increases in precipitation are expected to happen during the winter months with summer precipitation remaining normal. Climate variability in Tennessee will most likely produce severe weather conditions such as flooding, droughts, heat waves, and severe freezes [11].

Climate, especially temperature and precipitation, is a major factor in the production of corn and soybeans. Schlenker and Roberts [7] found a significant nonlinear relationship between temperature and corn yields in the eastern United States. Mishra and Cherkauer [8] found that cereal crop yields during the reproductive growth phase are positively correlated to daytime temperatures. They suggested that crop productivity initially increases due to warming temperatures. However, once temperatures reach 30℃, yields significantly decrease [7]. Lawlor and Gustafson [12] discovered that a 1℃ temperature increase would decrease the reproduction and grain filling growth stage by 5%, thus decreasing overall corn yield. Changes in reproduction, grain filling, photosynthesis, and maturity times are factors that lead to reduced yields due to temperature stress [6].

Past studies reveal precipitation projections are not as consistent as temperature. O'Gorman and Schneider [13] predicted more intense rainfall and wetter conditions with warming temperatures in subtropical areas. Charusombat and Niyogi [14] predicted 20-30% more rainfall in the winter and spring with significant variability in the summer and fall in the United States. However, the warming temperatures would reduce available water during the peak growing season in the United States [6]. Furthermore, changes in precipitation could result in a 3% crop loss in United States corn production [15].

Several studies have been conducted to analyze the effects of combined climatic factors. Niyogi and Mishra [6] analyzed corn and soybean yields in relationship to increases in temperature, CO_2, and irrigation in the Midwestern United States. Their study projected that soybeans would have a 9.9% increase in growth potential. Conversely, corn would experience a 3% decrease in growth potential. Alexandrov and Hoogenboom [16] found soybean yields would decrease due to increased temperature but will increase 14% to 30% due to increased atmospheric levels of CO_2.

Climate variability also affects other crops in addition to corn and soybeans. Hasanthika, Edirisinghe, and Rajapakshe [5] reveal precipitation and temperature changes are positively related to rice yield in Sri Lanka. Bauer, Fortnum, and Frederick [10] report cotton yields in the Southeastern United States are positively correlated to precipitation conditions. Doherty et al. [17] predict that cotton yields in the southeastern United States should increase due to increased CO_2 levels and warmer mean temperatures.

Climate variability could indirectly affect crop yields besides effects caused by temperature and available water. Increased precipitation can increase soil loss, leading to decreased soil carbon and nutrients. Weeds are expected to be more adapted to rising temperatures than crops. More weeds will increase competition for nutrients and available water, which will decrease crop yield. Studies are inconclusive on the effects of pathogen related crop stress due to climate variability [6].

Climate effects on crop yields can affect farm prices as well. Fishback, Fox, and Rhode [18] examined a 75 year period to determine if a relationship existed between weather and corn and cotton prices in the United States. Using data from the USDA, the researchers discovered changes in weather did not significantly affect cotton prices. However, the study concluded that increasing temperatures are negatively correlated to corn prices. This correlation suggests supply dominates demand in terms of climate variability in the United States.

Niyogi and Mishra [6] suggest corn and soybean production practices can be modified to adapt to climate variability. Crop producers can accomplish this by changing planting dates, using additional irrigation, and modifying fertilizer and pesticide use. Developing new varieties that are more tolerant to new climate conditions will also aid producers in maintaining, and possibly increasing, crop yields. Niyogi and Mishra [6] also predict that row crops will adapt to climate variability better than fruits and vegetables.

Tennessee, like the rest of the United States, has experienced diverse weather patterns over the last several years. Temperatures have remained consistent in Tennessee with an average growing season (April through October) temperature of 21.9℃ in 1955 and 21.0℃ in 2013 (NCDC, 2014). During the same time period, average growing season temperature ranged from 19.7℃ in 1976 to 23.1℃ in 2012. It is estimated that Tennessee's annual mean temperature could increase 3.5℃ per year due to increased carbon dioxide (CO_2) in the atmosphere [11]. Tennessee has experienced both drought and extreme wet conditions since 1955. Most recently, Tennessee was considered to have severe drought conditions in 2012 followed by wet conditions in 2013. Long term precipitation projections are more difficult to predict than temperature. Tennessee's precipitation could increase by as much as 15% and decrease as much as 3% [11].

Varied temperatures, seasonal flooding, and droughts have caused corn and soybean producers to consider altering their production strategies. Weather is one of the riskiest factors for which agricultural producers must develop a management plan. The purpose of this study was to determine if a relationship exists between corn and soybean yields and climatic conditions, specifically temperature and precipitation in West Tennessee from 1955 to 2013.

2. MATERIALS AND METHODS

2.1 Study Area

The study was located in West Tennessee. West Tennessee was defined as the area in Tennessee west of the Tennessee River as it flows north, east of the Mississippi River, south of Kentucky, and north of Mississippi. The area included the counties of Benton, Carroll, Chester, Crockett, Decatur, Dyer, Fayette, Gibson, Hardeman, Hardin, Haywood, Henderson, Henry, Lake, Lauderdale, Madison, McNairy, Obion, Tipton, Shelby and Weakley. The area defined as West Tennessee included USDA Delta and West Tennessee Agricultural Districts as well as NOAA's Tennessee District 4. The study area covered 10,649 square miles (2,758,078.3 ha or 6,815,360 acres).

