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ECONOMIC IMPACTS OF DROUGHT ON KENTUCKY CORN, HAY, AND SOYBEANS

A Thesis
Presented to
The Faculty of Geography and Geology
Western Kentucky University
Bowling Green, Kentucky

In Partial Fulfillment
Of the Requirements for the Degree
Masters of Science

By
Kortney E. Craft

May 2011

ECONOMIC IMPACTS OF DROUGHT
ON KENTUCKY CORN, HAY,
AND SOYBEANS

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ECONOMIC IMPACTS OF DROUGHT
ON KENTUCKY CORN, HAY,
AND SOYBEANS

Kortney Craft May 2011 140 Pages

Directed by: Rezaul Mahmood

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Understanding climatic impacts is important if we are to comprehend the relationship between climate and society. Weather phenomena can have environmental, economical, and social impacts. Drought is the natural hazard that affects people the most. It is also the most complex and least understood. There is no one universally accepted definition for drought which makes its examination difficult. Droughts' duration is also difficult to determine because it has no clearly defined onset and end. Also, drought varies both geographically and temporally making uniform drought monitoring difficult. Since drought is difficult to monitor and access, drought impacts are often poorly documented. The purpose of this research was to quantify (in dollars) the impacts of drought on Kentucky's agriculture. Drought has been recorded historically in Kentucky since the late 1800s. According to the Kentucky Climate Center, the most significant drought years occurred in 1930-31, 1940-42, and 1952-55. Analyses of these years are included as well as the most recent significant drought years in 1987-88, 1999-2000 and 2007. Four of Kentucky's important commodities, including corn, soybeans, hay, and beef cattle, were examined during the significant drought years. The total state revenue for these commodities was analyzed during severe drought years vs. non-severe drought years. The result of this research identified how much of a deficit severe drought causes on Kentucky revenue for each of these commodities. This research is important to the general public as well as planners and policy makers. Proper documentation of drought impacts will help identify drought vulnerabilities and result in better risk management and mitigation. Key Words: **Drought, Agriculture, Impact Assessment.**

CHAPTER 1
INTRODUCTION

Among society's greatest problems, perhaps the most complex is conserving natural resources while maintaining economic strength. This challenge becomes even more severe during periods of drought (Tol 2002; Touchan et al. 2010). The explicit goal set forth by The National Integrated Drought Information System (NIDIS) program is to enable society to respond to periods of drought by improving monitoring, prediction, risk assessment, and communication. NIDIS is viewed as an accessible drought risk information system that allows users to determine potential drought impacts, and decision support tools needed to prepare for and mitigate the impacts of drought (The National Integrated Drought Information System Implementation Plan 2007). This research coincides with the explicit goal set forth by NIDIS, as it aims to document drought impacts and improve drought mitigation.

Climate variability is expected to increase and recent trends suggest an increase in vulnerability to drought as well (IPCC 2007). A passive approach to drought management will only increase this vulnerability, thus proactive strategies to mitigate drought impacts need to be developed. Though the U.S. Drought Monitor and the U.S. Seasonal Drought Outlook are helpful tools in monitoring drought, a comprehensive federal drought policy needs to be implemented. This goal requires two types of information: 1. Relevant and historical record of past and current physical states of the environment. 2. Documented human and environmental impacts that are consequences of physical conditions. It will require scientists to collect and analyze data on drought impacts, as well as physical observations such as precipitation, humidity, wind speed and direction, soil and air temperatures, soil moisture, and solar radiation (Western Governors' Association 2004). This research contributes to this goal by studying historical records of past drought occurrences in Kentucky and documenting agricultural impacts caused by drought.

To date there is no systematic collection and analysis of drought impacts within the United States. Data on drought-related relief payments, revenue losses due to low water, ecological impacts, impacts of wildfires, reduced hydropower production, mental health visits during drought periods, agricultural yield losses, etc. needs to be collected. Since a centralized collection of this data does not exist, economic and social costs due to drought are often underestimated. Effective drought research efforts need to be made by the government, private entities, and universities to accelerate the development of a centralized drought response plan. Historical climate data, water supply and storage capabilities, drought indices, and GIS modeling framework need to be utilized and expanded to fill information gaps (Western Governors' Association 2004). Again, this research helps fill these gaps by collecting agricultural data, documenting drought impacts, and determining economic costs due to drought.

Drought affects more people than any other natural hazard, yet it is the most complex and least understood (Wilhite 1993; Cook et al. 2007). It differs from other natural hazards such as hurricanes, tornadoes, and floods in several ways. First, there is no universally accepted definition of drought. Drought affects many economic and social sectors and a variety of disciplines have developed their own definitions. This lack of a precise definition contributes to the difficulty of drought investigation (Yevjevich 1967; Heim 2002). Secondly, the effects of drought may continue to linger for several years making it difficult to determine a drought's onset and end (Wilhite 1993). Drought is often referred to as a "creeping phenomonenon" as it is a challenge to accurately determine a drought's duration (Gillette 1950). Thirdly, a drought's severity is difficult to determine. Every drought episode is specific to intensity, duration, and geographical extent. The severity of a drought's impacts depends on a society's vulnerability to drought at that particular time of occurrence. This means that droughts that occur in the same region will have different impacts, even though the droughts have similar characteristics (Wilhite et al. 1987; Sonmez et al. 2005; Quiring 2009).

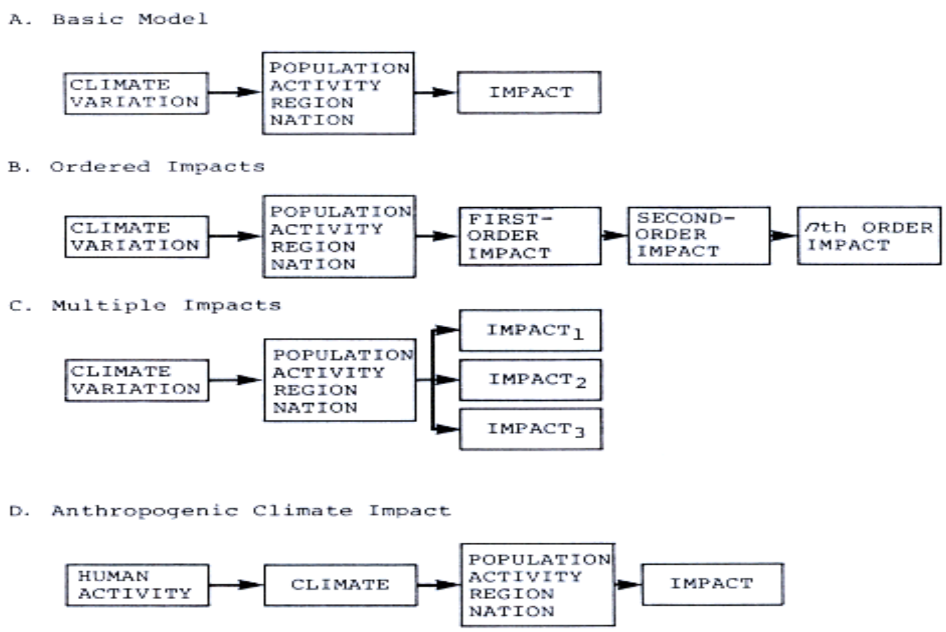
Since droughts play a role in virtually any climate, it is vital that plans are developed to reduce their impacts. The Intergovernmental Panel on Climate Change (IPCC) project increases in global mean surface air temperature continuing over the 21st century. According to IPCC (2007), it is very likely that heat waves will be more intense, more frequent, and longer lasting in a future warmer climate. Intensity for precipitation events is expected to increase, but there will be longer periods between rainfall events. Since mid-continental areas have a tendency of drying over the summer, longer periods between precipitation events indicate a greater risk for drought in those areas (IPCC 2007). The Western Governors' Association (2004) noted that, "The failure to take appropriate actions to address global climate change risks economic and societal damage." It is evident that drought is going to continue to be a part of our future and it is vital that we take the proper precautions to avoid drought vulnerabilities today. This is why research like this project is important. We cannot avoid drought vulnerabilities if we do not understand the impacts drought has had on society. To do this we must examine past droughts and record their impacts on humans and the environment.

Countries around the world are learning the importance of drought planning and are developing drought task forces and policies to help protect them against drought vulnerabilities (Liverman 1990; Dellicarpini et al 2002; Gosain et al. 2006; Larsen and Lone 2009; Touchan et al. 2010). Most economic estimations of impacts of drought are incomplete or based on outdated data (Hayes et al. 2002; Cook et al. 2007). Since drought impacts are not well documented or quantified economically, it is common for officials to underestimate the importance of being proactive in preparing for drought. Also, because of the geographic variability of drought, local impacts are often overlooked compared to statewide averages (Hayes et al. 2002). Proper quantification of drought impacts will improve understanding of economic losses that can occur from drought at local and regional levels.

The purpose of this research is to assess the economic impacts of droughts on Kentucky's agriculture. This includes estimation of economic losses in agriculture in dollar amounts. This was done by collecting historical commodity data including yield, production, price and revenue for four of Kentucky's most important cash crops and examining the data during significant drought years compared to non-significant drought years. Kentucky is a state that depends heavily on its agricultural revenues and drought occurrences can cause severe economic deficits. Drought can affect agriculture through soil, crops, disease, insects, weeds, and livestock (Kumar 1998). It is important to quantify the impacts of drought on Kentucky's agriculture so planners and policy makers can make better decisions about mitigating for drought. Three of Kentucky's most important cash crops including corn, hay, and soybeans were examined. Kentucky corn crops were valued at over $617 million and ranks 14th in the nation (Kentucky Corn Growers Association 2010). Kentucky hay is valued over $547 million and ranks 5th in the nation producing over 6,316 tons annually (USDA 2008). Soybeans have become a major crop in Kentucky and are valued over $415 million making it the 10th highest soybean producing state in the nation (USDA 2007). A decrease in these crop yields would have substantial repercussions on Kentucky's economy. Kentucky also has over 91,400 livestock farms which could experience extreme deficits due to droughts, so livestock inventory will also be examined. Kentucky is ranked 14th in the United States for all cattle inventory, and 8th in beef cattle inventory (Kentucky Department of Agriculture 2008). Quantifying impacts of past droughts on Kentucky's agriculture will help decrease drought vulnerability in the future.

Knowing the impacts associated with drought is important to reduce drought related risks in the future. Perhaps what is more important is completing an impact assessment that will quantify how severe these risks are. There have been many impact models made to assist scientists and policy makers in completing impact assessment. Kates et al. (1985) developed the following model based on the theory of cause and effect. It shows how climatic variation causes impacts on populations, activities, regions, and nations.

Figure 1. Impact Assessment Model. Source: Kates 1985.

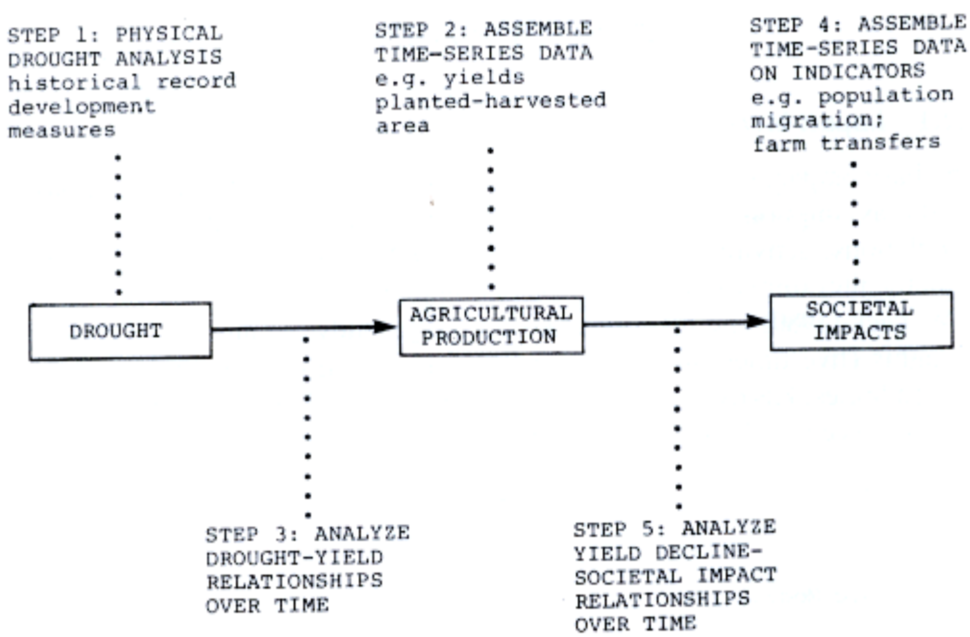


Warrick et al. (1980) developed a similar model based on the impacts of repeated droughts on the Great Plains. This model is even more appropriate for this research because it is based on agricultural impacts. Warrick (1980) made this model as an example of an ordered impact study. The first- order impacts are of agricultural productions which include crop yields, differences between area harvested and area planted, etc. These agricultural productions lead to socioeconomic impacts which are the second-order impacts in the model. The second-order impacts are a product of the effects of yield deficits moving through the social and economic network.

As Warrick's (1980) model demonstrates, yield deficits have socioeconomic impacts. However, there may be other first-order factors in agricultural production besides yield deficits that cause impacts. For example, it is possible for insect infestation to cause impacts on crop quality or the yields of other crops could affect the economic value of a crop yield. These are examples of multiple impacts which are highlighted in part C of the basic model.

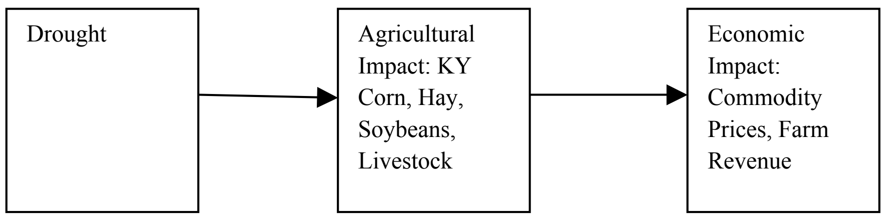
Part D of the model demonstrates how human activity can cause climatic variations that can have impacts on society. Recently, global climate change due to human activity has become a popular and debated subject in the media. Part D of the basic model is referring to climatic changes due to human production and consumption of fossil fuels and chlorofluorocarbons (Warrick 1980).

Figure 2. Drought Impact Model. Source: Warrick, 1980.



These two models have one important thing in common, they both highlight impacts. Both of these models show drought and climate variability resulting in economic, social, and environmental impacts. Kates' (1985) and Warrick's (1980) models both recognize the importance of impacts and the need to document them. This research follows these models by identifying and documenting drought impacts on Kentucky's agriculture. Figure 3 is a flow chart made specifically for this research. It is a guide for this research, as drought causes agricultural impacts which result in economic impacts, which causes problems for society.

Figure 3. KY Agricultural Drought Impact Model



CHAPTER 2
LITERATURE REVIEW

2.1 Defining Drought

Since drought affects many different sectors, a variety of definitions have been established. These definitions can be categorized as conceptual or operational. Conceptual definitions are thought of as generic in their descriptions and aim at generalizing the concepts of drought. These are often definitions where the main idea is "an extended period of time with no rain." Operational definitions are more specific and try to explain in detail the onset, severity, duration, and consequences of drought (Wilhite and Glantz 1985, 10). Wilhite and Glantz (1985) use the example of an operational definition of agricultural drought, as they compare daily precipitation to evapotranspiration rate to determine soil water depletion rate and their relationships to drought effects on plant behavior over different stages of development. These definitions are often used in drought analysis and are preferred over the generic conceptual definitions (Wilhite and Easterling 1987).

Wilhite and Glantz (1985) identify four different groups of drought. These groups are identified as meteorological, hydrological, agricultural, and socioeconomic. Meteorological drought is defined by the degree of dryness (in comparison to an average amount) and the length of the dry period. Meteorological drought can develop quickly and end as abruptly as over night (Heim 2002). Meteorological definitions are region specific because precipitation is an atmospheric condition that varies between regions.

For example, in some regions extended periods of rainfall are common and meteorological drought will be determined differently in these regions than in other regions that experience a drier pattern (Wilhite 1993).

Hydrological droughts are defined by the “effects of periods of precipitation shortfall on surface or subsurface water supply” (Dracup et al. 1980, 299). Hydrological drought can reduce lake levels, groundwater, reservoirs, and stream flow (Heim 2002). More time passes before deficiencies due to lack of precipitation show up in the hydrological system than in meteorological droughts. This elapsed time causes impacts to be out of phase with other sectors. Also, it is harder to quantify impacts because hydrological storage systems are used for purposes such as irrigation, power generation, recreation, etc. Because water is used for many different purposes, conflicts over water usage often arise during periods of drought. The influences of river basins define the frequency and severity of hydrological drought. A hydrological drought year can be defined by aggregate runoff compared to average runoff (Whipple 1966). Many streams experience a low-flow that fall below the average threshold. When this happens a hydrological drought is conceived as active (Wilhite 1993).

Agricultural drought combines meteorological and hydrological drought characteristics to determine agricultural impacts. It focuses on lack of precipitation, evapotranspiration rates, soil moisture content, etc. High temperatures, low relative humidity, and desiccating winds can also contribute to the impacts of an agricultural drought (Heim 2002). Assessment of agricultural drought is specific to characteristics of differing plants, their demand for water, growth and development stages, etc. It is also important to take into consideration what level of development that crops are at during the drought period. This is due to the fact that decreased subsoil moisture during the early phases of development can have little impact on crop yield along as topsoil moisture is sufficient, but if the drought occurs at a stage of later development the crop yield will be affected (Wilhite 1993).

The last type is socioeconomic drought, which involves supply and demand of goods or services affected by meteorological, hydrological, and agricultural drought. This concept supports the strong relationship that exists between drought and human activities. Drought affects society in many different ways. It has repercussions on water usage policies, recreation, tourism, agriculture, public health, and so forth. During a socioeconomic drought the demand for water increases and often the water supply cannot meet this demand (Wilhite 1993).

It is important to mention all four types of drought because they are all interconnected. This research focused on economical impacts on Kentucky's agriculture. Agriculture is a leading industry in Kentucky's economy; therefore agricultural deficits can have devastating repercussions. Corn, hay, soybeans, and livestock are four of Kentucky's most valuable commodities. Kentucky is also one of the leading producers of these commodities in the United States and society depends on their revenue. Drought has been a continuing natural disaster that can threaten these important cash crops. This is why it is important to identify drought vulnerabilities and mitigate to reduce drought impacts. First, an understanding for how drought is assessed and monitored needs to be established. Several indexes will be mentioned but for the purpose of this research, the Palmer Drought Severity Index was utilized.

2.2 Drought Indices

Palmer Drought Severity Index

Since there are several different types of drought, there are many different systems of measurement. The most popular and perhaps most widely used system is the Palmer Drought Severity Index (PDSI). Palmer's (1965) definition of drought was "an interval time, generally of the order of months or years in duration, during which the actual moisture supply at a given place rather consistently falls short of climatically expected or climatically appropriate moisture supply." From this definition, Palmer developed the PDSI to measure drought severity. The PDSI is mainly known as an index of metrological drought, but it also takes precipitation, evapotranspiration, and soil moisture into account (Alley 1984). It is a widely used system that is accessed by many governmental agencies such as the U.S. Department of Agriculture (USDA), the National Drought Mitigation Center (NDMC), and the National Oceanic and Atmospheric Administration (NOAA) (Svoboda et al. 2002). The PDSI is used all across the United Stated as well as other areas of the world (Kogan 1995; Hu and Willson 2000).

When Palmer (1965) was coming up with the criteria for the index, he first had to know what was considered a "normal" or climatically expected amount of precipitation. He had to determine how much precipitation should have occurred during a period, to keep water supply and demand in balance. After this was determined, he could compare how much precipitation actually did occur to how much should have occurred, to know the amount of moisture deficit. Knowing these deficiencies was important for the development of the index but it did not solve all the problems. In order for the index to be developed, the duration factor had to be considered. It wasn't enough to simply determine that there was in fact a moisture deficit, but the duration of the deficit had to be taking into account. Also, what is considered a deficit is not the same for every population. Some regions experience more precipitation than others, and what is considered a "normal" amount of precipitation for one area will not be the same for another. The time of year that the deficit occurs in is also a factor. Since some months experience more precipitation than others, time has to be considered in determining the severity of the deficit. Palmer had to weigh these factors and try to develop an index that was independent of space and time (Palmer 1965).