2.2 Data

The study evaluated corn and soybean yields from 1955 through 2013. County yield information was collected from USDA NASS [3] yearly surveys. Yields were recorded in bushels per acre. In the event a county had missing survey data for a particular year, the yield for Other (Combined) Counties was used for that county's yield. Decatur County had missing soybean yields from 1960 – 1966. Regional mean yield was used for Decatur County during that time period. Yearly mean yield was calculated for each crop.

Climate information was obtained from National Climatic Data Center's (NCDC) Climatic Data Online [19]. Information was collected for the years of 1955 through 2013. Monthly temperature data was recorded for minimum temperature index (TMIN), maximum temperature index (TMAX), and average temperature index (TAVG). NCDC derived TMIN and TMAX using area-weighted monthly averages of minimum and maximum temperatures from daily station data (NCDC, 2014). All temperatures were converted from Fahrenheit to Celsius. Monthly precipitation data was recorded for precipitation index (PCP), Palmer Drought Severity Index (PDSI), Palmer Z-Index (ZNDX), and one month Standardized Precipitation Index (SPI01). Monthly PCP data was derived from NCDC using area-weighted averages from local station data. Palmer indexes are a standardized measure of moisture supply and demand. They are calculated using evapotranspiration from temperature measurements (demand) and precipitation (supply). PDSI measures a twenty four month period. ZNDX measures a one month period. SPI measures only moisture supply compared to historical data. Positive PDSI, ZNDX, and SPI indicate wet conditions. Negative PDSI, ZNDX, and SPI indicate drought conditions. Because the study evaluated crop yields, climate data were recorded for the months of April through October only. The growing season was divided into three categories based on crop growth stages: planting (April and May), growing (June, and July), and harvesting (August, September, and October). For each climate factor (except PCP), means were calculated for the total growing season and for each category. PCP was totaled for the growing season and for each category.

2.3 Statistical Analysis

Statistical analyses were completed using Microsoft Excel 2007 and SAS 9.3. Correlations were calculated between West Tennessee mean corn yield and each climate factor (growing season mean for each factor and category mean for each factor). Correlations were calculated for soybean yield and climate data in the same manner. Simple and multiple linear regression models were constructed using corn and soybean yields for each county as well as West Tennessee mean yields. Each climate factor (growing season mean and category mean) was used to construct a model. All alpha levels were set at 0.05 ($\alpha = .05$).

3. RESULTS AND DISCUSSION

3.1 Basic Analysis

West Tennessee mean corn and soybean yields (Figs. 1 and 2) increased from 1955 to 2013. Regional corn yield increased from 32.4 bushels per acre in 1955 to 148.9 bushels per acre in 2013. Regional soybean yields increased from 15.9 bushels per acre in 1955 to 43.8 bushels per acre in 2013. Increases in yields during this time can be attributed to changes in agricultural practices such as better pest management, harvesting equipment, and fertilization. Irrigation and improved hybrids and cultivars are additional factors that contributed to increased corn and soybean yields in West Tennessee. Even though overall corn and soybean yields did increase, yields decreased during some years compared to previous years. These increases and decreases in corn and soybeans are predicted to be associated with climatic conditions.

Growing season climatic factors were cyclical in West Tennessee from 1955 to 2013. The average growing season temperature was 21.9℃ in 1955 and 21.0℃ in 2013 (Fig. 3). The average growing season temperature ranged from 19.7℃ in 1976 to 23.1℃ in 2012. Growing season precipitation increased and decreased between 1955 and 2013 as well (Fig. 4). West Tennessee received 28.70 inches of precipitation during the growing season in 1955 and 37.51 inches of precipitation during the growing season of 2013. Growing season precipitation ranged from 19.60 inches in 1956 to 41.34 inches in 2009. West Tennessee also experienced wet and drought conditions according to PDSI. Seven years exhibited drought conditions with PDSI less than or equal to negative two. Eight years exhibited wet conditions with PDSI greater than or equal to positive two.

3.2 Corn

3.2.1 Correlations

Significant correlations were observed between West Tennessee mean corn yields and several climate factors (Table 3). West Tennessee mean corn yields were positively correlated with growing season TMIN (P = .01), PCP (P = .03, ZNDX (P = .047), and SPI01 (P = .049). During the growing phase, significant correlations were observed between mean corn yields and TMIN (P = .003). No significant correlations were found to exist between mean corn yields and climate factors during the planting and harvesting phases.

The significant correlations led to some possible conclusions about the effects of climate on corn production. The positive correlation between TMIN and corn yields suggests that corn does require a high minimum temperature to optimize yield. However, the absence of significant correlations between corn yield and TMAX and TAVG does not provide support to the prediction that increases in temperature will lead to increased yields. The strong correlation between corn yield and TMIN during the growing season supports Mishra and Cherkauer's [8] findings of a relationship between cereal crop yields and daytime temperatures during the reproductive stage. Predictions by Schlenker and Roberts [7] and Lawlor and Gustafson [12] that yield would decrease after a maximum temperature was reached were not observed in this study. This may be due to the maximum temperature threshold not being reached. The positive correlation between PCP and corn yield shows that yield is closely related to precipitation as would be expected. Corn is affected by short term wetness and drought conditions as supported by the positive ZNDX and SPI01 correlations with corn yield.

3.2.2 Simple linear regressions

Constructing linear regression models for corn produced several significant results. Table 4 displays the R^2 values for growing season TMIN, PCP, ZNDX, and SPI01 as well as TMIN for the growing phase. Most statistically significant linear regression models occurred for these climatic factors. During the growing phase, linear regression models for Henry County (P = .03) and Weakley County (P = .04) were significant for precipitation. The counties of Carroll (P = .045), Henry (P = .02), Tipton (P = .04), and Weakley (P = .03) all had significant linear regression models for SPI01 during the growing season. Benton, Decatur, Hardin, Henry, and Weakly Counties were statistically significant for precipitation and Palmer's Z Index during the harvesting phase. During the harvesting phase, significant models were found for Lake County (P = .04), Hardin County (P = .04), Henry County (P = .046), and Decatur County (P = .03) for one month standardized precipitation index. Additionally, Henry County's (P = .04) regression model was found significant for PDSI during the harvesting phase. All additional linear regression models were not statistically significant (α = .05).

The significant linear regressions for growing season TMIN, PCP, ZNDX, and SP01 and growing phase TMIN are consistent with the correlations between mean corn yield and the same factors. The lack of significant results for PDSI (except for Henry County during the harvesting phase) indicate that long term drought conditions will not predict corn yields as well as short term drought conditions (ZHDX and SPI01). Henry and Weakley counties demonstrated significant regression models with precipitation factors in the growing and harvesting phases of the study. During the harvesting phase, counties bordering the Tennessee River (Benton, Decatur, Hardin, and Henry) showed significant models with PCP and ZHDX. All other simpler linear regression models were not significant for growing season, planting phase, growing phase, and harvesting phase. Further research should be conducted to determine reasons for these counties' significant linear regressions.

3.2.3 Multiple linear regressions

Multiple regression models for corn yields were significant for growing season, growing phase, and harvesting phase (Tables 5 and 6). These models included TAVG, TMIN, TMAX, PCP, PDSI, ZNDX, and SPI01. All models for the planting phase were not significant.

Multiple regression models should provide the best predictions for yield because they use both temperature and precipitation factors. The growing season models show that both temperature and precipitation are important during corn production. However, timing of temperature and precipitation are also important to growth processes. The significant models for growing phase (June and July) support the importance of climatic factors during the reproductive stage as indicated by Mishra and Cherkauer (2010). The lack of significant models during the planting stage (April and May) may indicate that actual planting time would differ from year to year based on climate factors. From a production stance, climate factors early in the growing season limit the timing of planting but do not affect yield. The significant regression models during the harvesting phase (August to October) indicate that climate factors continue to impact yield after the growing phase (June and July).