In order to do this, he conducted a study of two climatically different regions. Palmer (1965) chose the 31 counties comprising the western one-third of Kansas, which is a region with a semi-arid to dry sub-humid climate, and the twelve counties that make up central Iowa, which has a moist sub-humid climate. These two regions were selected because weather that is considered normal in western Kansas would be considered very dry in central Iowa. Since most of the economy in Iowa depends on adequate amounts of precipitation, great economic loss and hardship would occur if they experienced weather common to western Kansas. In the opposite case, an inch of rain in Kansas is of much greater importance than to Iowa. Since these areas are climatically different, Palmer could use their differences to create a meaningful index for drought severity. His study was based on periods of a month or longer and his objective was to take into account the distribution of precipitation during that period. The procedure Palmer (1965) used is exactly as follows:

1. “Carry out a hydrologic accounting by months for a long series of years.
2. Summarize results to obtain certain constants or coefficients which are dependent on the climate of the area being analyzed.
3. Reanalyze the series using the derived coefficients to determine the amount of moisture required for “normal” weather during each month.
4. Convert the departures to indices of moisture anomaly.
5. Analyze the index series to develop:
    A. Criteria for determining the beginning and ending of drought periods
    B. A formula for determining drought severity.”

Palmer (1965) used this procedure and the study on western Kansas and central Iowa to successfully develop an index for measuring drought. He concluded that categories of drought could be broken into four classes: mild, moderate, severe, and extreme. He assigned drought severity values ranging from -4.00 to 4.00, with positive numbers signifying wet conditions and negative numbers signifying dry conditions. The following table shows how Palmer (1965) divided the classes and assigned severity values:

Table 1. PDSI wet and dry classes. Source: Palmer 1965.

X	Class
≥4.0	Extreme Wet
3.00-3.99	Very Wet
2.00-2.99	Moderately Wet
1.00-1.99	Slightly Wet
0.50-0.99	Incipient Wet Spell
0.49- -0.49	Near Normal
-0.50- -0.99	Incipient Drought
-1.00- -1.99	Mild Drought
-2.00- -2.99	Moderate Drought
-3.00- -3.99	Severe Drought
≤-4.00	Extreme Drought

PDSI Limitations

Though Palmer's index is widely used and accepted it is not without limitations. One problem is that the PDSI uses a water balance computation method, in which several limitations exist. One of these limitations is that there is no one method for calculating potential evapotranspiration. Thornwaite's (1948) method is most often used but several other methods exist. Also, the water balance method assumes that two soil layers are not influenced by seasonal and annual root development and vegetation cover changes, which are important changes in cultivated areas (Alley 1984). The PDSI also assumes that runoff occurs after soil moisture capacity of the upper and lower layers have been filled. This method has been reviewed by Rushton and Ward (1979), who have found that this approach often underestimates runoff during summer and autumn seasons.

There are several other limitations of the PDSI. One is that it does not take frozen ground or snow melt into account. Although the PDSI is used all over the United States, because it does not consider frozen ground and snow melt, misleading results may be concluded in northern or mountainous regions (Alley 1984). Another issue is the way the PDSI defines drought severity classes. Palmer (1965) used a scale of -4.0 to 4.0 to quantify the presence of precipitation. Positive numbers yield wet conditions while negative number yield dry conditions. The problem with the scale is that it is derived only from central Iowa and western Kansas. Since different regions have different "norms" for precipitation downfall, one has to be careful in classifying a drought as "severe" or "extreme." Therefore the classes defined by the PDSI should be used loosely (Alley 1984).

Standardized Precipitation Index

Since the PDSI was established in 1964, several other indexes for measuring drought severity have emerged. One of these is the Standardized Precipitation Index (SPI). The SPI measures precipitation deficits on many time scales. Different time scales are used to accurately measure drought impacts on several water resources. The SPI can be determined by finding the standard deviation of a precipitation deficiency. SPI values generally range from -2.0 to 2.0. Positive numbers signify greater than median precipitation, while negative numbers signify less than median precipitation and indicate a drought. The SPI defines classes the same as the PDSI, as mild, moderate, severe, and extreme. The SPI is praised for its detection of early signs of drought and its assistance in assessment of drought severity (Goodrich and Ellis 2006). Some advantages of the SPI are its relation to probability, its ability to calculate average precipitation for a given period, it can monitor wet and dry periods, it can be calculated for several water variables, and it is normalized to represent wetter and drier climates in the same way (Mckee et al. 1993). However, it does have its own limitations. It is based on previous data that changes month to month as new data is added. Also, it only measures one side (input) of the water balance equation and ignores seasonal differences (Goodrich and Ellis 2006). The following table shows how the SPI assigns values for each category.

Table 2. SPI Values and Categories. Source: Mckee et al. 1993

SPI Values	Drought Category	Time In Category
0 to -0.99	Mild Drought	~24%
-1.00 to -1.49	Moderate Drought	9.2%
-1.50 to -1.99	Severe Drought	4.4%
≤ -2.00	Extreme Drought	2.3%
		~40%

Surface Water Supply Index

Another popular index for measuring drought severity is the Surface Water Supply Index (SWSI). This system was derived to fix some of the limitations set forth by the PDSI. Unlike the PDSI, this index takes into account snowpack water equivalent, reservoir storage, and precipitation. It is often used in mountainous regions where the PDSI was not as effective. It is an index derived for each major river basin and it expresses potential availability of water supply in the future. The SWSI is also based on a -4.0 to 4.0 scale, with the negative numbers signifying poor water supply prospects and the positive numbers signifying plentiful prospects (Wilhite 1993). The SWSI was originally developed for the state of Colorado in 1981 but it has been adopted by many western states. Though it is affective in assessing surface water supply, Doesken and

Garen (1991) have identified several concerns. Some of these concerns for the SWSI are that there is no general consensus of the definition of surface water supply, factors vary across location and time, and the river basins in the western US result in SWSIs that do not yield the same meaning in all places and at all times.

Normalized Difference Vegetation Index

Another index used by the National Oceanic and Atmospheric Association (NOAA) is the Normalized Difference Division Index (NDVI). This index uses NOAA Advanced Very High Resolution Radiometer (AVHRR) data. The NDVI is measured by the "difference in radiation of two different wavelength bands divided by the sum of the radiation in the two bands (Wilhite et al. 1987, 12)." The NDVI is often mapped and used to estimate photosynthetically active radiation. The NDVI can be used to measure drought severity by monitoring photosynthetic capacity deficiencies in drought years compared to non-drought years. NDVI values for vegetation range from 0.1 to 0.6, the higher values are associated with greater green leaf area and biomass (Nemani and Running 1988).

The Drought Monitor

At the end of the 20th century there was a collaborative effort to centralize drought monitoring. The National Oceanic and Atmospheric Association (NOAA), US Department of Agriculture (USDA), and the National Drought Mitigation Center (NDMC) teamed up to develop a weekly drought monitor. Since there are many different types of drought the weekly drought monitor takes several indicators from different agencies into account. These indicators include normal precipitation percentiles, soil moisture percentiles, crop status, daily stream flow percentiles, topsoil moisture, snowpack conditions, and reservoir levels. Other indicators come from a satellite based Vegetated Health Index, the Crop Moisture Index (CMI), Palmer Drought Index (PDI), Surface Water Supply Index (SWSI), Standardized Precipitation Index (SPI), Keetch-Byram Drought Index (KBDI), and the USDA.

These indicators were used to develop a drought monitor based on a 5 class scale. This scale ranges from D0 (abnormally dry area) to D4 (exceptional drought event) and includes labels that indicate which sectors are being affected by drought (A signifies agricultural impacts, W signifies hydrological impacts, and F signifies high risk of wildfires). Drought Monitor Maps are based on real-world conditions and are made with the assistance of reports from experts across the country (Svoboda et al. 2002). The drought monitor is a collaborative product that reflects the best judgment of experts based on several indicators (Heim 2002). It can be accessed publicly via the Internet (http://enso.unl.edu/DM/MONITOR.html).

2.3 Drought Impacts

Perhaps the most important reason to study drought is to better understand its impacts on the environment and society. Water is essential for not only survival, but our ability to produce goods and provide services. Therefore, anytime there is a water deficit, there are sure to be repercussions. The repercussions or impacts are classified as either direct or indirect. Some direct impacts of drought include increased occurrences of forest fires, wildlife and fish habitat degradation, or reduced crop yields and higher livestock mortality rates, which are highlighted in this research. An example of an indirect impact would be economic hardship put on farmers due to reduced crop yields caused by drought. The further away the impact moves from the cause, the harder it is to determine exactly what the cause is. Sometimes it becomes so difficult, that it is challenging to determine financial estimates of the loss (NDMC 2006 *a*). This is why economic drought impacts are not well documented.

The National Drought Mitigation Center (NDMC) classifies the impacts of drought into three categories. The first impact is economic. Drought can affect the economy in many different ways. It can affect agricultural producers by decreasing a farmer's income due to reduced crop yields, cause crop quality damage, cause insect infestation and plant disease, increase irrigation costs and cause money to be spent on new water resource developments. Drought also has impacts on livestock producers by causing decreased rangeland productivity, unavailability of feed and water for livestock, range fires, reduced milk production, and so on (Hadjigeorgalis 2008). It can affect timber and fish production as well by causing tree diseases to spread and loss of the amount of fish due to decreased flows (Elliott and Swank 1994). Drought also has impacts on industries such as tourism, recreation, transportation, and food production (NDMC 2006 *a*).

The second impact from drought is environmental. One environmental impact of drought is the negative effect it can have on animals. It can cause habitat degradation, disease, decreased water and food supplies, vulnerability to predators, and even result in a loss of biodiversity. The same is true for plant species, without adequate water supply plants cannot survive and many species cannot prevail during a drought period. Besides animals and plants being affected, the hydrological system is impacted as well. During drought, water levels in rivers, streams, and reservoirs are diminished and flow is often reduced. Also, water quality becomes an issue because of increased sodium concentration, higher water temperatures, and alteration of pH levels. Other environmental impacts such as increases in forest fires, soil erosion, air pollution, and landscape quality often occur as a result of drought (NDMC 2006 *a*).

The third impact of drought is social. A major social impact of drought is on health and quality of life. Drought can cause people to experience both mental and physical stress. Drought has been found to be related to some forms of anxiety, depression, domestic violence, respiratory ailments, and stress induced heart conditions (Alston and Kent 2004). Drought can also impact society by causing water usage, management, and political conflicts. When a drought occurs water policies have to be administrated which can result in dissatisfaction from different social sectors and cause conflicts (Baura et al. 2009). This is why it is important to have a sufficient drought mitigation plan that will yield the best policy for society. Other social problems caused by drought are an increase in poverty, disruption of religious and scientific beliefs, cultural sites degradation, and population migrations away from the region experiencing drought (NDMC 2006 *a*).

Though most of these impacts seem unavoidable, there are ways to reduce the severity of impacts caused by drought (Knutson et al. 1998). The Preparedness and Mitigation Working Group of The Western Drought Coordinate Council constructed a guide to help identify ways to reduce risks associated with drought. The Group made this guide flexible and understandable for all drought managers so that it can be used in any region. This guide first identifies the impacts, then determines the causes, and chooses the best methodology for addressing the problems. The steps for this guide are as follows:

1. **Getting Started**

   The first step in the analysis started is to hire the appropriate people and provide them with adequate information. Since drought affects many different sectors, people educated in environmental, economic, and social topics are needed. Different perspectives need to be covered so it is also important to get input from the public on their views and awareness of drought risk analysis. It is also a good idea to incorporate mitigation from the NDMC into the plan. This will help strengthen the plan by identifying mitigation actions.

2. **Drought Impact Assessment**

   This step identifies the outcomes caused by drought. First, direct impacts have to be identified and then indirect. This is an initial assessment of impacts but not an assessment of the underlying causes. There are three types of impacts caused by drought: environmental, economic, and social. Most impacts fit into one of these three classes but there are some that fit in more than one. After identifying the impacts, they should be examined for their relevance compared to past droughts. Questions on what possible impacts of drought we could see in the future should also be considered. Comparing these impacts to those of past droughts will help trends to be identified. This will highlight areas that are vulnerable to drought and help identify what plans should be made in the future to reduce this vulnerability.

3. Ranking the Impacts

After all the impacts have been compiled it is necessary to rank them in order of importance. This ranking should consider cost of damages, areal extent, impact trends, public opinions, and recovery time. It is recommended that several different groups of people are involved in these rankings to yield the fairest policy. The Group developed the following three questions to help choose which impacts should be rated the highest:

- Which impacts have the greatest affect on the public's way of life?
- Should groups hit the hardest receive the most attention?
- Do some impacts show bigger trends than others?

These questions should help determine which impacts should be addressed first and which can be deferred. No impact should be left unattended but some should have higher priority over others.

4. Vulnerability Assessment

This step identifies environmental, economic, and social causes of the determined impacts. It directs attention to causes of vulnerability rather than results. The Group uses the example that a lack of precipitation can be a direct impact of decreased crop yields, but the underlying cause may be that farmers chose not to use drought resistant seeds. It is therefore important to ask why these impacts have occurred and what factors could produce these impacts. It may be helpful to draw a tree diagram to represent these relationships. This will aide in examining the impacts from several perspectives to determine their true causes.

5. Identification Assessment

The next step is to determine actions to reduce drought risks. Some important questions to ask when trying to develop potential actions are:

- Can the underlying cause be mitigated? If so, how?
- Can this cause be modified during or after a drought? How?
- Is there an underlying cause than cannot be modified and has to be accepted as a risk?

Answering these questions should assist in developing adequate actions to take. The answers to these questions should help determine the actions needed to reduce drought risks. If underlying causes of impacts of drought can be changed before a drought occurs, risks associated with drought could be avoided.

6. Developing the "To Do" List

The last step is to choose which actions are the most effective in reducing drought risks. The actions chosen should be reasonable in cost, have adequate feasibility, be effective, and be fair. The Group lists the following questions as important to ask when determining the best actions to take:

- Are the benefits worth the costs?
- Which actions do the general public view as feasible?
- Which actions are environmentally sensitive?
- Do the actions address the right questions to reduce drought impacts?

- Do your actions have short-term or long-term problems?
- Which actions represent individuals and groups fairly?

Once the best actions have been determined a "To Do" list can be formed. This list should be divided into actions that should be done before a drought occurs and actions that should be done during or after a drought. These actions should reduce drought risks and provide insight on drought impact planning for the future (Knutson et al. 1988).

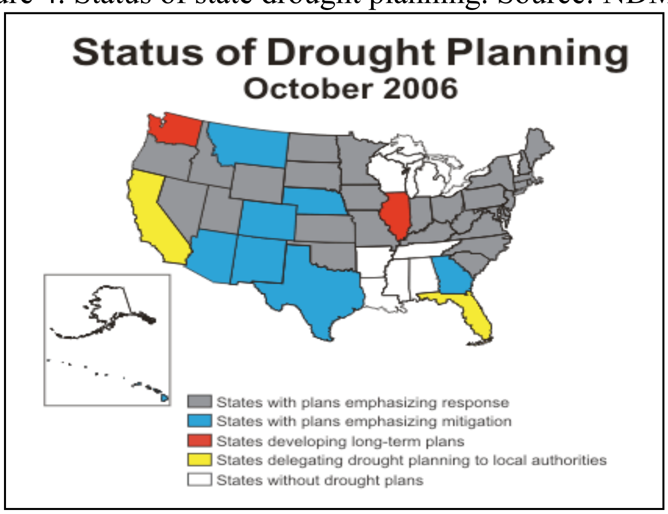
2.4 The National Integrated Drought Information System

The National Integrated Drought Information System (NIDIS) is led by NOAA and was established to assist users in determining potential impacts of drought and the risks associated. Its goals are as follows:

- Establish a successful integrated national drought monitoring and forecasting system.
- Focus on impact mitigation and predictive capabilities.
- Create a drought early warning system that is accurately able to supply timely and integrated information on drought conditions at a relevant spatial scale to help with decisions that will minimize economic, social, and environmental loss.
- Provide interactive delivery systems that are standard and comprehensible.
- Provide a plan for educating those affected by drought, about drought occurrences and associated impacts (Western Governors' Association 2004).

The NIDIS plan incorporates observations, analysis techniques, and forecasting methods into one system. It was made to be used at a variety of scales from national to the county level (NIDIS Implementation Plan 2007). This research examined drought impacts at the county and state levels. Drought planning at the county and state levels has become more of a concern since water shortfalls are regional issues. Today, most states have some form of a drought plan due to the potential economic loss associated with drought (NDMC 2006 *b*). The revised Kentucky Drought Mitigation and Response Plan was developed in 2008 and is applicable to the public via the internet (http://www.water.ky.gov/NR/rdonlyres/A4EF5D07-2FBA-487D-B0B3-7E6EBF3E8320/0/StatePlanFinal.pdf). The following map illustrates the status of state drought planning as of October 2006:

Figure 4. Status of state drought planning. Source: NDMC 2006.



Implementation of the NIDIS plan is important if our current system is to improve. NIDIS is made up of Pilots whose purpose is to provide information, tools, and pathways for areas sensitive to drought. Each Pilot's goal is to educated the public and raise awareness, integrate monitoring and forecasting subsystems, generate risk assessments, develop a plan to reduce drought related damages, improve communication by delivering timely information, and help develop new technologies for more efficient water resource management (NIDIS Implementation Plan 2007). This research coincides with the goals set forth by NIDIS and it is expected to be useful in the quest for efficient drought mitigation.

2.5 Further Justification for KY Drought Impact Assessment

Impact assessment is a vital process if we are to understand the relationship between climate and humans. A study titled 'Drought and Man' examined the impacts of drought in many parts of the world in 1972 (Garcia 1981). The year of 1972 was selected for the study because during that year drought affected food production in China, the Soviet Union, Eastern Europe, Latin America, and sub-Saharan Africa. The purpose of the study was to establish an understanding of the relationship between climate anomalies of 1972, which was the first major food production decline since 1945. The 'Drought and Man' study was led by Rolando Garcia, who formed several research teams in Latin America, Africa, and South Asia. The research teams were instructed to assess the events of 1972 by using a three level structural approach. At the first level, the teams were instructed to examine atmospheric anomalies, soil systems, agricultural systems, social systems, and economic systems. At the second level, the teams had to identify likely causes for the observed events, such as the global market, urbanization, and industrialization. The third level consisted of identifying causes of the observed events at the second level (Kates et al. 1985).

The results of this study showed that drought had several impacts on society and the economy. For example, due to the severe lack of precipitation, the Soviet Union experienced an agricultural deficit and was forced to purchase large quantities of grain from the United States. This led to the depletion of US grain reserves and to shortages in the international market. These shortages resulted in extreme price increases in grain and other grain products. This imbalance of supply and demand caused societal, political, and economical problems. All of which were examined through impact assessment so that the relationship between drought and man could be clearly understood (Kates et al. 1985).

Knowing the impacts associated with drought is important to reduce drought related risks in the future. Impact assessment is necessary to determine economic losses associated with drought. Most estimations of the economic impacts of drought are incomplete and have not been well quantified economically. This often causes officials and policy makers to underestimate the severity of drought and the importance of drought preparedness (Hayes et al. 2002).

A study done by the National Climatic Data Center (NCDC), lists the 57 weather related disasters that have caused over $1 billion dollars of economic loss in the United States between 1980 and 2003 (http://www.ncdc.noaa.gov/oa/report/billionz.html). 10 of the 57 disasters are drought related and range from over $80 million to $1.3 billion (normalized to 2010 dollars). These are devastating amounts, but it is important to remember that these are rough estimations that were not determined in a uniform manner (Hayes et al. 2002). The estimates were produced by the NCDC and were derived by the guidelines set for by the National Drought Mitigation Center (NDMC). In this study very few sectors are represented and only a hand full of states. The study did not include all of the states affected by the drought and sectors such as energy production, recreation, health care, etc. that certainly would be affected by drought also. Obviously these estimates are not full representations of all sectors and areas affected by drought and therefore are unreliable. The U.S. needs to develop a consistent methodology for determining economic losses that is applicable across all scales and sectors (Hayes et al. 2002).

The importance of impact assessment is not just comprised by drought specialists. Flood, timber, tourism, ecology, etc. specialists have documented the need for impact assessment as well (Gosain et al. 2006; Kundzewicz et al. 2007; Canadell et al. 2008; Mokrech et al. 2008). Regional impact assessment for flood prone areas has become a growing concern (Richards et al. 2008). Flood and coastal projects that examine climate and socio-economic changes, and impacts of flood risks have been important developments in the UK (Evans et al. 2004). These projects showed that future flood risks will increase if the current approaches and expenditure on flood coastal management do not change. This means that there is a significant need for additional adaptive measures in order to prepare for future climate (Mokrech et al. 2008).

Forestry is another field where the importance of impact assessment has been recognized. Much of Sweden is covered by forests which provide raw materials, environmental, recreational, and industrial values (Schlyter et al. 2006). Swedish forestry specialists are concerned about the future impacts of climate change because forests planted today will be harvested in 70-100 years from now. Since weather and climate have a direct impact on trees, the need for impact assessment has become an obvious necessity. A workshop was held in Helsinborg, Sweden in 2004 to discuss impact assessment for Sweden forestry. Participants included the National Board of Forestry, the Swedish Environmental Protection Agency, the Swedish Meteorological and Hydrological Institute, the Swedish University of Agriculture, and many other stakeholders and representatives. Their goals was to begin the policy making process to protect their forests from impacts of climate change (Kundzewicz et al. 2008).

Though these studies were not focused on the impacts of drought, they are still representations of the relevance of impact assessment. Whether the issue is flood, timber management, or drought, impact assessment must be done to reduce future impacts. Knowledge can be obtained from impact assessment studies across a number of different sectors. Even though the studies mentioned are not focused on drought, they are focused on the need and importance of impact assessment. This provides further justification for documenting drought impacts and completing impact assessments. Without drought impact research, drought vulnerable areas will remain vulnerable and efficient monitoring and assessment will not exist.

2.6 Climate Change

Climate change impact assessment is designed to identify and analyze future changes in climate that could impact human activities and the environment, as well as possible responses to a changing climate (Tol 2002). Since adaptation can reduce impacts, it is important to include adaptation assessment in impact studies. Since the goal is to assess the future, it is not possible to conduct a controlled experiment by altering the atmosphere to test changes on human and environmental systems (Xu and Tung 2009). In this absence, other methods have to be developed to explore the impacts of climate change. Five approaches identified by the United Nations Environment Programme (1998) have been applied to try and accomplish this goal:

1. Palaeological, archaeological, or historical studies of climate change and variations and their effects on humans and the environment.
2. Studies of climatic events that are analogous to events predicted to occur with human induced climate change, such as drought.
3. Studies of the impacts of present climate and climate variability.
4. Formation of 'what if' kinds of questions created from models that quantify the relationship between climatic events and impacts.
5. Development of a general consensus view made by expert judges.

Climate change impact assessment needs to be done so that mitigative and adaptive measures and policies can be taken. Climate change is a global problem and involves decision-making at the local or community level up to the international level. Without impact assessment it would be difficult for appropriate decisions to be made. Impact assessment is an important key in understanding what actions need to be taken to produce the most satisfying relationship between climate and humans in the future (United Nations Environment Programme 1998).

Establishing an estimate of the impact of climate on mankind is extremely difficult. Monetary impact assessments are necessary, but have played a limited role in public debates (Nordhaus and Yang 1996; Tol 1999). Previous studies that have included estimates of impacts were mostly deficient in their methods for developing numbers. Also, assessment models that focus on climate change impacts have been weak in economic analysis (Tol and Frankhauser 1998). There is a need for a uniform methodology for determining the economic impacts on climate change (Tol 2002). This research coincides with these “big questions” as it estimates economic impacts (in dollars) of drought on Kentucky’s agriculture.

CHAPTER 3
DATA AND METHODOLOGY

In order to quantify the economic impacts of drought (in dollars) on Kentucky's agriculture, several data sets and sources were utilized. The commodity data was downloaded via the Internet from the National Agricultural Statistics Service (http://www.nass.usda.gov/). From this website, state-wide and county-wide agricultural data is available for download. For this research, both Kentucky state-wide and county-wide data were downloaded and saved as Microsoft Office 2007 Excel® spreadsheets (.xls). Since this research is focused on drought impacts, the original county-level data was sorted into Kentucky's four climate divisions; Western, Central, Bluegrass, and Eastern. Drought is variable between regions so to account for this variability all four of the state's climate regions were represented (Wilhite et al. 1987; Sonmez et al. 2005; Quiring 2009).

Figure 5. Kentucky Climate Divisions. Source: KCC 2007.

Once the county-level data was sorted into the appropriate climate divisions, unit conversions were performed. The raw yield data was measured in bushels per acre which was converted to metric tons per hectare. The conversion factors utilized in this research are provided by Iowa State University and are accessible via the internet (http://www.extension.iastate.edu/agdm/wholefarm/html/c6-80.html).

After the conversions, the yield data was then plotted alongside the production data for comparison. The county and state level corn data covers the period of 1929-2009 and for county-level soybean, hay, and livestock it covers the period of 1974-2009. However, state-level soybean and hay data are available from 1929-2009. Having a long range of data allows for better comparison and analysis. The data was plotted so that dips and spikes in each commodity's yield and production could be seen over time. This allows patterns to be evident between yield and production and drought years. It is expected that during drought years, the plots will show dips in yield and production. It should however, be noted that county-level corn data is missing the year of 1949.

Annual price data for each commodity came from the National Agricultural Statistics Service. This source has price data dating back into the early 1900's for corn and into the 1940's for hay, soybeans, and livestock. To make the price data relative to the present, the data was normalized to 2010 dollars. This was done by multiplying the commodity price by the appropriate inflation rate. An inflation calculator that was used for this research is available via the Internet (http://www.usinflationcalculator.com/). The 2010 real price for each year was multiplied by the production for the same year and plotted. It was hypothesized that prices will increase during drought years due to lower production caused by drought.

PDSI values for each climate division were obtained from the NCDC. As discussed previously, PDSI was developed to measure drought severity. It is based on a scale of -4.0 to 4.0 to quantify the presence of precipitation. Positive numbers yield wet conditions while negative numbers signify dry conditions (Palmer 1965). For the purposes of this research only severe drought years were included in the analysis, which includes 1930-1931, 1940-1942, 1952-1955, 1988, 1999-2001, and 2007. These years were chosen because of their significantly negative PDSI values and they are also delegated as Kentucky's most severe drought years by the Kentucky Climate Center (KCC 2010). Precipitation and temperature data were used to show the variability between climate divisions, the data is provided by the Kentucky Climate Center.

Each of the significant drought years was examined individually in order to quantify the impacts of drought during that year. Once the economic impact on each crop was determined, the revenue during that year was compared to the decade average. For example, the state revenue for corn during the significant drought year of 1940 was determined and compared to the average revenue of that decade (1940-1949). A decade average was used to account for the change in technology over time. This was done to determine if revenue was lower during a significant drought year compared to neighboring years.

CHAPTER 4
RESULTS AND DISCUSSION

Kentucky is centrally located in the eastern half of the Unites States. The majority of the state lies below 1,000 feet above sea level. However, there is an exception around the western margin of Kentucky that drains into the Mississippi River where elevation decreases. Kentucky is rich in natural resources including coal, lumber, fish and wildlife, lakes and reservoirs, etc. These resources help fuel Kentucky's economy and generate billions of dollars in revenue annually (http://kentucky.gov/Pages/home.aspx).

Kentucky is approximately 25.6 million acres in size, of which approximately 13 million is farmland. The majority of Kentucky farms lie on 1-99 acres. During 2008 the net farm income for Kentucky was approximately $1.6 million. The top commodities in Kentucky during 2009 were horses, broilers, soybeans, corn, cattle and calves. These commodities alone generated $4,257,623 in cash receipts during 2009 (USDA 2010). Agriculture is an important component of Kentucky's economy and degradation of Kentucky crops can cause severe economic impacts. It is important to understand how Kentucky commodities are affected during periods of drought so that policy makers can develop plans to reduce drought vulnerabilities and avoid extreme economic deficits.

The purpose of this research was to quantify (in dollars) the economic impacts of drought on Kentucky's agriculture. Four of Kentucky's cash crops were examined including: corn, soybeans, hay, and beef cattle. Each of the commodities' yield, production, price, and revenue were analyzed for each of Kentucky's four climate divisions and state-wide. According to the Kentucky Climate Center (2010), the years that are considered Kentucky's historically significant droughts are 1901-1909, 1904-

1905, 1908-1909, 1913-1915, 1930-1931, 1934, 1936, 1940-1942, 1944, 1952-1955, 1963-1964, 1988, 1999-2001, and 2007. According to the Kentucky Climate Center (2010), the droughts of 1930-1931, 1940-1942, and 1952-1955 are classified as the most severe, based on their PDSI values. These years and the most recent significant drought years of 1988, 1999-2001, and 2007 were examined individually.

Climate elements that are important to drought analysis were examined to determine whether temperature, precipitation, and PDSI varied between Kentucky's four climate divisions. Since drought varies geographically (Hayes 2002), it is expected that there will be some variation in drought characteristics between climate divisions.

4.1 Climate Divisions

4.1.1 Western Division

The Western climate division is located in the western part of the state and consists of 26 counties. Its average annual temperature is approximately 13.8°C (57°F) and it receives around 1168-1244 millimeters (46-49 inches) of precipitation annually (Kentucky Climate Center, 2010). Figure 6 is shows mean annual temperature for the Western climate division. Significant drought years are represented by yellow bars. It is apparent that temperature fluctuates year from year, with an average around 14°C. The top five highest mean temperatures occurred in 1998, 2007, 1999, 1931, and 1991. 1998 is the year with the highest mean temperature recorded during this time period. During this year the mean temperature reached 15.5°C (59.9°F), just slightly higher than the 2007 average of 15.2° C (59.4°F). Other years with high mean temperatures occurred in 1930-1931, 1941-1942, 1946, 1952-1955, and 1986-1987. As mentioned previously, a common characteristic of drought is warm temperatures. All of the years just mentioned, are considered to be significant drought years. Therefore, it should come as no surprise that many of the Western division's highest temperatures occurred during these years.

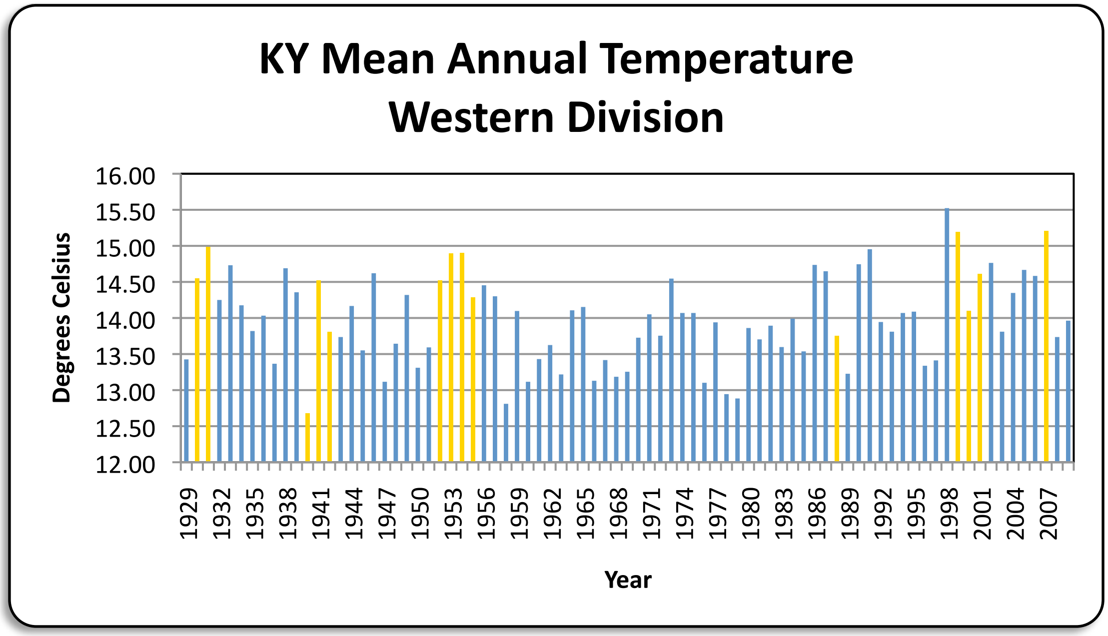


Figure 6. Kentucky Mean Annual Temperature for the Western Division. Source: NOAA 2010.

As discussed previously, there are many different definitions for drought, but they all seem to have one common theme. This theme is a period of dryness or lack of precipitation. Since lack of precipitation is a common characterisitc of drought, it is important to include precipitation data in this research. Precipitation in Kentucky is generally plentiful, with spring being the wettest season and fall being the driest. Average annual rainfalls range from 1016-1270 millimeters (40-50 inches), half of this amount occurs during warmer months (Kentucky Agricultural Weather Center 2008). Figure 7 shows Kentucky's annual precipitation totals for the Western climate division. The five years with the lowest precipitation totals are 1963, 1941, 1930, 1943, and 1953. The year of 1963 had the lowest recorded precipitation total for any year in Kentucky's Western climate division during this time period. That year the precipitation total only reached 769.62 mm, which is 7% of the long run average. All of the five years with lowest precipitation totals are years of significant drought in Kentucky (Kentucky Climate Center 2010).

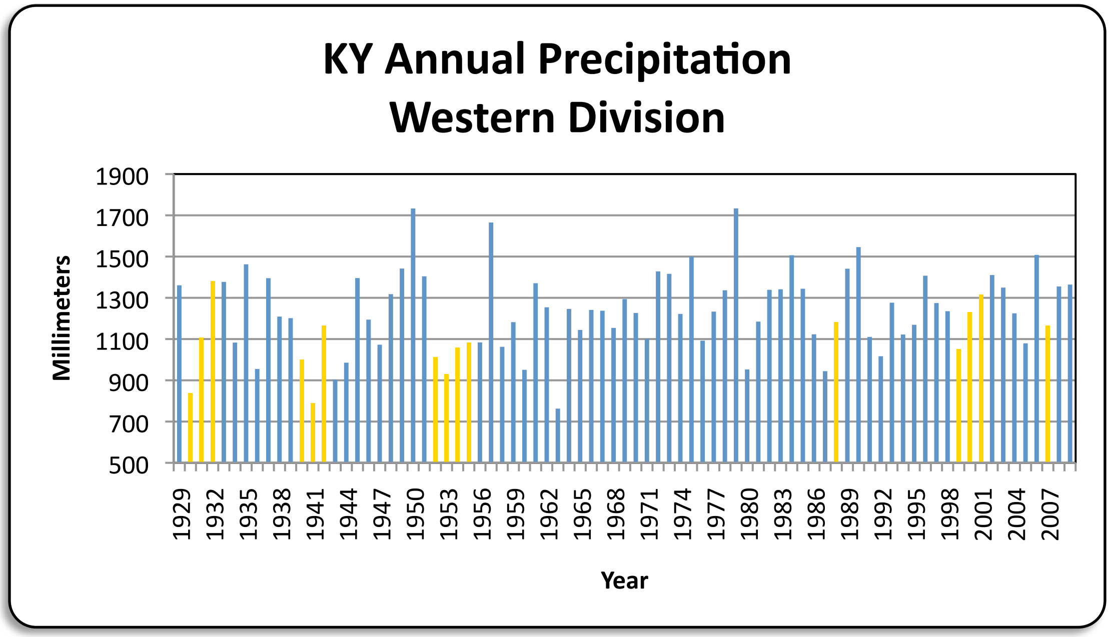


Figure 7. Kentucky Annual Precipitaion for the Western Division. Source: NOAA 2010.

Figure 8 shows annual PDSI values for Kentucky's Western climate division. Recall that negative values signify dry conditions, while positive values signify wet conditions (Palmer 1965). The five lowest values occur in 1941,1954,1931,1944, and 1953. Less severe negative values also occurred in 1952, 1955, 1988,1963-1964, 200-2001, and 2007. All of these years have recorded annual negative PDSI values and all of these years are documented as historically significant periods of drought in Kentucky (Kentucky Climate Center 2010).

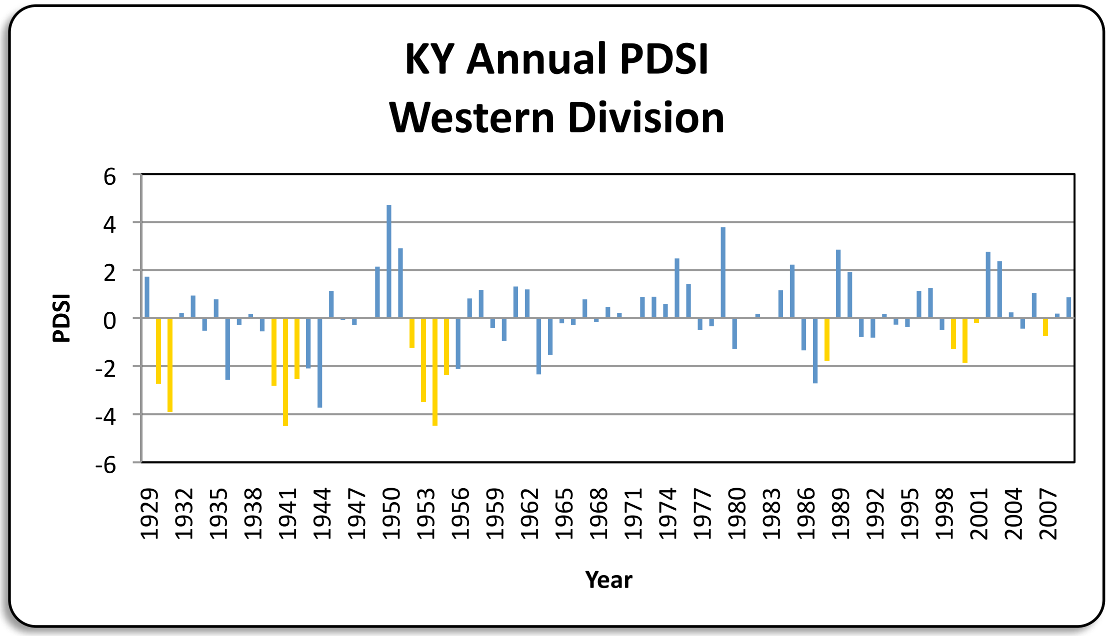


Figure 8. Kentucky Annual PDSI for the Western Division. Source: NOAA 2010.

4.1.2 Central Division

The Central division is located in the southcentral part of the state and includes 24 counties, its mean annual temperature is around 13.3° C (56°F) and it recieves around 1193-1270 mm (47-50 in) of precipitation annually, making it just slightly cooler and wetter than the Western Division (Kentucky Climate Center 2010). The Central division is a major contibutor to Kentucky's agricultural industry, producing corn, soybeans, hay, and beef cattle.

The Central's division mean annual temperatures are shown in Figure 9. Figure 6 shows similar trends between years to that of the Western division. The five years with the highest mean annual temperature are 1998, 2007, 1931, 1991, and 1999. These years were also the highest mean annual temperature years in the Western division, and predominately occurred during significant drought.