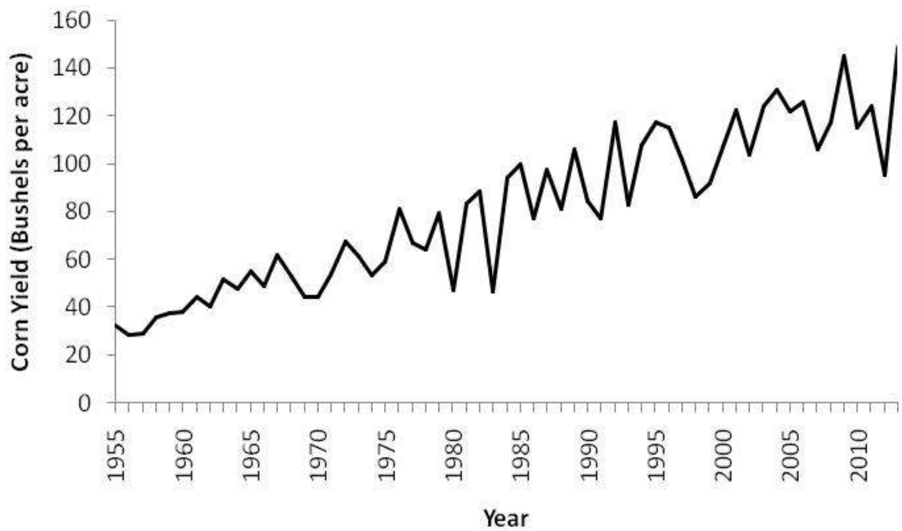

Fig. 1. Annual corn yields in west Tennessee from 1955 to 2013

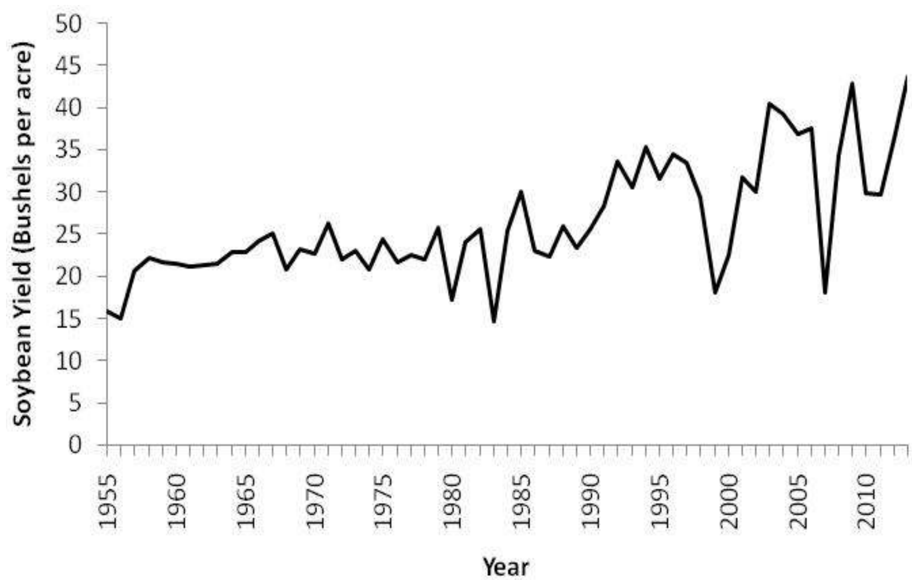

Fig. 2. Annual soybean yields in West Tennessee from 1955 to 2013

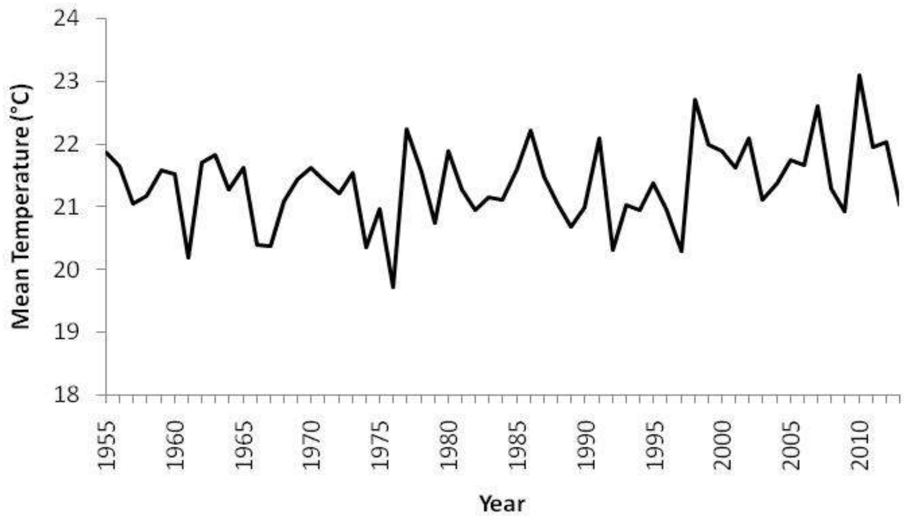

Fig. 3. Growing season TAVG in West Tennessee from 1955 to 2013

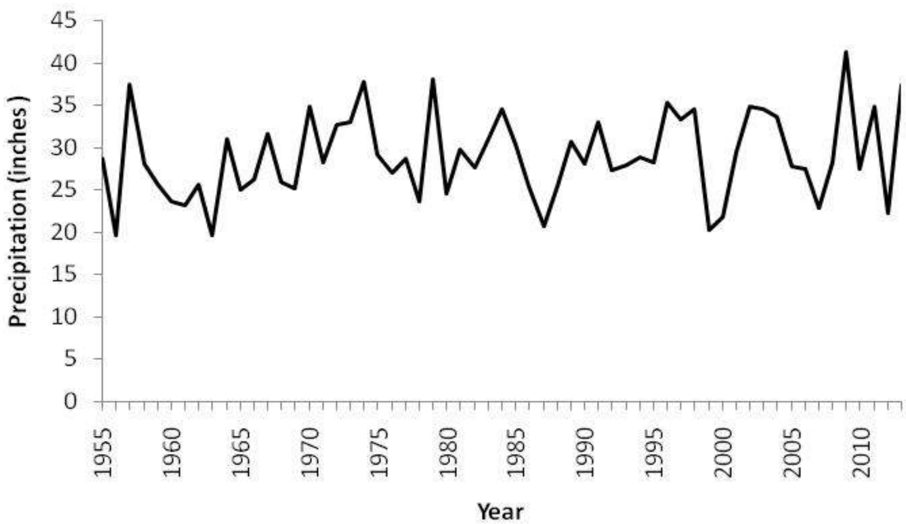

Fig. 4. Growing season PCP in West Tennessee from 1955 to 2013

Table 3. Pearson's correlation coefficients between corn yield and climatic factors in West Tennessee

Climatic Factor	Growing season		Planting phase		Growing phase		Harvesting phas	
	Corr	P	Corr	P	Corr	P	Corr	P
TAVG	0.05	0.70	0.02	0.91	0.14	0.30	0.003	0.98
TMIN	0.32	0.01	0.07	0.60	0.38	0.003	0.21	0.11
TMAX	-0.17	0.21	-0.03	0.80	-0.13	0.34	-0.18	0.18
PCP	0.29	0.03	0.08	0.58	0.21	0.12	0.22	0.09
PDSI	0.12	0.38	0.00	0.99	0.11	.41	0.16	0.21
ZNDX	0.26	0.047	0.06	0.64	0.17	0.20	0.24	0.07
SPI	0.26	0.049	0.04	0.76	0.22	0.09	0.18	0.17