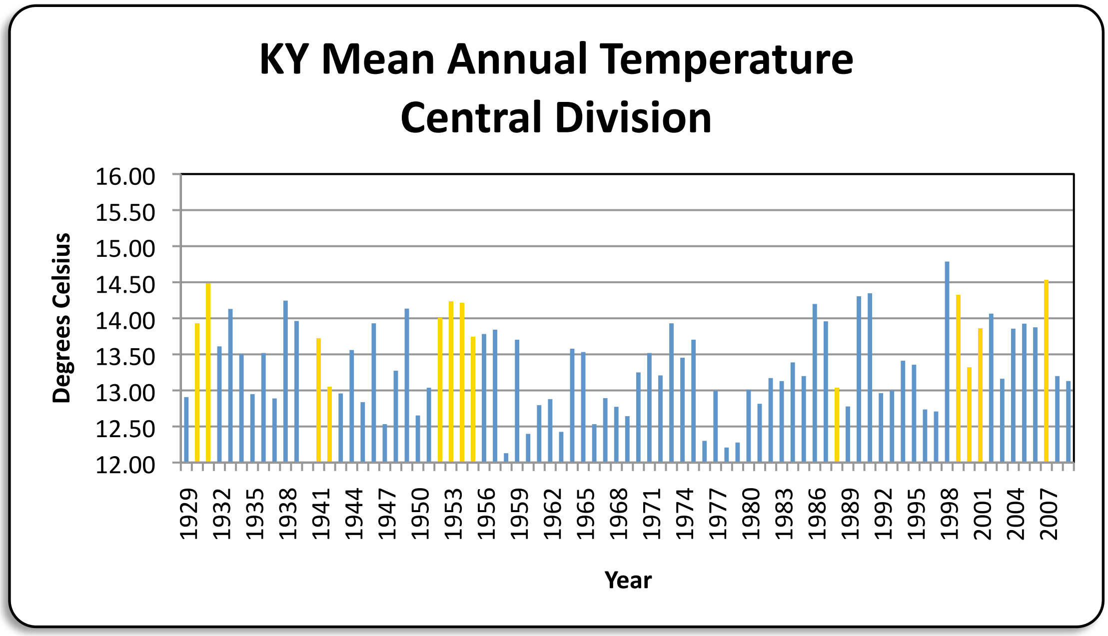


Figure 9. Kentucky Mean Annual Temperature for the Central Division. Source: NOAA 2010.

The average precipitation for 1929-2009 is 1242 mm (49 in). The five years with the lowest precipitation totals are 1930, 1941, 1963, 1934, and 1953. All of the years are delegated by the Kentucky Climate Center (2010) as severe drought years. It is important to note that precipitation is a localized phenomena and varies geographically (Hayes et al. 2002). Refering back to Figure 7, the years with the lowest annual precipitaion totals in the Western division are not the same as the Central division. Drought is also a phenomenon that varies geographically and not every climate division or county will be affected the same (Bonaccorso et al. 2003).

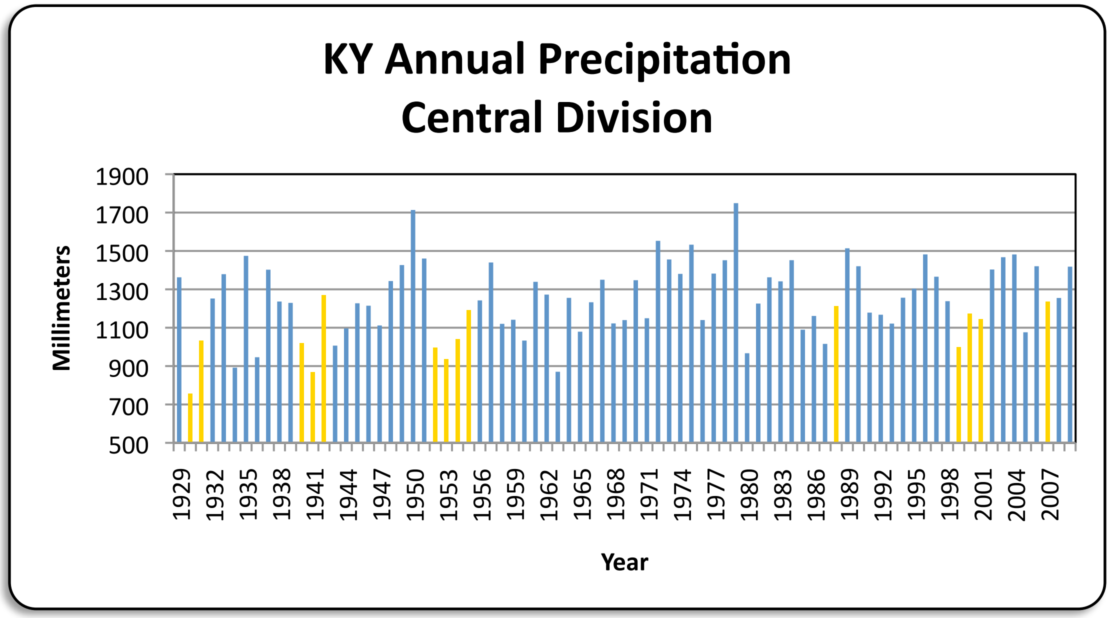


Figure 10. Kentucky Annual Precipitation for the Central Division. Source: NOAA 2010.

Central division PDSI, as seen in Figure 11, were lowest during 1931, 1954, 1941, 1953, and 1930. Similar to the Western division, these are considered severe drought years.

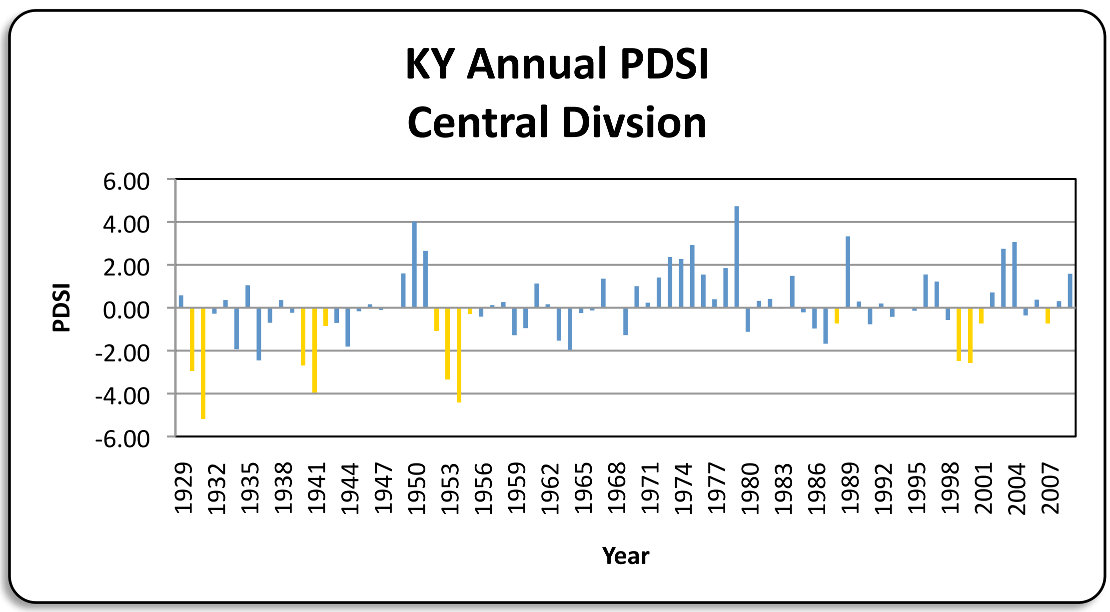


Figure 11. Kentucky Annual PDSI for the Central Division. Source: NOAA 2010.

4.1.3 Bluegrass Division

The Bluegrass division, located in north central Kentucky, consists of 35 counties and is the most industrialized and urbanized region of the state. Its mean annual temperature is 12.2° C (54ºF) and it recieves 1143-1193 mm (45-47 in) of rain annually (Kentucky Climate Center 2010).The Bluegrass division is usually slightly cooler and drier than the Western and Central divisions. It is important to note that tobacco and horse farms are important economic sources to the region, even though they will not be examined in this research.

In the Bluegrass division, the 5 years with the highest mean annual temperatures are 1988, 1931, 1938, 2007, and 1953. Each of these years was an extreme drought year and had mean annual temperatures ranging from 13.6-14.1° C (56.6°F- 57.4°F). These years vary from the Western and Central divisions' highest mean annual temperature years, which were 1988, 2007, 1931, 1999, and 1991. Though 1991 and 1999 were not in the Bluegrass division's highest 5 years, they did make the highest 10 years list. However, the years that did make the highest 5 years list are severe drought years, which is expected since warm conditions are associated with drought.

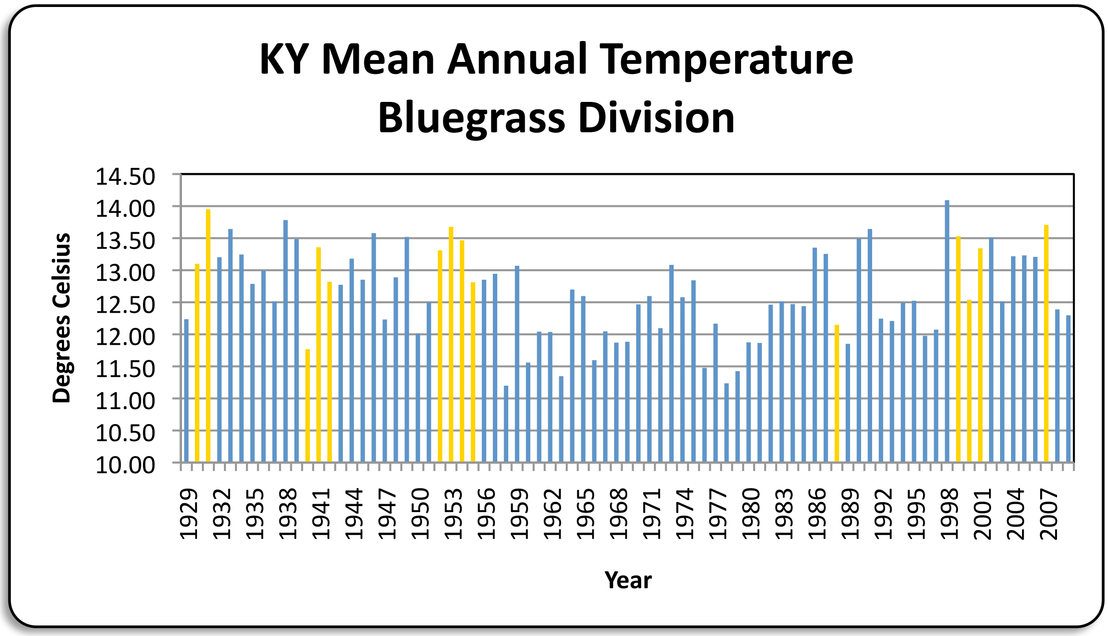


Figure 12. Kentucky Mean Annual Temperature for the Bluegrass Division. Source: NOAA 2010.

Kentucky annual precipitation for the Bluegrass division is shown in Figure 13. The average annual precipitation for the Bluegrass division from 1929-2009 is 1154 mm (45 in). This is approximately 76 mm less than the Western and Central division averages. Since lack of precipitation is a common characterisitic of drought, the years with the lowest annual precipitation totals should be noted. These years include 1930, 1941, 1963, 1987, and 1999. The year of 1930 was the lowest year with only 671 mm of precipitation. The years of 1936, 1943-1944, 1952-1954, 1988, 2001, and 2007 were also in the bottom 30 years for annual precipitation totals.

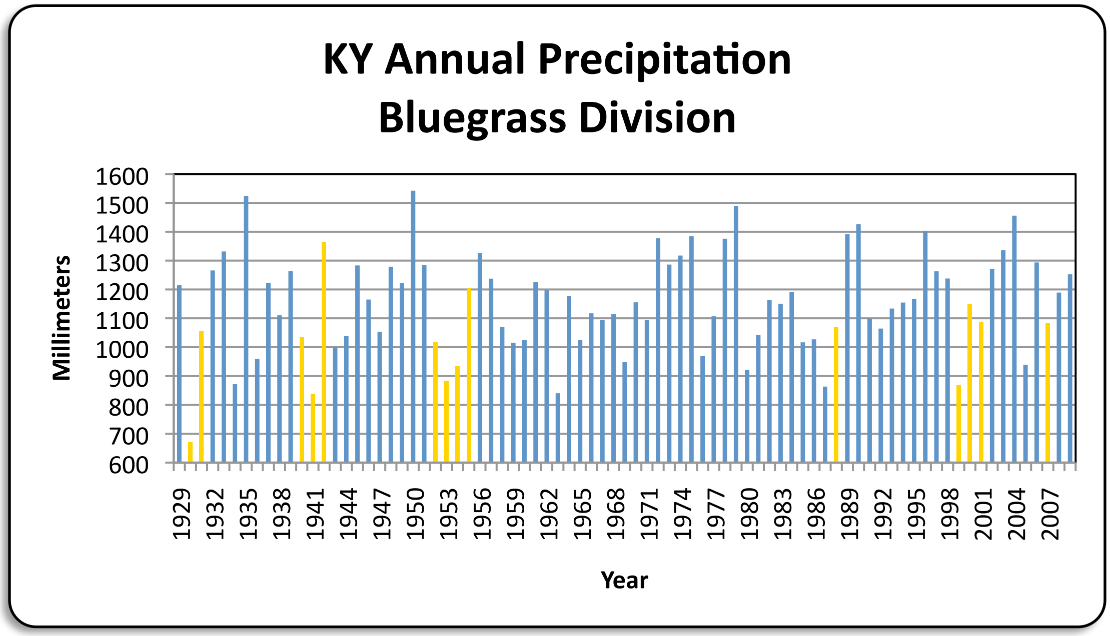


Figure 13. Kentucky Annual Precipitation for the Bluegrass Division. Source: NOAA 2010.

Similar to temperature and precipitation, there is variability of PDSI across climate divisions. For example, 1931 had the lowest PDSI for the Bluegrass and Central divisions (refer to Figures 11 and 14). For the Bluegrass division, the annual PDSI for 1931 was -5.47, for the Central division it was -5.18. For the Western division, 1931 had the 3rd lowest PDSI with a value of -3.90. Variability in PDSI between climate divisions is expected because drought varies geographically (Hayes 2002). This is why different divisions within the same state can have different drought impacts. Sometimes one division can be affected more severely by drought than others and vice versa.

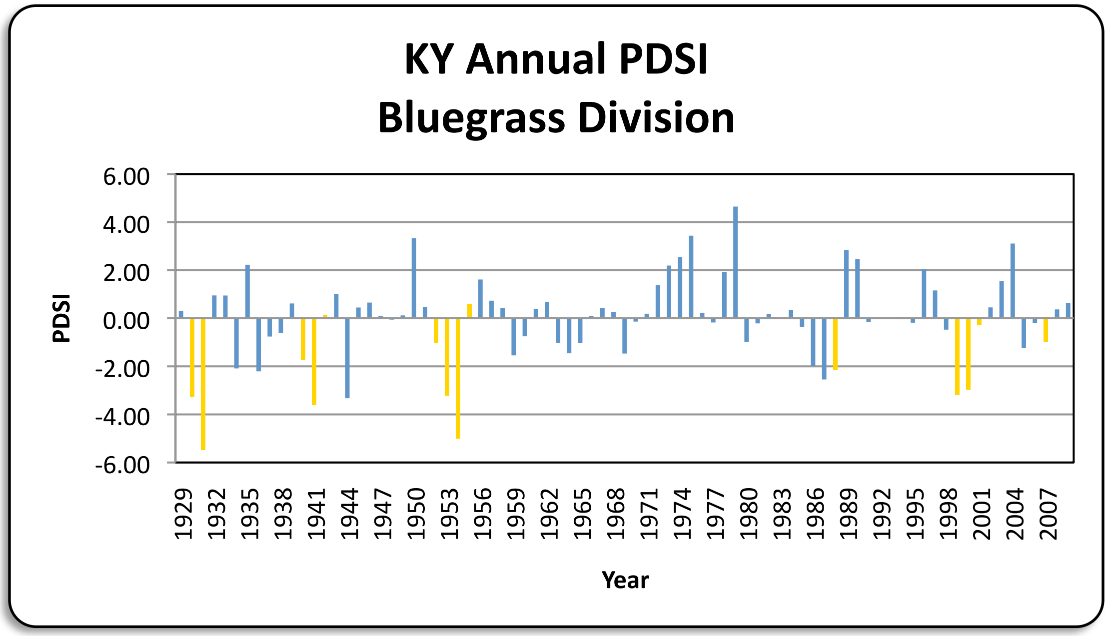


Figure 14. Kentucky Annual PDSI for the Bluegrass Division. Source: NOAA 2010.

4.1.4 Eastern Division

The Eastern division is located in the eastern half of the state and consists of 35 counties. The Eastern climate division is distinguished by its rugged terrain. The majority of the region lies on the Appalachian Plateau, which was carved by water to form hills, valleys, and hollws. Tobacco, corn, hay, and cattle are produced in the region but on a small scale. This is due to poor soils and scarcity of flat land. The Eastern division is typically cooler and slightly wetter than the other three divisions, its mean temperature is around 12.7°C (55°F) and precipiation averages around 1168-1219 mm (46-48 in) annually (Kentucky Climate Center 2010).

The highest mean annual temperature years occurred in 1938, 1949, 1946, 1998, and 1931 (Figure 15). During these years mean annual temperature ranged between 14-14.2°C (57.2°-57.6°F), about 2-4 degrees cooler than the other climate divisions' highest mean annual temperature years. This variation is expected because temperature is not uniform across the state, ranging from approximately 11.6°C in the northeast to 15°C in the southwest. There is also seasonal variation in temperature across the state. During the summer, high temperatures exceed 32.2°C for an average of 20 days in the north and east, and an average of 40 days in the south and west (Kentucky Climate Center 2010).

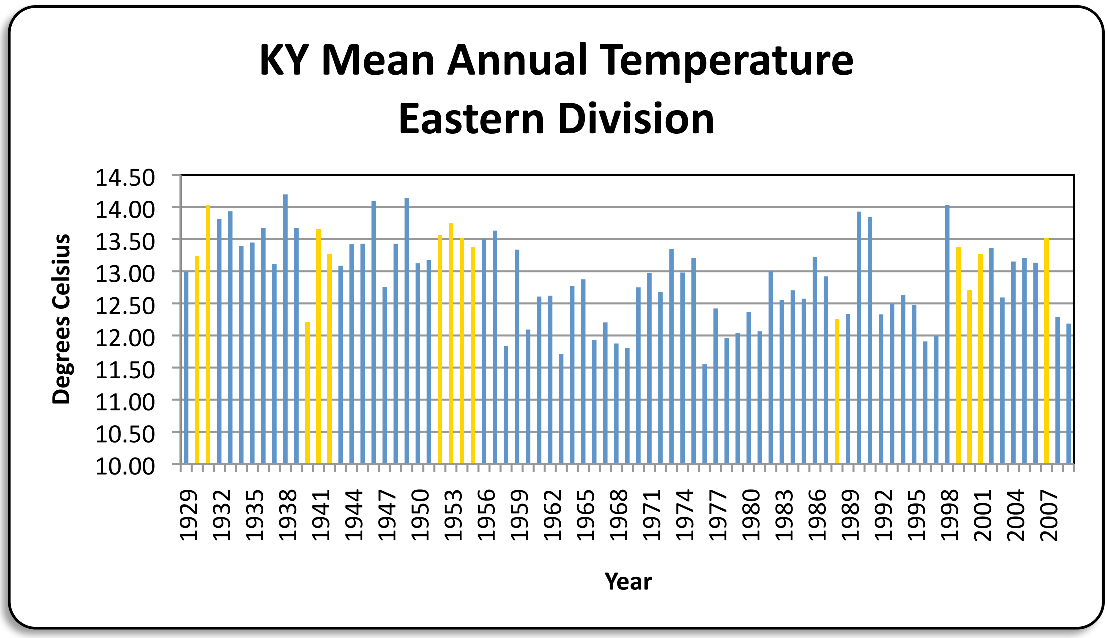


Figure 15. Kentucky Meand Annual Temperature for the Eastern Division. Source: NOAA 2010.

The three lowest annual precipitaion years occurred in 1930, 2007, and 1941 (Figure 16), which are significant drought years in Kentucky. Like the Central and Bluegrass divisions, 1930 experienced the lowest annual precipitaion total in the Eastern division with a value of 719 mm of precipitation, which is approximately 471 mm less than 1929-2009 average. The second lowest precipitaion year occurred during 2007. During that year, the Eastern division received a total of 896 mm of precipitation, which is 327 mm less than the previous year and 294 mm less than the 1929-2009 average.

During the year of 1941, the Eastern division received 904 mm of precipitation. This amount is approximately 59 mm lower than the previous year of 1940, which had a total of 963 mm.