Corr: Correlation; p: p value
TAVG: Average Temperature; TMIN: Minimum Temperature; TMAX: Maximum Temperature
PCP: Precipitation; PDSI: Palmer Drought Severity Index; ZNDX: Palmer Z-Index;
SPI: One Month Standardized Precipitation Index

Table 4. R^2 values for simple linear regression models for selected climate factors and corn yield in West Tennessee

	Growing season				Growing phase
County	**TMIN**	**PCP**	**ZNDX**	**SPI01**	**TMIN**
Mean[†]	0.10*	0.08*	0.07*	0.07*	0.15**
Benton	0.11*	0.08*	0.06	0.07*	0.12**
Carroll	0.11*	0.09*	0.08*	0.07*	0.16**
Chester	0.07*	0.07*	0.06	0.05	0.14**
Crockett	0.10*	0.07*	0.06	0.06	0.15**
Decatur	0.11*	0.12**	0.10*	0.11*	0.10*
Dyer	0.09*	0.06	0.05	0.04	0.13**
Fayette	0.07*	0.07*	0.06	0.05	0.11**
Gibson	0.10*	0.08*	0.07*	0.07*	0.13**
Hardeman	0.09*	0.07*	0.05	0.05	0.12*
Hardin	0.07*	0.11**	0.10*	0.10*	0.08*
Haywood	0.12**	0.09*	0.06	0.07*	0.17**
Henderson	0.11*	0.07*	0.05	0.05	0.15**
Henry	0.10*	0.15**	0.14**	0.14**	0.13**
Lake	0.12**	0.03	0.02	0.02	0.18**
Lauderdale	0.11**	0.05	0.03	0.03	0.18**
Madison	0.08*	0.07*	0.06	0.05	0.17**
McNairy	0.09*	0.07*	0.05	0.05	0.13**
Obion	0.06	0.06	0.06	0.05	0.13**
Shelby	0.09*	0.08*	0.07*	0.06	0.11**
Tipton	0.10*	0.10*	0.08*	0.08*	0.14**
Weakley	0.09*	0.10*	0.10*	0.09*	0.14**

[†] = Mean for West Tennessee
** p value < 0.05, ** p value <0.01*

Table 5. Multiple regression β values for West Tennessee corn yield during the growing season, growing phase, and harvesting phase

	Growing season (April to October)	Growing phase (June to July)	Harvesting phase (August to October)
Intercept (β_0)	479.50	367.87	404.34
TAVG (β_1)	247.89	382.54	565.22
TMIN (β_2)	-73.68	-159.65	-255.62
TMAX (β_3)	-167.72	-220.66	-313.45
PCP (β_4)	2.31	2.87	14.08
PDSI (β_5)	-5.99	-4.93	-0.75
ZHDX (β_6)	18.60	-5.15	-4.39
SPI01 (β_7)	-94.13	-4.55	-100.30

3.3 Soybeans

3.3.1 Correlations

Significant correlations were observed between West Tennessee mean soybean yield and several climate factors (Table 7). There was a significant negative correlation (P = .01) between mean soybean yield and growing season TMAX. Mean soybean yields in West Tennessee were positively correlated with growing season PCP (P < .001), PDSI (P = .03), ZNDX (P < .001), and SPI01 (P < .001). During the growing phase, significant positive correlations were observed between mean soybean yield and PCP (P = .03) and SPI01 (P = .01). Significant positive correlations were found during the harvesting phase for all precipitation factors: (PCP (P = .004), PDSI (P = .006), ZNDX (P < .001), and SPI01 (P = .003). During the harvesting phase, there was a strong negative correlation between mean soybean yield and TMAX (P = .002). No significant correlations were found between mean soybean yields and climatic factors during the planting stage.

Table 6. R^2 values for multiple regression models for corn yield in West Tennessee. Independent variables included average temperature, minimum temperature, maximum temperature, precipitation, palmer drought severity index, palmer Z-index, and one month standardized precipitation index

	Growing season (April to October)	Planting phase (April to May)	Growing phase (June to July)	Harvesting phase (August to October)
West Tennessee	0.43**	0.15	0.42**	0.31**
Benton	0.42**	0.17	0.33**	0.32**
Carroll	0.45**	0.13	0.46**	0.33**
Chester	0.37**	0.16	0.38**	0.30**
Crockett	0.34**	0.11	0.43**	0.25*
Decatur	0.45**	0.14	0.36**	0.34**
Dyer	0.38**	0.14	0.40**	0.29*
Fayette	0.38**	0.16	0.41**	0.27*
Gibson	0.37**	0.14	0.40**	0.28*
Hardeman	0.39**	0.16	0.41**	0.30**
Hardin	0.44**	0.18	0.30**	0.37**
Haywood	0.38**	0.15	0.43**	0.26*
Henderson	0.42**	0.18	0.38**	0.33**
Henry	0.48**	0.12	0.46**	0.33**
Lake	0.42**	0.14	0.37**	0.30**
Lauderdale	0.43**	0.19	0.45**	0.28*
Madison	0.39**	0.12	0.44**	0.30**
McNairy	0.44**	0.17	0.38**	0.32**
Obion	0.38**	0.13	0.36**	0.29**
Shelby	0.40**	0.13	0.41**	0.29*
Tipton	0.38**	0.17	0.39**	0.28*
Weakley	0.43**	0.12	0.43**	0.32**

** p value < 0.05, ** p value <0.01*

Results from correlations led to several conclusions. The significant positive correlations between all precipitation factors (PCP, PDSI, ZNDX, and SPI01) and soybean yield during the growing season, growing phase, and harvesting phase demonstrate the importance of precipitation to soybean production. With no conclusive precipitation projections from previous research, it will be important to continue to monitor these factors as they relate to soybean production. The negative correlations between mean soybean yield and TMAX for the year and harvesting phase are not consistent with the prediction from Niyogi and Mishra [6] that soybean yield will increase due to temperature increases. Due to the negative correlation between soybean yield and TMAX, producers should be aware that if mean temperature increases as projected then maximum temperature could increase as well, resulting in decreased soybean yields. Further research should be conducted to determine if a maximum temperature ceiling exists for soybean production in West Tennessee.

3.3.2 Simple linear regressions

Several linear regression models produced significant results for soybean yield. Table 8 displays the R^2 values for the growing season (April to October), Table 9 displays results for the growing phase (June to July), and Table 10 displays results for the harvesting phase (August to October). TAVG was not included in these tables because no significant linear regression models were found for this factor. TMIN was not included in Table 10 for lack of significant linear regressions. Also no significant linear regression models were discovered during the planting phase of the study.

The overall abundance of significant linear regression models indicates the importance of climate factors in soybean production. This is especially true for precipitation factors. Linear regression models were consistent with significant correlations that were observed. Several individual counties did have significant linear regression models for growing season TMIN and growing phase TMIN, PDSI, and

ZNDX. Lake and McNairy counties did not consistently have significant regression models as did other counties. Further study should be conducted to determine differences in these counties compared to other counties in the region. The abundance of significant models in the harvesting phase and lack of significant models in the planting phase may be attributed production practices in West Tennessee. Soybeans are typically planted later in the growing season compared to corn. Thus, they are expected to develop later in the growing season. The number of significant linear regression models demonstrates the importance of maximum temperature and precipitation factors to soybean production.

3.3.3 Multiple linear regressions

Several multiple regression models for soybean yields were significant (Table 11). With the exception of three counties (Dyer County growing phase (P = .01), Lake County growing phase (P = .02), and McNairy County harvesting phase (P = .02)), all multiple regression models for growing season, growing phase, and harvest phase were highly significant (α < .01; Table 12). All models for the planting phase were not significant.

Table 7. Pearson's correlation coefficients between soybean yield and climatic factors in West Tennessee

	Growing season		Planting phase		Growing phase		Harvesting phase	
Climatic factor	**Corr**	**p**	**Corr**	**P**	**Corr**	**p**	**Corr**	**P**
TAVG	-0.087	0.513	0.040	0.763	0.008	0.955	-0.165	0.212
TMIN	0.246	0.060	0.083	0.530	0.235	0.074	0.158	0.232
TMAX	-0.326	0.012	-0.005	0.971	-0.218	0.097	-0.399	0.002
PCP	0.438	<0.001	0.100	0.452	0.286	0.028	0.371	0.004
PDSI	0.278	0.033	0.084	0.526	0.238	0.070	0.355	0.006
ZNDX	0.431	<0.001	0.086	0.519	0.256	0.051	0.428	<0.001
SPI	0.459	<0.001	0.740	0.578	0.318	0.014	0.384	0.003

Corr: Correlation; p: p value
TAVG: Average Temperature; TMIN: Minimum Temperature; TMAX: Maximum Temperature
PCP: Precipitation; PDSI: Palmer Drought Severity Index; ZNDX: Palmer Z-Index;
SPI: One Month Standardized Precipitation Index

Table 8. R^2 values for simple linear regression models for selected climate factors and soybean yield during the growing season (April to October) in West Tennessee

County	TMIN	TMAX	PCP	PDSI	ZHDX	SPI01
Mean†	0.05	0.11*	0.19**	0.08*	0.19**	0.21**
Benton	0.07*	0.07*	0.12**	0.03	0.11**	0.13**
Carroll	0.07	0.09*	0.15**	0.05	0.15**	0.16**
Chester	0.04	0.09*	0.17**	0.08*	0.17**	0.20**
Crockett	0.02	0.17**	0.24**	0.13**	0.26**	0.27**
Decatur	0.04	0.07	0.10*	0.04	0.10*	0.13**
Dyer	0.04	0.12**	0.17**	0.06	0.16**	0.19**
Fayette	0.04	0.12**	0.20**	0.09*	0.19**	0.22**
Gibson	0.06	0.11**	0.21**	0.09*	0.21**	0.23**
Hardeman	0.03	0.11**	0.18**	0.09*	0.17**	0.19**
Hardin	0.03	0.12**	0.20**	0.08*	0.20**	0.22**
Haywood	0.03	0.12**	0.19**	0.08*	0.19**	0.22**
Henderson	0.07*	0.08*	0.18**	0.06	0.17**	0.20**
Henry	0.03	0.15**	0.17**	0.10*	0.21**	0.22**
Lake	0.05	0.07*	0.10*	0.03	0.09*	0.11**
Lauderdale	0.05	0.11*	0.21**	0.09*	0.19**	0.22**
Madison	0.03	0.15**	0.22**	0.12**	0.23**	0.25**
McNairy	0.05	0.05	0.11*	0.04	0.09*	0.11*
Obion	0.10*	0.05	0.14**	0.03	0.11**	0.15**
Shelby	0.09*	0.06	0.20**	0.09*	0.17**	0.20**
Tipton	0.05	0.09**	0.22**	0.08*	0.19**	0.22**
Weakley	0.07*	0.12**	0.22**	0.08*	0.22**	0.25**