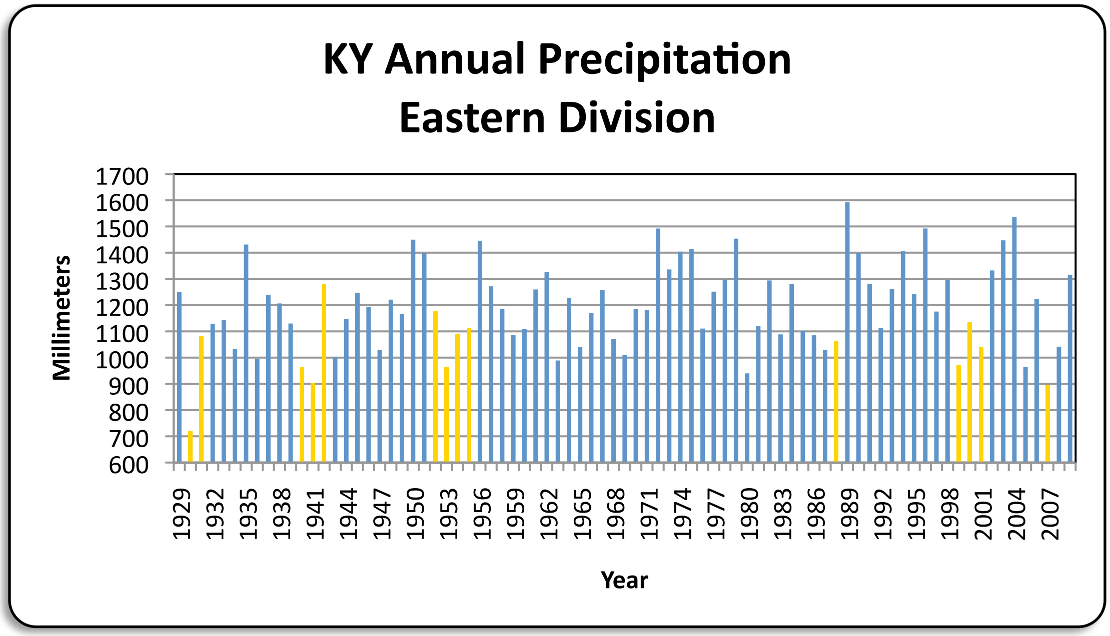


Figure 16. Kentucky Annual Precipitation for the Eastern Division. Source: NOAA 2010.

As expected, the years with the lowest PDSI values are also significant drought years. The year with the most severe annual PDSI value (-4.35) for the Eastern division occurred during 1931, which is considered an extreme drought. The year of 1931 was a warm and dry year, with a mean annual temperature of 14°C and an annual precipitaion total of 1056 mm. The previous year of 1930 experienced the third lowest PDSI value. During that year the annual PDSI value was -3.45. This value means that the Eastern division was in a severe drought for most of the year. The year of 1930 was also a particulalry warm and dry year for Kentucky. All of Kentucky's climate divisions experienced severe negative annual PDSI values and the drought of 1930-1931 is considered the most severe drought in Kentucky's history by many climatologists (Kentucky Climate Center 2010).

Other years with negative PDSI values occurred during 1934, 1936, 1940-1941, 1953-1954, 1999, and 2007. During these years annual PDSI ranged from -3.87 during 1941, to -2.05 during 1953. All of these years were warm, dry, and classified as significant drought years. The years of 1930-1931, 1940-1942, 1952-1955 are considered the most severe drought years for the state and will be examined later in the chapter, as well as the most recent significant drought years of 1988, 1999-2001, and 2007.

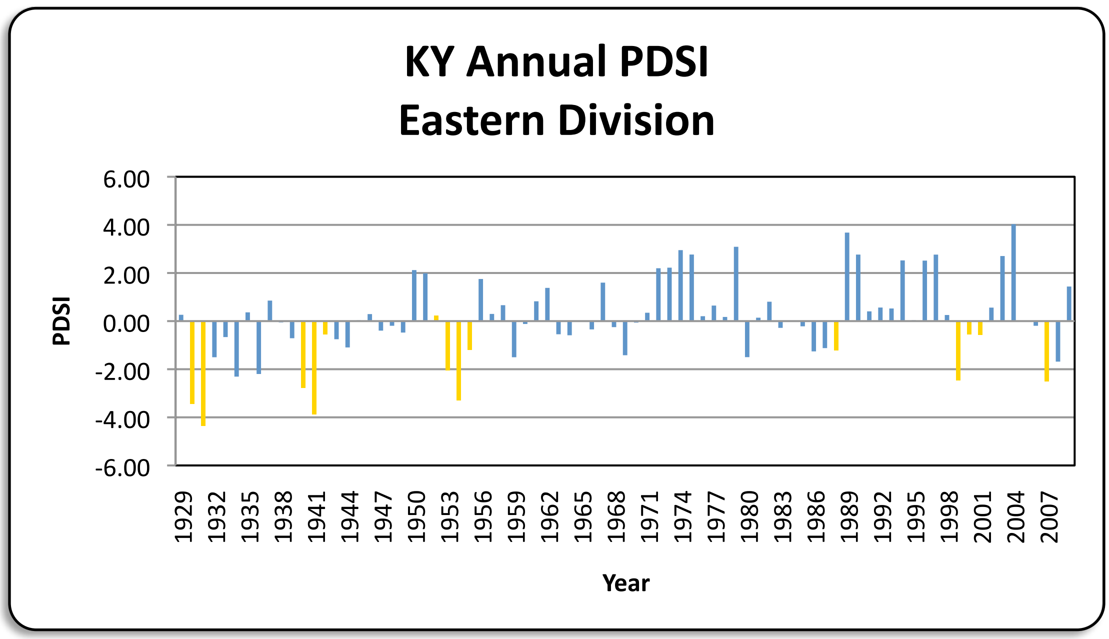


Figure 17. Kentucky Annual PDSI for the Eastern Division. Source: NOAA 2010.

4.2 Commodities

4.2.1 Corn

In 2009, Kentucky produced over 190 million bushels of corn. Corn is a major cash crop for the state, as it generated over 617 million dollars in 2009 (Kentucky Corn Growers' Association 2010). During periods of drought corn yield can be negatively affected which can have devastating repercussions on Kentucky's economy. An objective of this research was to determine just how devastating these repercussions can be.

Figures 18 and 19 are plots of 1929-2009 corn used for grain yield measure in metric tons per hectare and production measured in metric tons for Kentucky's four climate divisions and the state-level. Significant drought years are depicted on the graph by the yellow diamond symbol. As expected, the graphs show a gradual increase in yield throughout time. This is expected because of the increase in technology, including the invention of farm tractors, pesticides, fertilizers, and drought-resistant seeds (Sunding and Zilberman 1999). The Western and Central divisions have experienced an overall positive trend throughout time; however, the Bluegrass and Eastern divisions' production have decreased during recent years. In the Bluegrass division production increased in the 1970s, then declined and recent years have had similar production totals to those in the 1930s. This trend is even more severe for the Eastern division, where production has been steadily decreasing since the 1950s.

Though the Western and Central divisions' yield and production has increased over time, there are some significant dips in the data, where yield and production are lower than neighboring years. The year with the lowest yield and production for both divisions occurred in 1930. In the Western division corn yield was 0.63 metric tons per hectare and production was 236,175 metric tons. The Central division experienced even lower yield and production that year, with a yield of only 0.60 metric tons per hectare and 196,575 metric tons of corn produced. It is not surprising that yield and production were low during 1930, because that year was one of Kentucky's historically significant drought years. Referring back to Figures 7-17, 1930 was a hot and dry year for Kentucky, with annual PDSI values of -2.72 for the Western division and -2.95 for the Central division. The year of 1930 was also the lowest yield year for the Bluegrass and Eastern divisions as well; however, it was not the lowest production year.

All of the severe drought years had lower yield and production totals than neighboring years. Of course the most recent severe drought years had significantly higher yields and production totals than earlier years due to the increase in technology. However, recent severe drought years also suffered decreases in yield and production. The two most recent severe drought episodes were 1999-2001 and 2007. The 1999-2001 drought brought low yields and production for Kentucky corn. The year of 1999 was the worst year of the three year drought period in terms of agricultural impacts. This year the Western division had the highest production of the four climate divisions with a total of 2,470,875 metric tons. It is expected that the Western division would have the highest production totals compared to the other divisions because more corn is produced there annually. The 1999 production total was a 68,685 metric ton decrease from the previous year of 1998. For the Central and Bluegrass divisions 1999 was in the lowest 21 years for corn production and was in the lowest 10 years for the Eastern division.

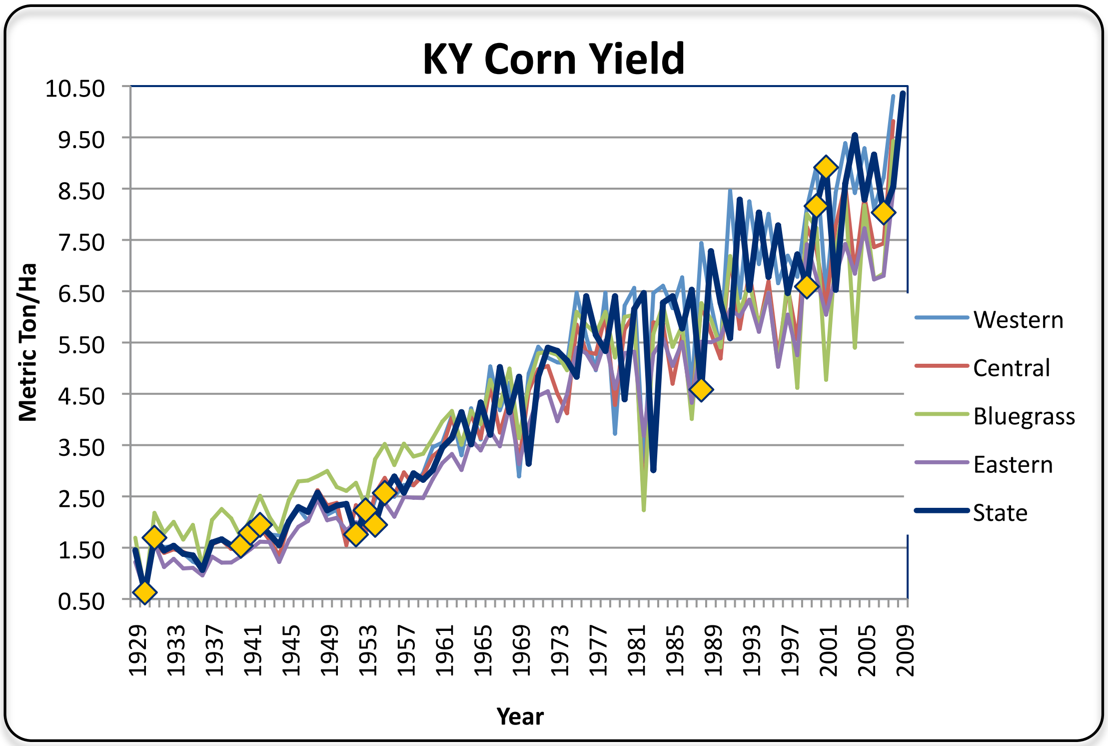


Figure 18. Kentucky Corn Yield. Source: NASS 2010.

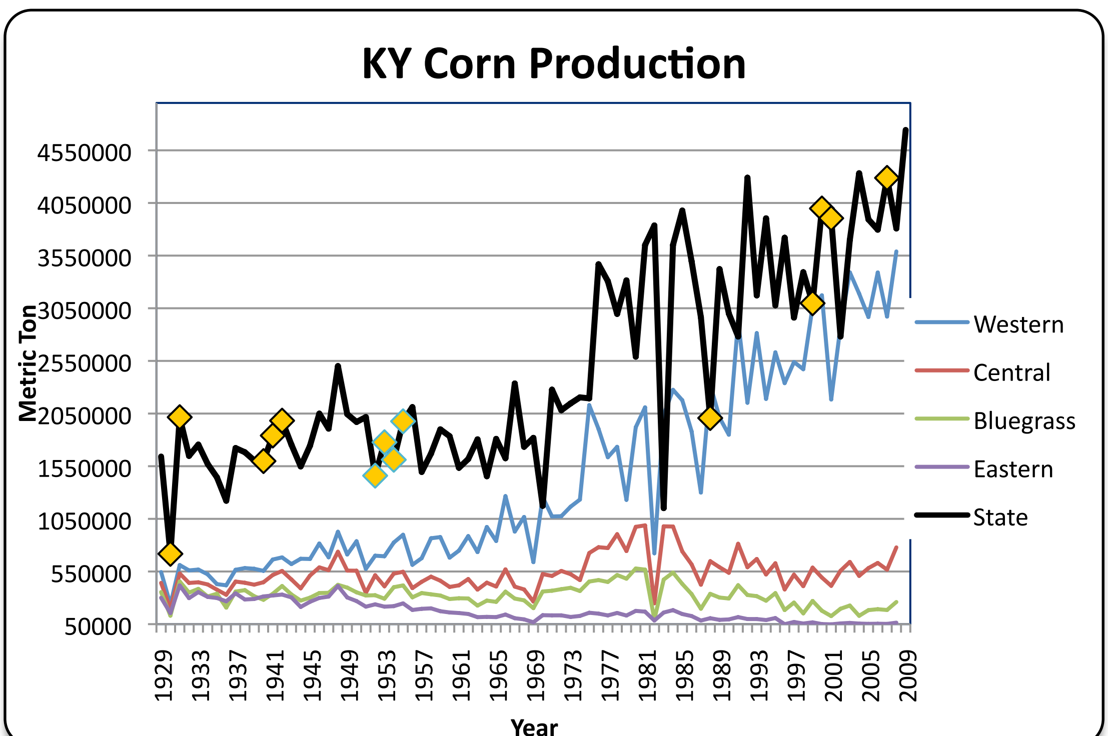


Figure 19. Kentucky Corn Production. Source: NASS 2010.

Since drought impacts are poorly documented, economic impacts are often underestimated (Hayes et al. 2004). It is no secret that drought impacts Kentucky's agricultural economy, but the severity of these impacts is difficult to decipher. Figure 20 is a graph showing Kentucky corn prices that have been normalized to 2010 dollars. Normalizing the data makes it accurate for the 2010 US inflation rate. For example, KY corn prices in 1929 were around $38.80/ton. Using an inflation calculator, $38.80 in 1929 would be equal to $494.56 in 2010. This is important to note because the price and revenue data used in this research are based off the normalization of historic dollars to 2010 dollars.

The data is skewed to the left, meaning that prices decreased throughout time. This is expected because of the improvement in technology. Technology has made it possible for farmers to produce more corn and increase corn quality. Since more corn is being produced in recent years compared to the past, the price is lower because the supply of corn has increased drastically. This can be seen in Figure 20, as prices in the 1930s and 1940s ranged between 200-800 dollars per ton, and prices in the 1990s to the present range anywhere between 100-300 dollars per ton. Since less corn was being produced in the 1930s and 1940s, corn was scarcer which drove up the prices. Today, Kentucky farmers are producing over twice as much corn as they did in the early 1900s on about 70% less land (Kentucky Corn Grower's Association 2010). Due to this abundance of corn, prices can be much lower than they were in the past.

Since drought can affect the relationship between supply and demand (Wilhite 1993), it is expected that the price for corn is higher during periods of drought. This is due to the fact that common characteristics of drought are hot and dry conditions, which can have negative impacts on corn production and quality. Therefore, it is expected that prices will be higher because corn is scarcer. Corn prices have decreased over time because of the increase in technology and higher yields and production. This can be evident by the fact that some of the years with the highest corn prices occurred in 1936, 1943-1947, and 1952-1954; all of which are drought periods.

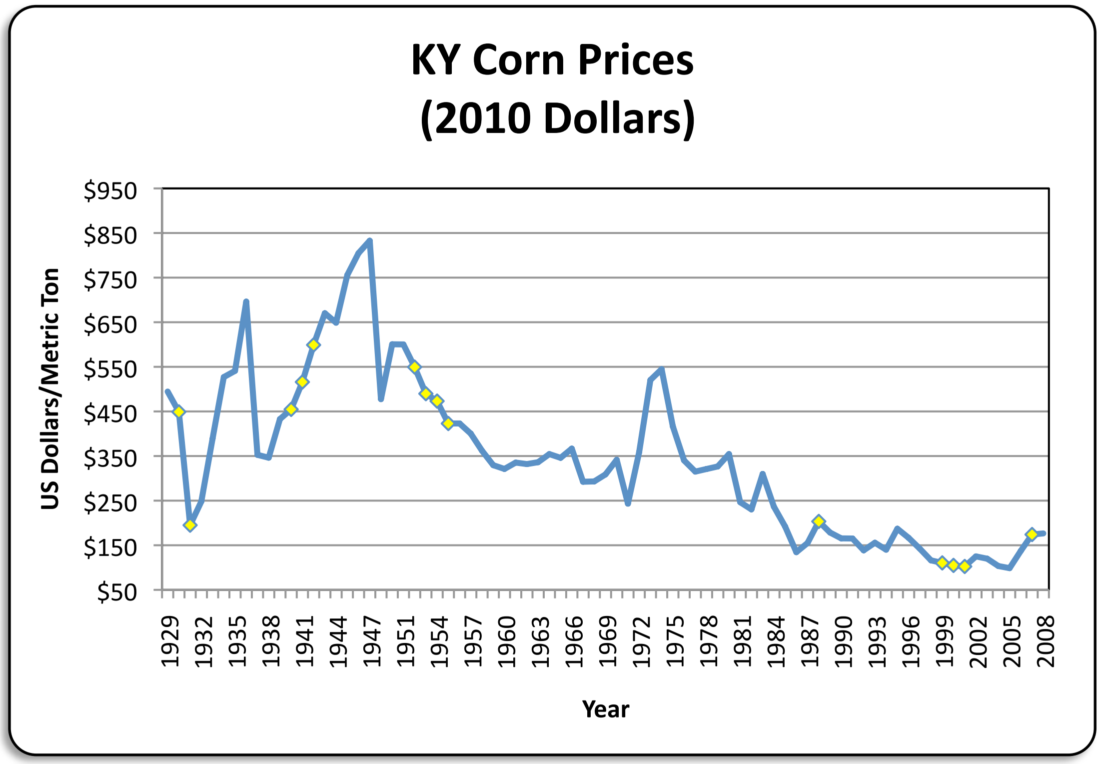


Figure 20. Kentucky Corn Prices. Source: NASS 2010.

Kentucky corn brings in millions of dollars annually to Kentucky's economy. Corn is an important cash crop to the state and the economy depends on its revenue (Kentucky Corn Grower's Association 2010). Figure 21 shows the results of multiplying corn total production by price (normalized to 2010 dollars). The Western climate division has generated the most corn revenue compared to the other divisions. For the 10 year period of 1999-2009, the Western division has generated $4,272,601,530 in corn revenue. The Central division generated the second highest revenue during this time period with a total of $801,161,773. The Bluegrass division came in third generating $269,684,604 and the Eastern division came in last with a total of $78,787,197.

For the Western division the lowest revenue year occurred in 1930, with a total of $106,037,852. For the Central division, the lowest corn revenue year was 1999. The year of 1999 marked the beginning of the 1999-2001 severe drought, it is likely that revenue was low this year because of the damage the drought caused to crop quality and production. The year of 2005, was the lowest revenue year for the Bluegrass division. The revenue during that year totaled $12,747,859. That year was also the third lowest production year for the Bluegrass division and the lowest price year for Kentucky corn. The year of 2001 was the lowest revenue year for the Eastern division. Refering back to Figure 15, 2001 was the third lowest production year for the Eastern division. During that year the Eastern division brought in a total of $5,195,234 from corn. This amount is $2,064,636 less than the decade average for the 2000's.