*† = Mean for West Tennessee; * p value < 0.05, ** p value <0.01*

Table 9. R^2 values for simple linear regression models for selected climate factors and soybean yield during the growing phase (June and July) in West Tennessee

County	TMIN	TMAX	PCP	PDSI	ZHDX	SPI01
Mean[†]	0.06	0.05	0.08*	0.06	0.07	0.10*
Benton	0.10*	0.01	0.05	0.02	0.03	0.06
Carroll	0.05	0.06	0.08*	0.03	0.06	0.11
Chester	0.03	0.06	0.10*	0.06	0.08*	0.11**
Crockett	0.01	0.11*	0.12**	0.11*	0.11*	0.14**
Decatur	0.03	0.03	0.05	0.02	0.03	0.07*
Dyer	0.04	0.03	0.03	0.04	0.03	0.04
Fayette	0.04	0.05	0.08*	0.06	0.06	0.10*
Gibson	0.05	0.06	0.08*	0.06	0.07*	0.10*
Hardeman	0.04	0.06	0.08*	0.06	0.06	0.10*
Hardin	0.02	0.06	0.10*	0.06	0.08*	0.12**
Haywood	0.04	0.05	0.09*	0.06	0.07*	0.12**
Henderson	0.09*	0.02	0.09*	0.06	0.07*	0.11*
Henry	0.02	0.11*	0.12**	0.08*	0.12**	0.15**
Lake	0.06	0.02	0.02	0.02	0.02	0.04
Lauderdale	0.07*	0.02	0.06	0.07*	0.05	0.08*
Madison	0.03	0.08*	0.13**	0.09*	0.10**	0.15**
McNairy	0.05	0.03	0.03	0.02	0.02	0.04
Obion	0.11**	0.01	0.04	0.02	0.03	0.05
Shelby	0.11*	0.02	0.08*	0.07*	0.06	0.10*
Tipton	0.09*	0.02	0.07	0.06	0.06	0.09*
Weakley	0.05	0.07*	0.10*	0.07*	0.09*	0.12**

*[†] = Mean for West Tennessee; * p value < 0.05, ** p value <0.01*

Table 10. R^2 values for simple linear regression models for selected climate factors and soybean yield during the harvesting phase (August to October) in West Tennessee

County	TMAX	PCP	PDSI	ZHDX	SPI01
Mean[†]	0.16**	0.14**	0.13**	0.18**	0.15**
Benton	0.13**	0.16**	0.07*	0.18**	0.16**
Carroll	0.12**	0.14**	0.11*	0.17**	0.12**
Chester	0.13**	0.12**	0.13**	0.17**	0.13**
Crockett	0.20**	0.14**	0.19**	0.22**	0.16**
Decatur	0.12**	0.13**	0.08*	0.16**	0.14**
Dyer	0.18**	0.14**	0.10*	0.17**	0.15**
Fayette	0.17**	0.15**	0.15**	0.20**	0.17**
Gibson	0.16**	0.16**	0.14**	0.20**	0.16**
Hardeman	0.14**	0.11*	0.13**	0.15**	0.12**
Hardin	0.16**	0.14**	0.15**	0.20**	0.16**
Haywood	0.17**	0.10*	0.12**	0.16**	0.12**
Henderson	0.16**	0.11*	0.10*	0.16**	0.12**
Henry	0.19**	0.16**	0.17**	0.23**	0.17**
Lake	0.13**	0.11**	0.06	0.12**	0.12**
Lauderdale	0.18**	0.13**	0.12**	0.17**	0.15**
Madison	0.19**	0.14**	0.18**	0.20**	0.15**
McNairy	0.08*	0.06	0.06	0.08*	0.07*
Obion	0.08*	0.08*	0.05	0.10*	0.09*
Shelby	0.10*	0.09*	0.10*	0.12**	0.10*
Tipton	0.14**	0.10*	0.10*	0.14**	0.11*
Weakley	0.16**	0.19**	0.15**	0.23**	0.19**

*[†] = Mean for West Tennessee; * p value < 0.05, ** p value <0.01*

Table 11. Multiple Regression β values for West Tennessee soybean yield during the growing season, growing phase, and harvesting phase

	Growing season (April to October)	Growing phase (June to July)	Harvesting phase (August to October)
Intercept (β_0)	150.22	78.91	116.33
TAVG (β_1)	167.34	143.14	70.04
TMIN (β_2)	-75.38	-67.26	-29.40
TMAX (β_3)	-92.60	-75.77	-41.47
PCP (β_4)	-0.02	-0.58	0.72
PDSI (β_5)	-1.31	-0.21	-0.27
ZHDX (β_6)	-1.26	-2.06	0.80
SPI (β_7)	3.10	6.21	-10.01