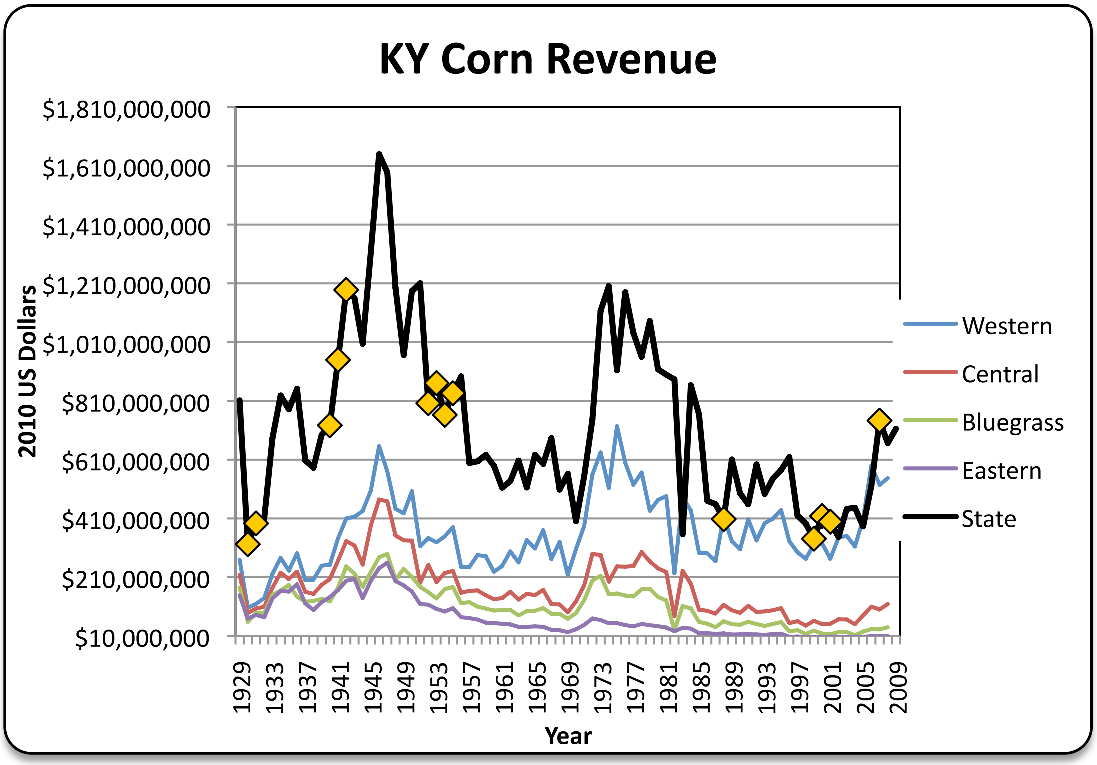


Figure 21. Kentucky Corn Revenue. Source: NASS 2010.

Kentucky corn state-level data is avaliable from 1929-2009. Similar to the pattern seen in the climate divisions, corn production and yield has been increasing state-wide throughout time. As illustrated in Figure 21, corn yield and production stayed relatively flat until the mid-1950s when conditions began to improve. After World War II, farming techniques improved with the addition of chemical fertilizers and pesticides. This advancement allowed yields to increase which is why we see a positive trend in the data. Corn production continued to evolve with the addition of tractors and more effective farm equipment. Tilling practices have also changed and nowadays most farmers use a conservation type or a no-till process which allows farmers to spend less time in the field and can increase profit (Allmaras et al. 1997).

The advancement of technology and adoption of more efficient farm management techniques has allowed production to increase and prices to decrease. Since corn is no longer a scarce commodity, farmers are able to sell their corn at lower prices than in the past (Figure 22). Figure 21 shows Kentucky corn revenue in 2010 dollars. Kentucky corn revenue appears to be significantly lower in recent years than in the 1940s and 1970s. Since it has become easier to produce corn in recent times, perhaps the market is more competitive today. With more farmers entering the market there is more competition to sell. The abundance of corn has decreased prices and the demand can easily be met by the supply which may explain why revenue has decreased.

It may seem that irrigation may be a simple resolution to lack of moisture during drought years. Kentucky corn irrigation data is avaliable through the NASS for 2007. During that year 542,290 hectares of corn were harvested in Kentucky, of which approximately 3,349 hectares were completely irrigated. Approximately 494,375 hectares of corn during that year were not irrigated at all. It is obvious that during that year, irrigation of corn crops was not a common practice in Kentucky (NASS 2010).

4.2.2 Soybeans

Soybean is another important cash crop for Kentucky. Kentucky is the 10th ranked state in the nation for soybean production (USDA 2007). In Kentucky, soybeans are usually planted around mid-May, when temperatures are usually warm and precipitation is plentiful (Egli 2008). Figure 22 and 23 are graphs of soybean yield and production for Kentucky's climate divisions. The data begins in 1972 because that is the first year of county-level data avaliable provided by the National Agricutlural Statistics Service. Since the data does not begin until 1972, several of the historically significant drought years were not accounted. However, the 1988, 1999-2001, and 2007 droughts can be analyzed.

The lowest soybean production year for the Western division occurred in 2007, which was the most recent significant drought year in Kentucky. During this year the Western division produced 538,039 metric tons of soybeans, which was 717,336 tons less than the previous year. Refering back to Figures 6-17, 2007 was a particularly warm and dry year. For the other climate divisions, 1972-1976 were the lowest soybean production years. During this period the Central division produced 230,774 tons of soybeans, while the Bluegrass division produced 58,312, and the Eastern division produced 16,727 tons. Refering to Figures 8, 11, 14 and 17, Annual PDSI values for these years were positive, annual temperatures were moderatley warm, and precipitation was plentiful. Results suggest that drought was not the cause for the low production during this time. Perhaps, the low production was due to the lack of technology and the inexpereince of soybean farming, as soybeans were a fairly new commercial crop to these divisions during this time.

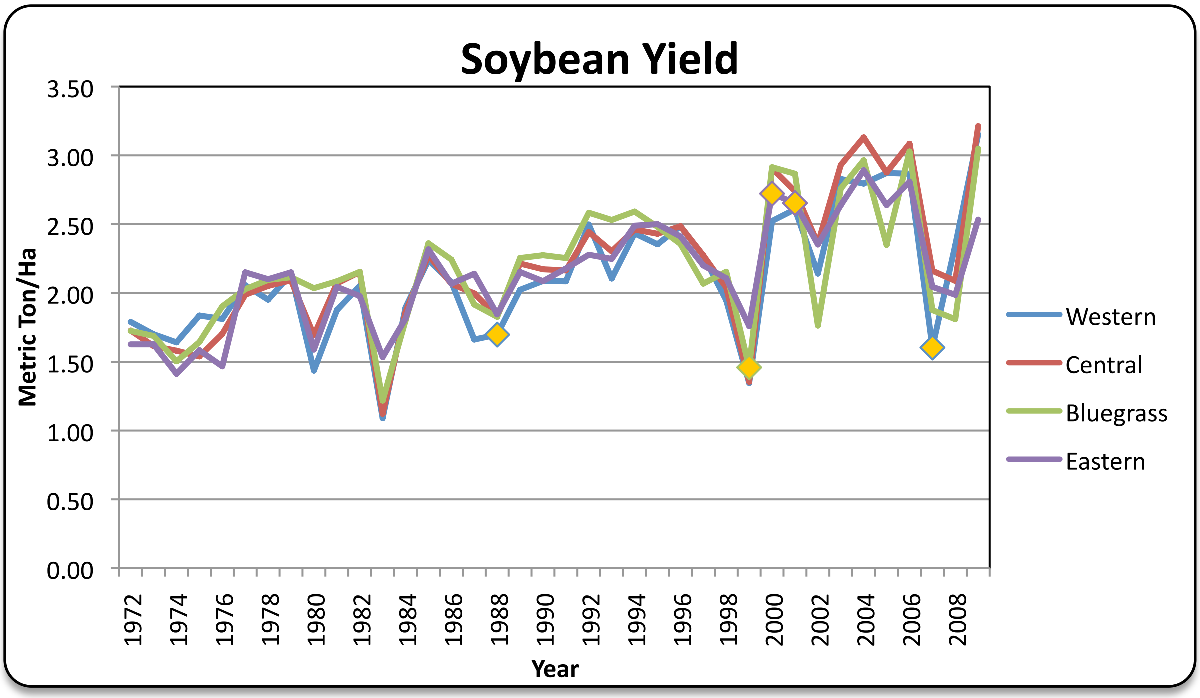


Figure 22. Kentucky Soybean Yield (Climate Divisions). Source: NASS 2010.

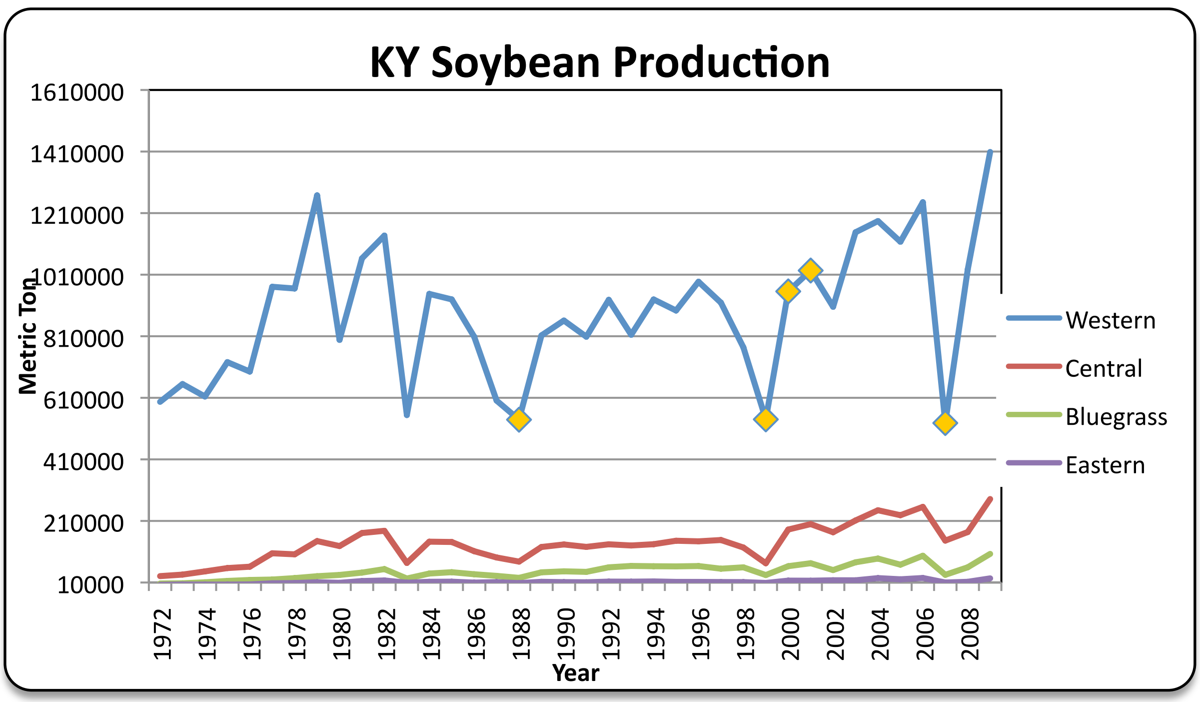


Figure 23. Kentucky Soybean Production (Climate Divisions). Source: NASS 2010.

Kentucky soybean price data could be found from 1940-2009 and is shown in Figure 24. The years with the highest prices occurred during the 1940s and 1970s. It is expected that prices would be high during the 1940s because production was lower compared to recent years and the supply could not be met by the demand. Also, World War II caused prices to increase.

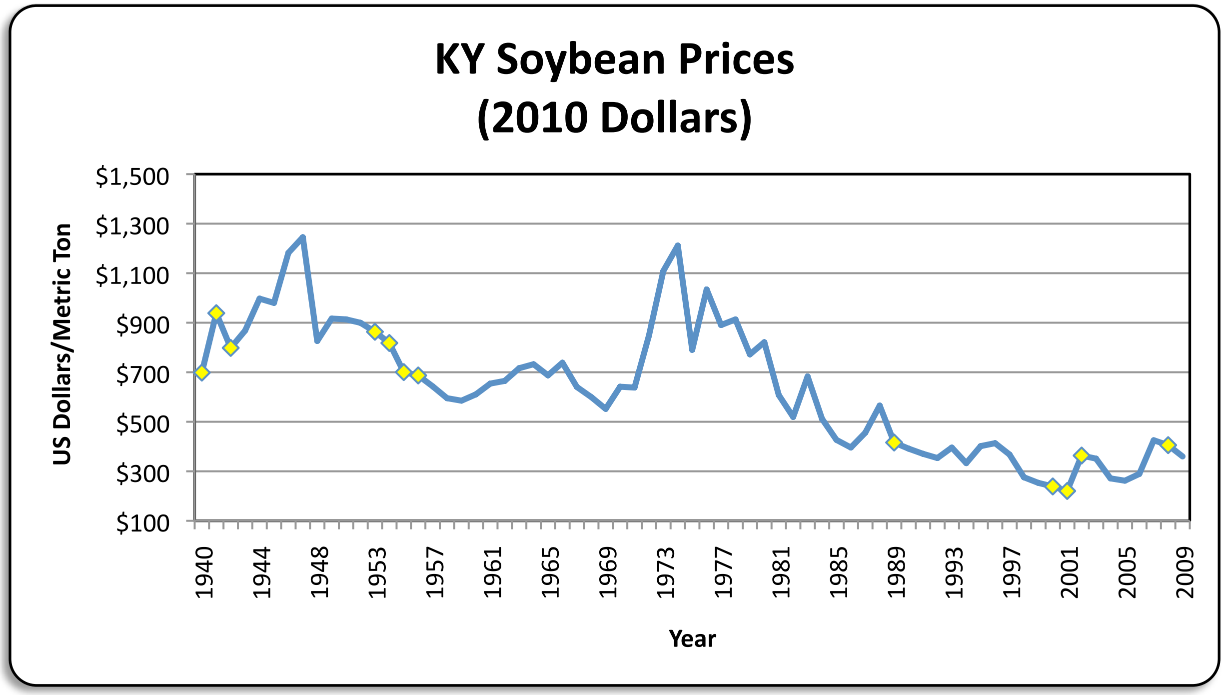


Figure 24. Kentucky Soybean Prices.Source: NASS 2010.

Since the county-level production data does not begin until the 1970s, revenue before this time period cannot be determined. The year of 1999 was the lowest soybean revenue year for the Western and Central divisions and among the five lowest years for the Bluegrass and Eastern divisions (Figures 25). This year also had the 3^{rd} lowest price during 1940-2009, with a price of $253.17/ton. The year of 1999 was a particulary hot and dry year for Kentucky. The Central division had an annual PDSI of -2.48, while the Western division experienced an annual PDSI of -1.28. The year of 1999 will be examined in more detail during the drought of 1999-2001 discussion later in the chapter.

The lowest revenue year for the Bluegrass and Eastern divisions occurred in 1972. During that year the Bluegrass division generated $5,674,833 in soybean revenue. This amount is $2,612,337 less than the following year of 1973. The Eastern division also experienced it's lowest revenue during this year with a total of $2,164,131 in soybean revenue. Production during 1972 was fairly low which likely contributed to low revenue.

Other low revenue years occurred in 1987-1988, 1991, 2000-2001, and 2007. Hot and dry conditions occurred in 1987 which lead to the severe drought of 1988. Many Kentucky stations reported temperatures of above 100°F during summer of 1988 (U.S. Department of Commerce 1988). The hot and dry conditions contributed to making 1987-1988 in the lowest 20 soybean production years for all four of Kentucky's climate divisions. Though prices during 1987-1988 were among the highest years, decreased productivity and quality resulted in low revenues (Tables 5-6).

The year of 1991 was among the lowest 10 soybean revenue years for all four climate divisions. During this year revenue ranged from $3,551,932-$265,461,248 across the commonwealth. The year of 1991 was also in the bottom 20 production years for all of the climate divisions, with the Western division having the highest production during this year and the Eastern division having the lowest. Annual mean temperature in 1991 was among the 20 highest years for all four climate divisions, and was even the 4th highest mean annual temperature year for the Central division (Figure 9). Precipitation totals ranged from 1099 mm in the Bluegrass division to 1280 mm in the Eastern division (Figures 13 and 16). Annual PDSI values during this year were also in the negatives for the Western, Central, and Bluegrass divisions. For the Eastern division annual PDSI was 0.41, which is expected since the Eastern division experienced the highest amount of precipitation during this year compared to the other divisions.

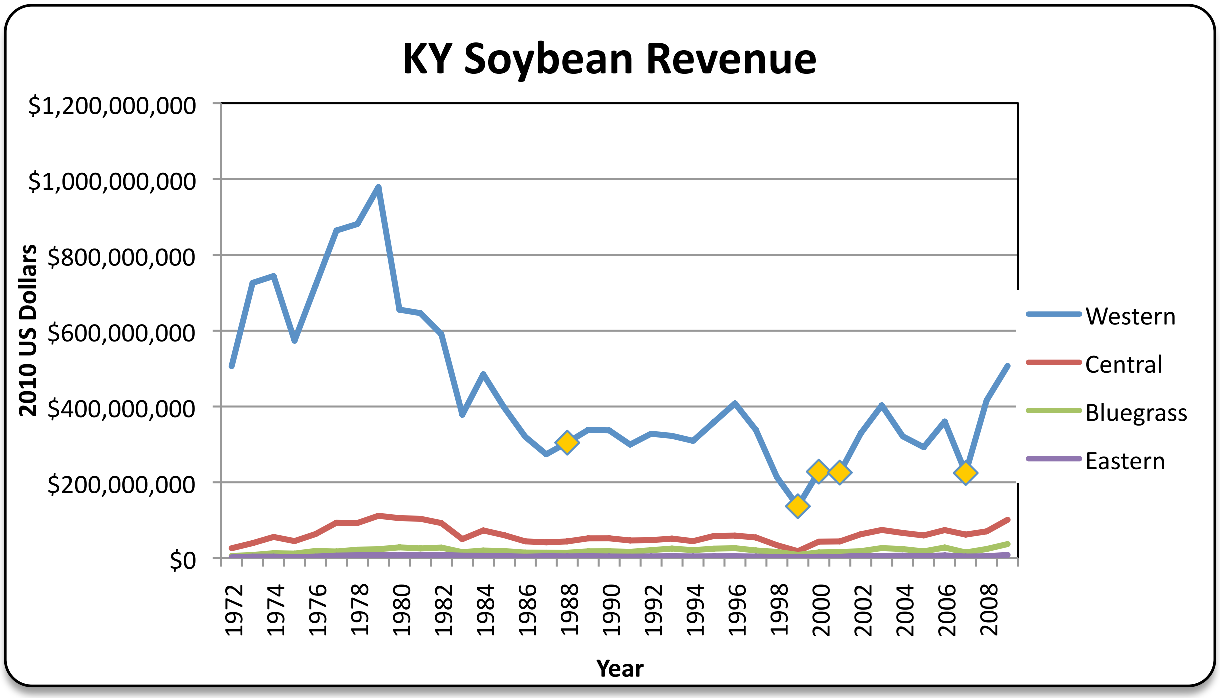


Figure 25. Kentucky Soybean Revenue (Climate Divisions). Source: NASS 2010.

Soybean data is available at the state-level from 1929-2009 and is shown in Figure 26. As illustrated in the figure below, soybean production remained flat until around the 1960s. Prior to that time soybeans in Kentucky were mostly used for forage or grain. It wasn’t until later that we began to use them for oils and other products. This abundance of products that contain soybeans made soybeans a more desirable commodity and farmers began to increase planting soybean seed (Harrison and Klotter 1997). Today soybeans have become one of Kentucky’s most valuable crops and in 2009, the state produced 1,816,374 metric tons of soybeans.

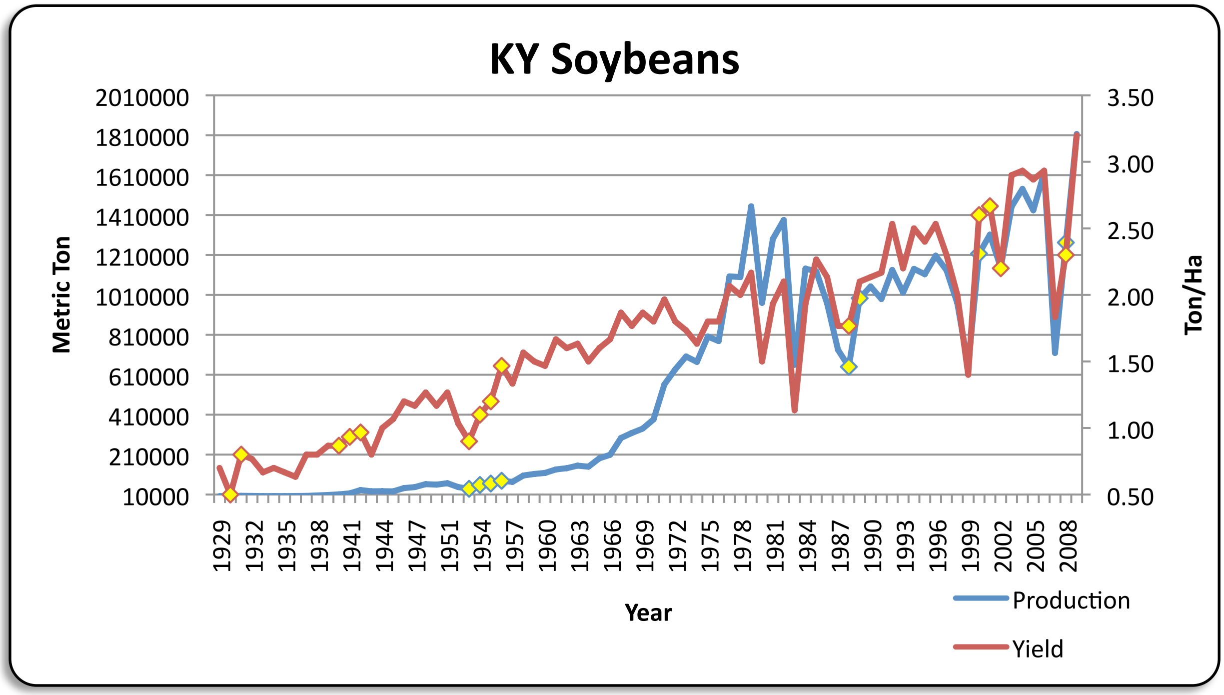


Figure 26. Kentucky Soybean Yield and Production. Source: NASS 2010.

Kentucky soybean revenue remained relatively flat from 1940 through the 1950s. Once soybeans become a desired commodity, more farmers began to produce and sale soybeans. Since many products contain oils from soybeans the demand increased which increased revenue significantly. As illustrated in Figure 27, revenue increased dramatically throughout the 1960s-1970s. Thereafter, revenue began to decline and level-off.

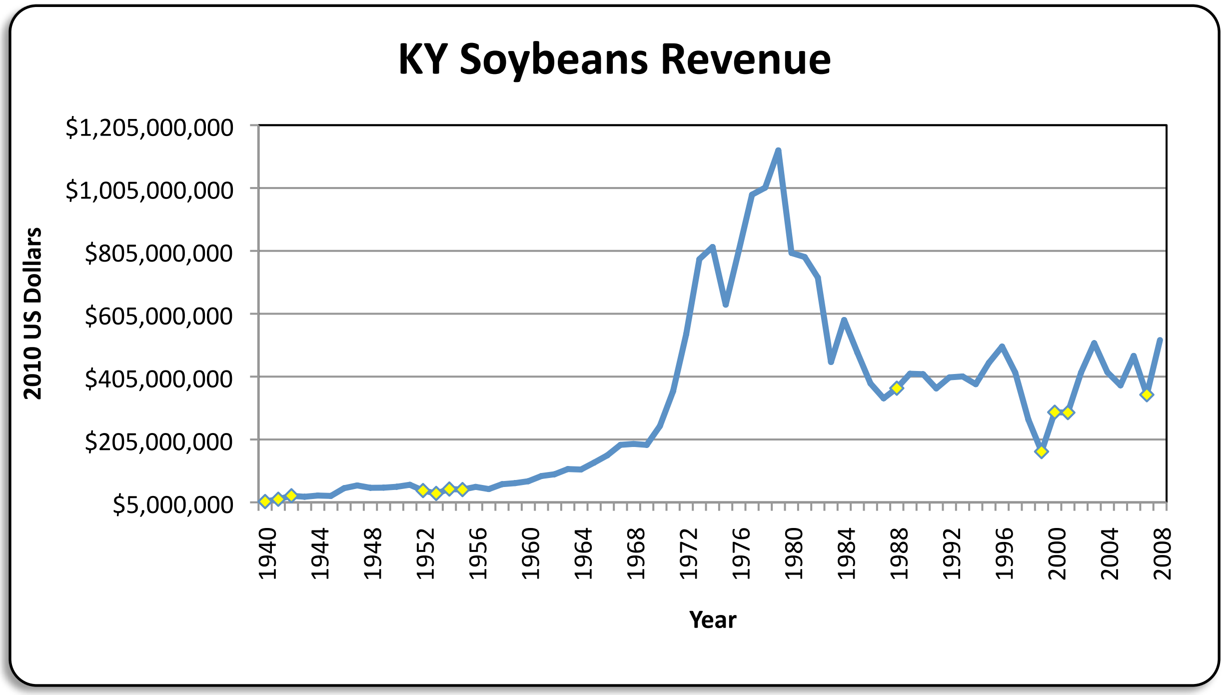


Figure 27. Kentucky Soybean Revenue. Source: NASS 2010.

During 2007 there was approximately 445,163 hectares of soybeans harvested in Kentucky. According to the NASS (2010) 425,806 hectares were not irrigated. The remaining 193,757 hectares harvested that year were only partially irrigated and the data showed that 0 hectares were fully irrigated. Perhaps, we could reduce soybean's vulnerability to drought in the future if more soybean crops in Kentucky were irrigated. This would be an important topic for future research.

4.2.3 Hay

Another valuable crop to Kentucky is hay. Kentucky ranked 3rd in the United States for All Other Hay production and 25th for Alfalfa Hay in 2006. Sales of Hay generated over $92 million in cash receipts to Kentucky farmers in 2005 (USDA 2007). Figures 28-29 are graphs of hay yield and production for Kentucky's climate divisions.

For this research hay classified as All Hay was used instead of Alfalfa Hay. As expected there is a positive trend in the yield and production data due to the advancement in technology, however there are a few exceptions. As shown in Figures 28-29, 1983 was the lowest hay production year for all four climate divisions. Unlike corn and soybeans, the Western division was not the highest producer. During this year the Bluegrass produced the most hay with a total of 995,523 metric tons. The Central division came in second with 744,374 tons, followed by the Western division with 378,128 tons, and the Eastern division with 247,792 tons. Annual temperatures during 1983 ranged from 12.2-13.9° C and annual precipitation totals ranged from 1089-1342 millimeters.

Another year of exceptionally low hay production occurred in 2007. During that year every climate division experienced lower than average hay production. The year of 2007 was the 14th lowest hay production year for the state from 1974-2008. The year of 1980 was also an exceptionally low hay production year for Kentucky, the fifth lowest hay production year for the Western and Central divisions, fourth lowest for the Bluegrass division, and the second lowest for the Eastern division. The state production total for 1980 was 2,689,074 metric tons of hay. This amount is 1,401,323 metric tons less than average production total from 1974-2008. Most years during the 1970's-1980's experienced lower than average hay production. As seen in Figures 28-29 hay production has increased over time, so it is expected for hay production to be lower in past years than recent due to the advancement in technology.

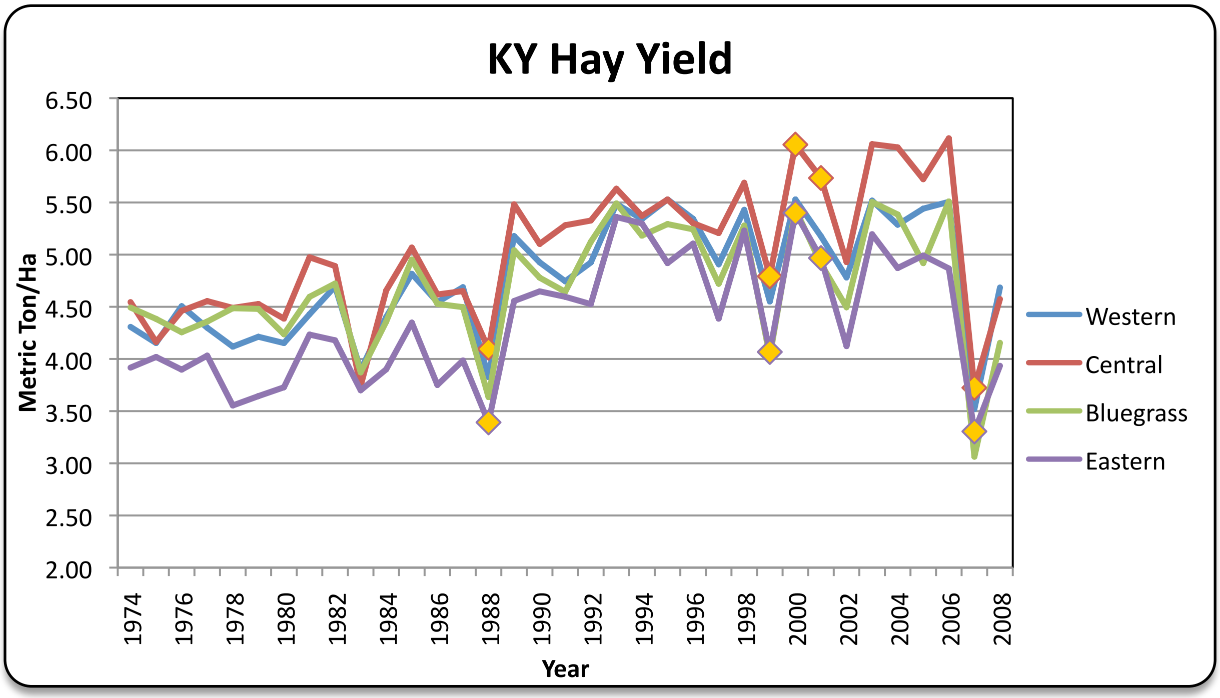


Figure 28. Kentucky Hay Yield (Climate Divisions). Source: NASS 2010.

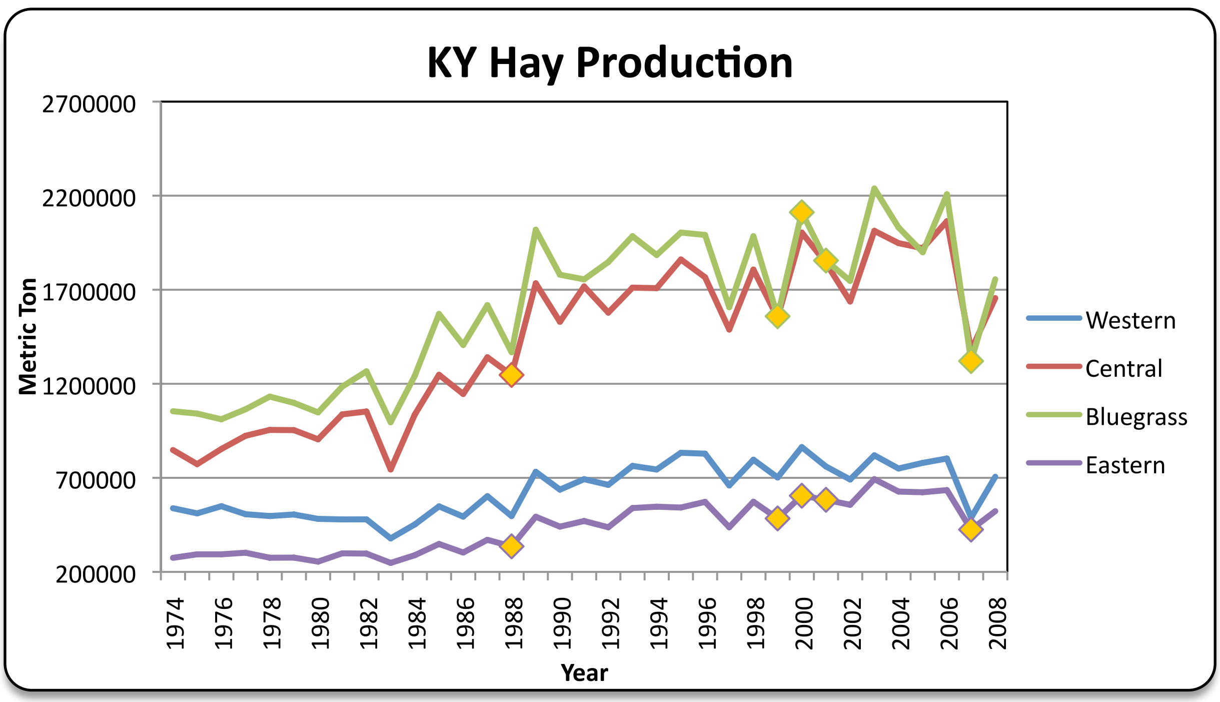


Figure 29. Kentucky Hay Production (Climate Divisions). Source: NASS 2010.

Hay has become one of Kentucky's most valuable crops. Similar to corn and soybeans, the price of hay has decreased over time due to higher yields and production. This trend can be seen in Figure 30. It should be noted that hay price data is avaliable at the state-level dating back to 1949.

In the mid-70s and 1980s hay cost around 116-160 dollars per metric ton. In recent years that price has decreased to around 80-100 dollars per ton (Figure 30). Even though prices have decreased throughout time, Kentucky still generates millions of dollars from hay. The trend of higher yields and production make hay more abundant and allows farmers to reduce their prices but still make a profitt. Kentucky hay prices were at their lowest during 2004; averaging $75/metric ton, which was approximately $4.00/ton less than 2003 and $8.72/ton less than 2005. Production in 2004 was high for all of the climate divisions. High production made prices decrease because there was an abundance of hay to be sold.

The highest Kentucky hay price during 1974-2008 occurred in 1983. During that year the average price of hay was $167.31/metric ton. As discussed previously, 1983 was an extremely low hay production year and it is likely that hay was scarce and farmers were able to sell at high prices. Other high price years occurred during 1976, 1974, 1977, and 1984. Referring back to Figures 28-29, production during these years were low compared to recent years. It can be seen in the figures, that hay production in Kentucky was relatively flat until the late 1980s when production began to increase. Low production during these years allowed farmers to increase their prices due to scarcity.

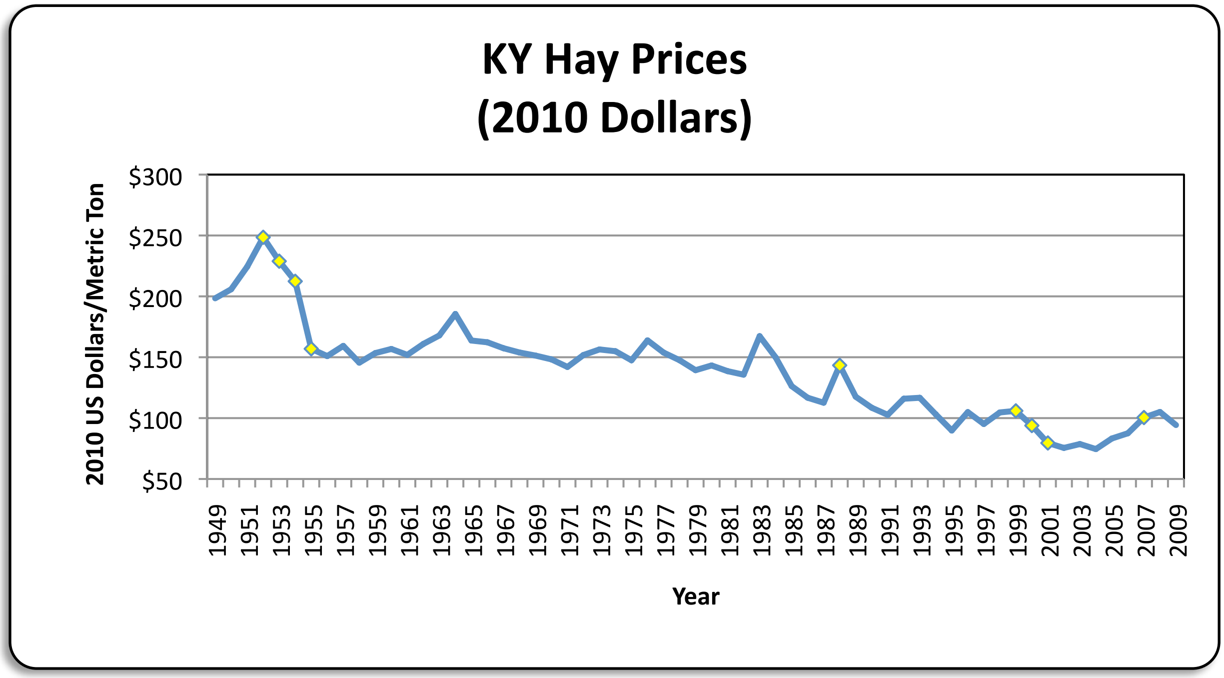


Figure 30. Kentucky Hay Prices. Source: NASS 2010.

As can bee seen in Figure 31, hay revenue fluncuates from year to year and between climate divisions. The year of 2007 was a significantly low year for all of Kentucky's climate divisions. It was the lowest revenue year for the Western division and a significantly low year for the Central, Bluegrass, and Eastern divisions. The average price of Kentucky hay in 2007 was $100.46/metric ton, making it the 10th highest year for hay price during 1975-2008. It is expected that 2007 would be a low revenue year since it is also a significant drought year. As previously discussed, a pattern has emerged as price tends to increase during low production years. As expected prices were high during 2007 but hay was scarce and there wasn't enough avaliable to produce high revenue.

The year of 2002 was also a low revenue year for all of Kentucky's climate divisions. This year was in the bottom 10 revenue years for all of the climate divisions and was even the lowest year for hay revenue for the Bluegrass division. During this year the Bluegrass division only generated $131,944,738 from hay. The total revenue for the whole state was $349,888,803. This amount is $103,738,244 less than the next year of 2003. The year of 2002 ranked as the 14th highest production year from 1975-2008 and hay prices were among their lowest. Perhaps the supply for hay was greater than the demand during this year and farmers had difficulty selling and had to decrease prices in order to compete in the market.

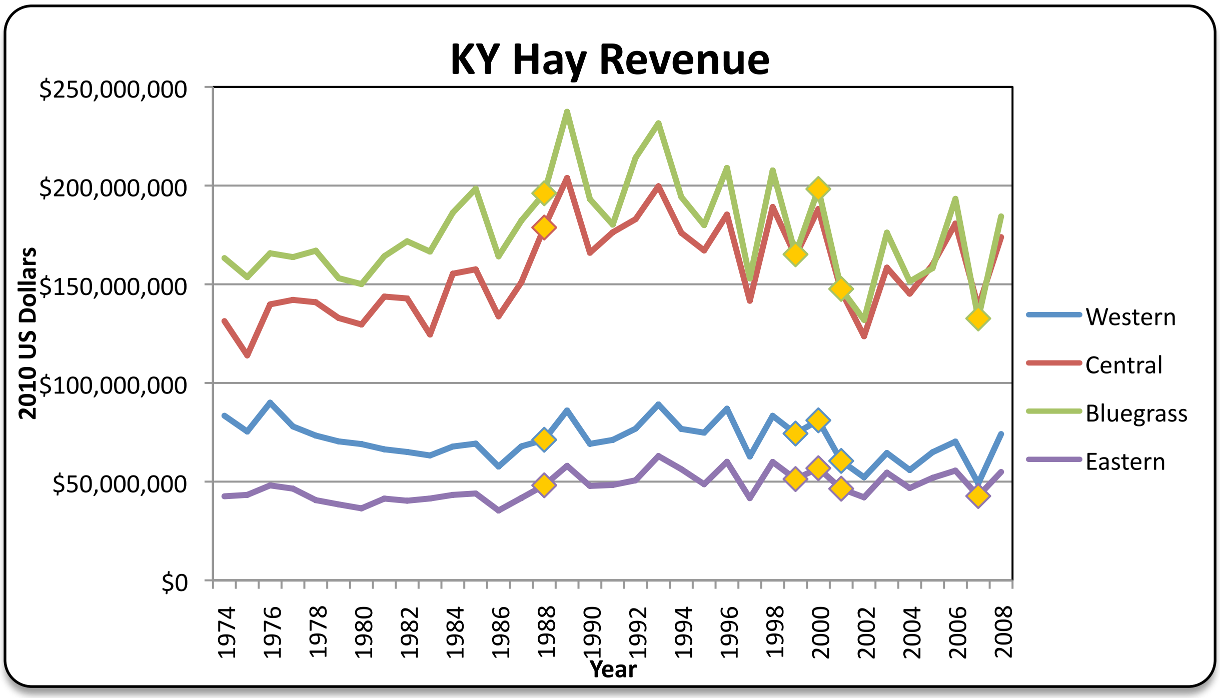


Figure 31. Kentucky Hay Revenue (Climate Divisions). Source: NASS 2010.