Table 12. R^2 values for multiple regression models for soybean yield in West Tennessee. Independent variables included average temperature, minimum temperature, maximum temperature, precipitation, palmer drought severity index, palmer Z-index, and one month standardized precipitation index

	Growing season (April to October)	Planting phase (April to May)	Growing phase (June to July)	Harvesting phase (August to October)
West Tennessee	0.46**	0.05	0.36**	0.39**
Benton	0.45**	0.07	0.32**	0.40**
Carroll	0.46**	0.04	0.40**	0.38**
Chester	0.39**	0.04	0.33**	0.34**
Crockett	0.46**	0.05	0.37**	0.41**
Decatur	0.39**	0.06	0.33**	0.33**
Dyer	0.45**	0.06	0.29*	0.40**
Fayette	0.44**	0.07	0.38**	0.37**
Gibson	0.47**	0.06	0.34**	0.37**
Hardeman	0.39**	0.07	0.36**	0.34**
Hardin	0.39**	0.06	0.31**	0.39**
Haywood	0.43**	0.04	0.36**	0.39**
Henderson	0.44**	0.06	0.35**	0.35**
Henry	0.48**	0.05	0.33**	0.38**
Lake	0.39**	0.06	0.26*	0.33**
Lauderdale	0.42**	0.09	0.30**	0.39**
Madison	0.47**	0.04	0.41**	0.44**
McNairy	0.32**	0.09	0.30**	0.27*
Obion	0.45**	0.07	0.34**	0.33**
Shelby	0.42**	0.10	0.40**	0.34**
Tipton	0.43**	0.09	0.35**	0.34**
Weakley	0.53**	0.05	0.34**	0.43**

** p value < 0.05, ** p value <0.01*

Like corn, soybean multiple regressions should provide the best prediction models. The results of these models are similar to results of the multiple regression models for corn. The high significance of these models indicates the importance of temperature and precipitation to soybean production. The lack of significant models in the planting phase and the abundance of the models during the growth and harvest phases demonstrate the importance of climatic timing. In selecting which model to use, multiple regression models with growing season climate factors have the highest R^2 values compared to growing phase and harvesting phase R^2 values. Weakley County exhibited the highest R^2 value with 0.53. The choice between using growing phase and harvesting phase multiple regression models depends on location. Some counties have high R^2 values for one phase and low for another. Dyer County has a 0.29 R^2 value for the growing phase and 0.40 R^2 value for the harvesting phase. Other counties have very similar R^2 values. Decatur County has a R^2 value of 0.33 for both the growing and harvesting phases. Madison County has the highest R^2 values for both the growing (0.41) and harvesting (0.44) phases. In selecting which model to use, producers and researchers should use location, R^2 values, and available climate data or projections to determine which model best fits their individual situation.

4. CONCLUSION

In this study, several significant correlations were observed between yield and climate factors. Corn yields were found to be positively correlated to growing season TMIN, PCP, ZHDX, and SPI01 Index as well as TMIN during growing phase (June to July). Soybean yields were positively correlated with PCP, PDSI, ZHDX and SPI01for the entire growing season as well as the harvesting phase (August to October). Furthermore, during the growing phase, positive correlations were found between soybean yield and PCP and SPI01. Negative correlations existed between soybean yield and TMAX for the growing season and harvesting phase.

Numerous significant linear and multiple regression models were developed. All multiple regression models were significant with the exception of the planting phase in which no significant models were discovered. The abundance of significant multiple regression models indicate that corn and soybean yields are affected by multiple climate factors. Producers should use multiple regression models instead of linear regressions models when the information is obtainable due to higher R^2 values.

From the correlations and regression models, several conclusions can be made. Corn appears to thrive once a minimum temperature is reached. The negative correlation between soybean yield and maximum temperature indicates that a "temperature ceiling" could exist for soybean production. If average temperature increases in the upcoming years, it can be predicted that corn yields should increase and soybean yields should decrease for West Tennessee. Both corn and soybeans require adequate precipitation for optimal yields. The correlations and regression models indicate that short term drought conditions will affect corn and soybean production more than long term drought conditions. Both long and short term drought conditions will influence yield, but short term drought conditions will have an immediate impact. Further conclusions can be made from the overall lack of significant findings for average temperature and the planting phase. The lack of significant findings during the planting phase indicates that climatic factors will not affect yield until the crop is established. Maximum and minimum temperatures have a greater importance than average temperature in West Tennessee. This study concludes that several primary and secondary temperature and precipitation factors will impact corn and soybean yields in West Tennessee.

These results could have several implications to individuals directly involved in the agricultural industry, primarily for risk management. Producers should select varieties and hybrids that are drought resistant. Soybean producers should consider planting schedules to avoid heat stress during the summer months. Linear and multiple regression models can be used to determine how much crop to place under contract. Crop producers should consider using irrigation because of the importance of precipitation to both corn and soybean production. Variety and hybrid selection and irrigation could reduce downside risks associated with temperature and precipitation. To deal with increasing climatic variability, continuous climate monitoring is imperative for agricultural producers to be able to continue fulfilling the world's food and fiber demand.

DISCLAIMER

This study was presented as a poster at the 2016 Southern Agricultural Economics Association Annual Meeting in San Antonio, Texas, February 6-9. Poster is available at http://ageconsearch.umn.edu/handle/230009

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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