Hay data is avaliable at the state-level from 1929-2009 and is shown in Figure 32. As expected hay yield and production has been increasing throughout time. More efficient equipment and farming management have made it possible for farmers to produce more hay than in the past (Hayes and Klotter 2009). Hay production in Kentucky remained below 3,000,000 metric tons until the early 1980s. From there hay production began to drastically increase and in 2009 over 5,700,000 metric tons of hay were produced in Kentucky. Hay is an important source of livestock feed and a decrease in hay production will not only have reprecussions on the hay industry but on the livestock industry as well. Without enough feed, livestock body compositions will suffer and farmers may lose profits.

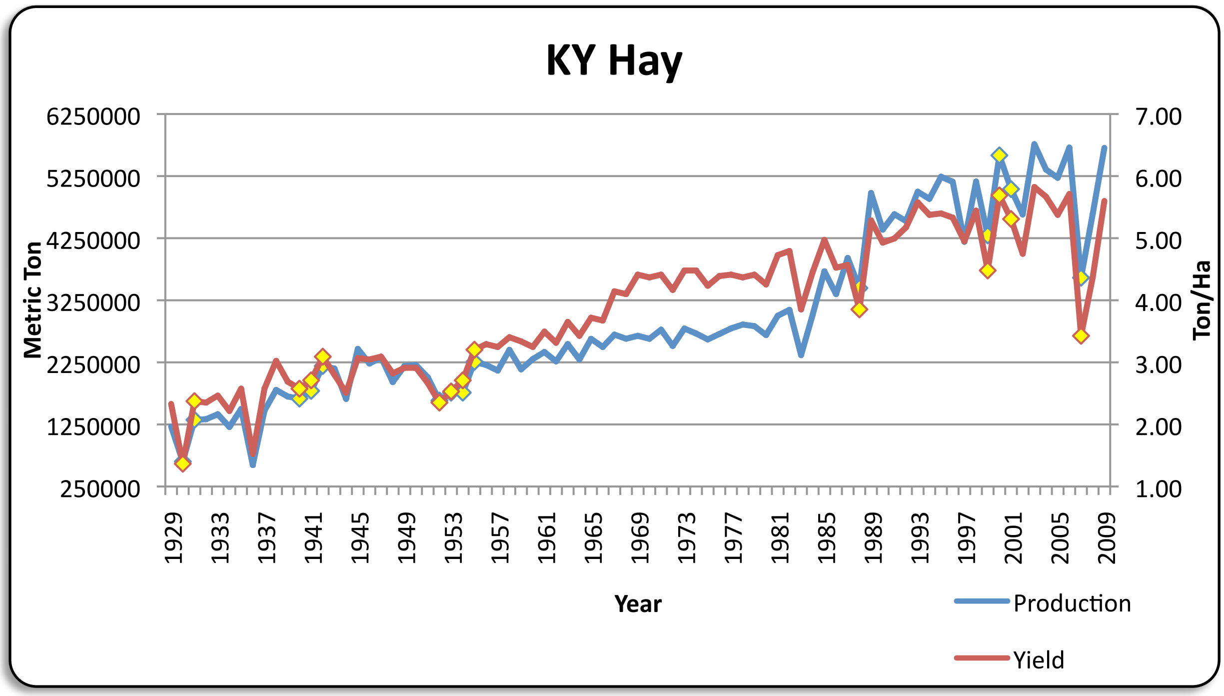


Figure 32. Kentucky Hay Yield and Production. Source: NASS 2010.

Since historical hay price data is only avaliable from 1949-2009, revenue can not be determined prior to that. Kentucky hay revenue can be seen in Figure 33. During the 1950s hay revenue averaged around $379,806,883. This average increased during the 1960s and 1970s but there was not a drastic incline until later. As expected hay revenue remained stable until around the 1980s. During the 1980s hay production began to increase drastically and as expected, revenue increased along with it. In the mid-1980s the state's revenue increased to over $460,000,000 and even reached over $580,000,000 in 1989 and 1993. One of the lowest revenue years in recent times occurred during 2007, which was a significant drought year.

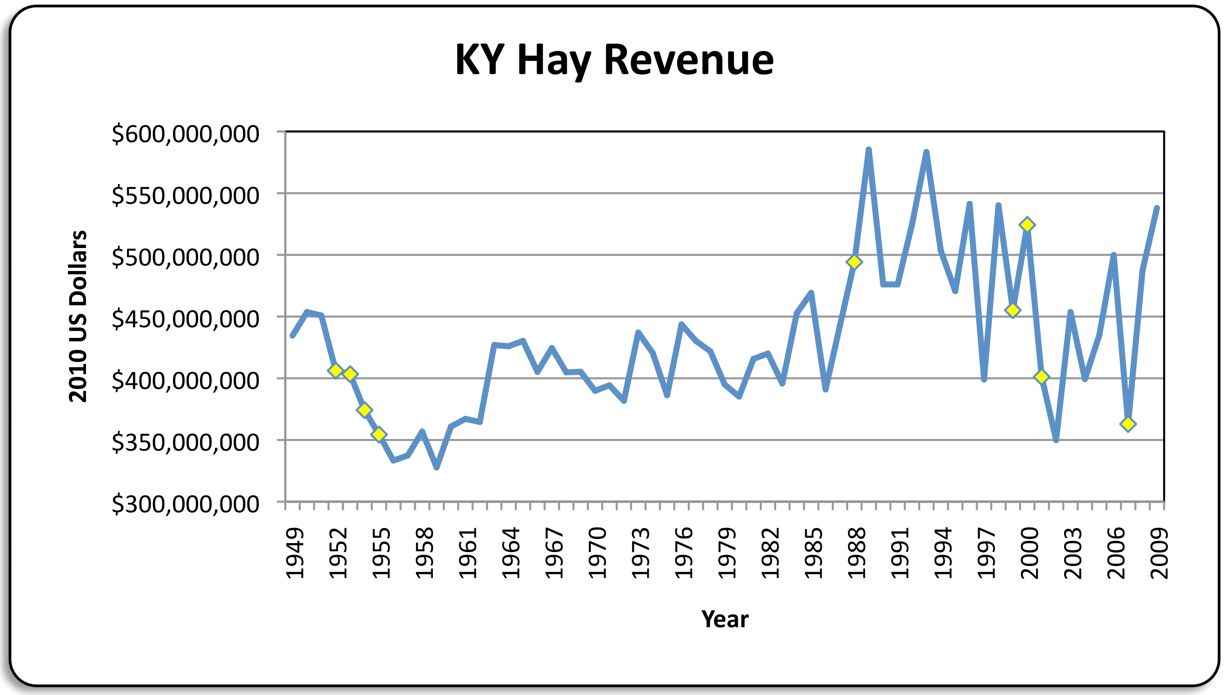


Figure 33. Kentucky Hay Revenue. Source: NASS 2010.

During 2002, there was approximately 979,359 hectares of hay harvested in Kentucky, of which approximately 162 of those hectares were completely irrigated (NASS 2010). In 2007 the number of hectares harvested increased to 1,084,580. During that year the number of hectares completely irrigated also increased to approximately 1,352 hectares. Though complete irrigation of hay crops are more commonly being used in recent times, the majority of Kentucky hay remains unirrigated or only partially irrigated. Perhaps, the complete irrigation of more Kentucky hay crops could help to reduce drought vulnerabilities in the future.

4.2.4 Beef Cattle

In 2010, Kentucky produced over 2,300,000 head of cattle; 1,070,000 of which are just beef cows (NASS 2010). Kentucky is the largest beef cattle producing state east of the Mississippi River and ranks 5th nationally in the total number of farms (Kentucky Cattleman's Association 2010). Like corn, soybeans, and hay, drought can negatively effect beef cattle production. Hot and dry conditions make it challenging for beef cattle to thrive. The avaliability of feed and water are important to cattle survival and in times of drought, proper livestock ranch management is necessary. Since decisions during a drought period are often made on emotion instead of logic, it is important to plan ahead inorder to make a ranch less sensitive to drought. For every rancher there are four important factors to consider. These factors include: estimating the duration of the drought, evaluating water and feed inventories, analyzing the body condition of the cow herd, and knowing the financial resources avaliable. If these factors can be addressed ahead of time, drought impacts can be severely reduced (Paterson et al. 2000).

Figure 34 shows Kentucky beef cattle production for the four climate divisions. The data ranges from 1977- 2009 and is measured in head. As can be seen in Figures 51-54, year to year flunctuation in the data is not as drastic as previously discussed commodities. However, there is some variation in beef cattle production from year to year and between climate divisions. The year of 1986 was the lowest production year for all climate divisions except the Bluegrass division, where it happens to be the second lowest year. In fact 1986-1988 were in the 10 lowest production years for all climate divisions. These years were also low hay production years for the state. It is likely that low hay production resulted in scarcity of feed for the beef cows which made survival difficult. This was also a warm and dry period leading up to the significant drought of 1988. The warm and dry conditions coupled by less hay for feed are the likely cause for beef cattle production being so low.

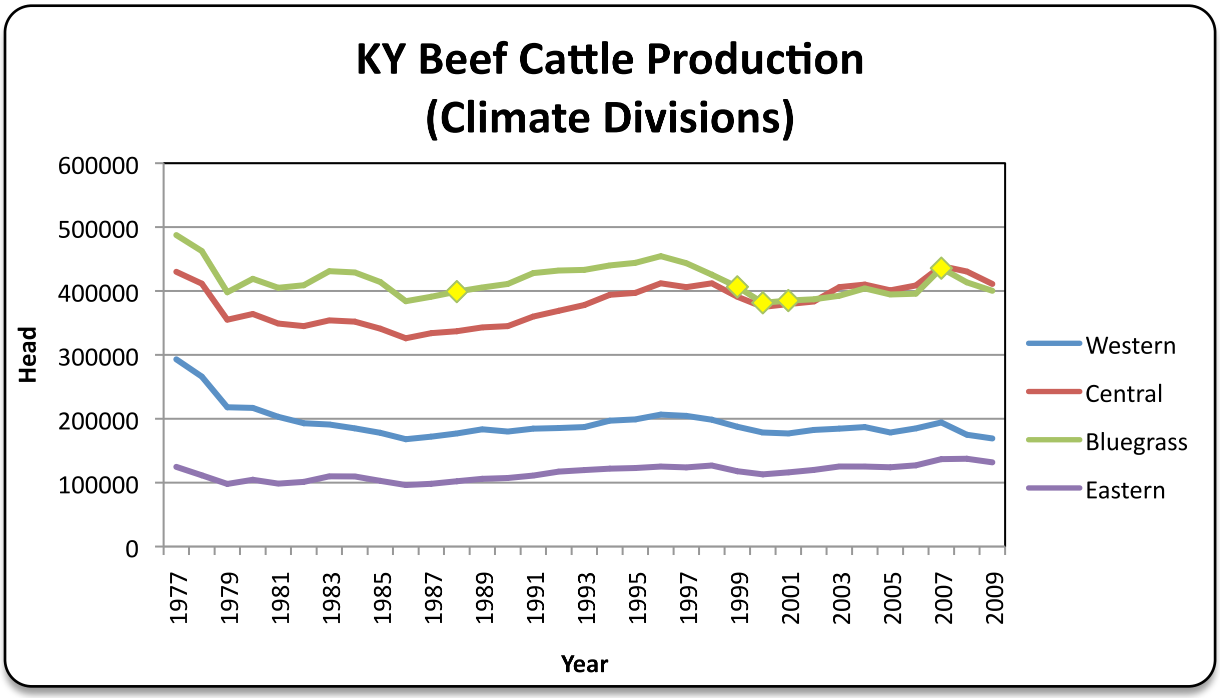


Figure 34. Kentucky Beef Cattle Production (Climate Divisions). Source: NASS 2010.

Kentucky beef cattle price data was more challenging to find than the other commodities. The span of data is also not as long as the other commodities. The avaliable data ranges from 1988-2007. Figure 35 shows prices received for Kentucky beef cattle (excluding calves) measured in dollars per counterweight. The year with the lowest prices was 1996, with an average price of $43.80/CWT. The year of 1996 was also the year of highest beef cattle production during this time period. The Western division produced 206,500 head this year. This was also a cooler year with plenty of precipitation, the mean annual temperature was 13.3°C and Kentucky received 1407.16 mm of precipitation. It is not surprising that 1996 had the lowest prices during this time period. The favorable weather made it easier for grains to grow and provided plenty of feed for the livestock.

The years with the highest prices occcurred in 2004-2007 and 2000-2001. It is expected for prices to be high in 2000-2001 and 2007 because those were significant drought years. It is likely that many beef cows could not survive the hot and dry weather. These were also low production and high price years for the other commodities examined as well. The years of 2004-2006 were also in the top 24 years with the highest annual mean temperatures. Production was also lower compared to neighboring years with totals ranging between 353,000-371,500 head. It is likely that drought is the cause of decreased production and higher prices.

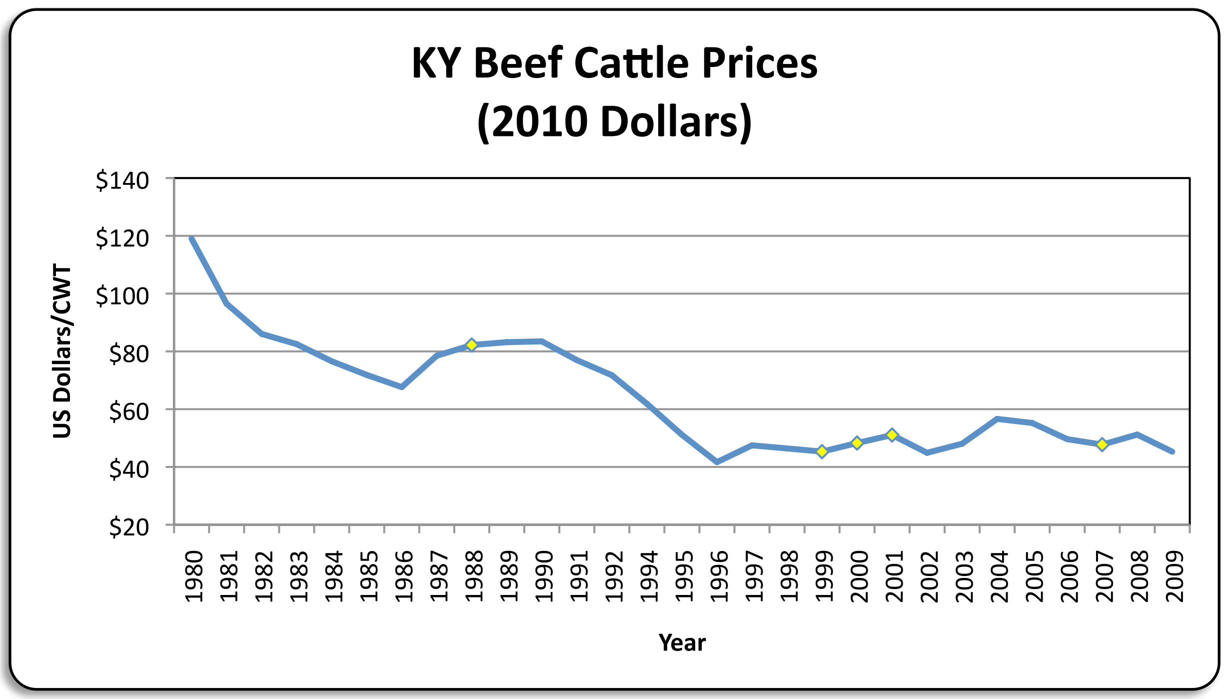


Figure 35. Kentucky Beef Cattle Prices. Source: NASS 2010.

Since the beef cows price data is measured in $/counterweight, the weight of each beef cow produced would have to be known in order to determine revenue. This information is not avaliable through the NASS where the beef cows production data was obtained. However, state level beef cows sales data is avaliable. Figure 36 is a graph showing Kentucky beef cows sales measured in head from 1988 to 2008. During the year of 2005, 481,000 Kentucky beef cows were sold. This is the lowest number of beef cows sold during 1988-2008. During that year the price of beef cows were around average with an approximate value of $55.23/cwt. If the weight of each of the beef cows that were sold was avaliable the revenue could be determined. However, we may be able to make some assumptions about the relationship between beef cows and drought from this data. The lowest number of heads sold during a severe drought year occurred during 2001. During that year the state sold 555,000 head of beef cows. This value is 214,000 head lower than the average head sold. In fact, all of the other significant drought year dating from 1988-2008 also expereinced lower than average total amount of heads sold. During the years of 1988, 2000, and 2001, production was lower than normal. Lower production results in there being less beef cows to sell, so it is expected that sales would be lower during these years. However, during 1999 beef cows production was moderate and during 2007, production was high. Perhaps, sales were not good during these years even though there was substantial production, because the decrease in hay production resulted in poor body composition of the beef cows. Since hay yield and production were low due to the drought, feed supplies were cut down and the body composition of beef cows suffered, making them to difficult to sell. Perhaps, we will learn more from the number of deaths of beef cows, that will be examined for the significant drought years later in the chapter.

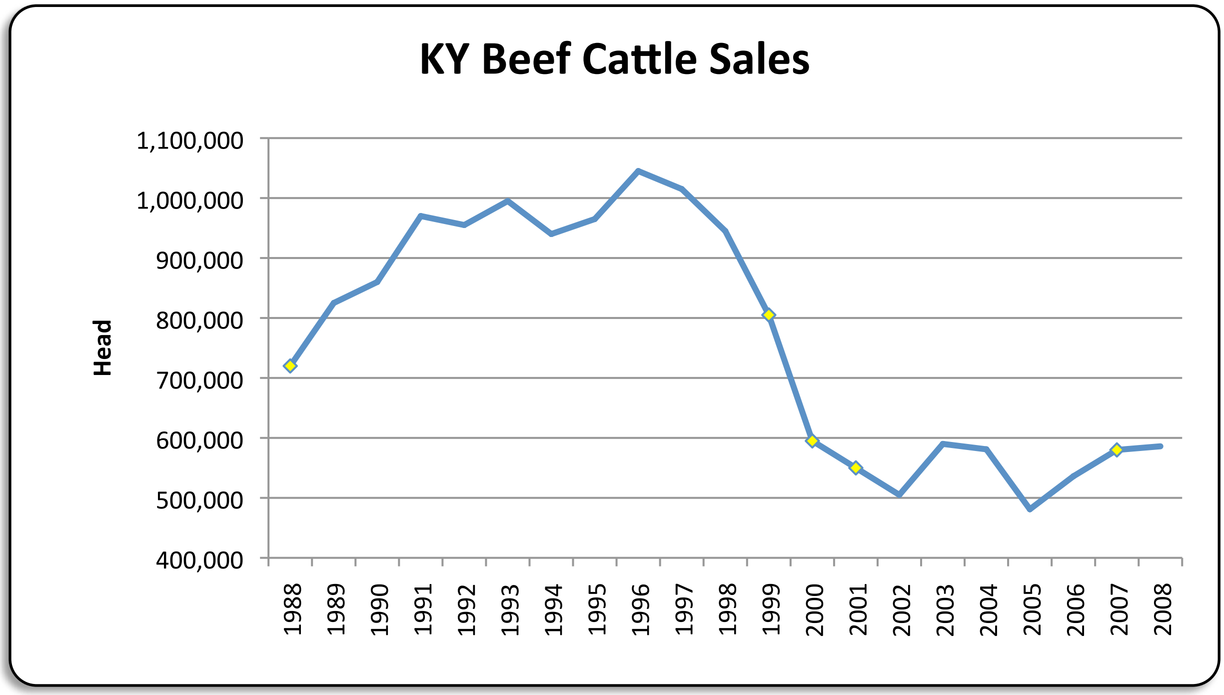


Figure 36. Kentucky Beef Cattle Sales. Source: NASS 2010.

4.4 Significant Drought Years

4.4.1 Drought of 1930-1931

The drought of 1930-1931 was perhaps the worst drought of the last century for Kentucky. The drought began to appear in the Northeast and upper Midwestern United States in 1930. During this time the Ohio Valley and regions of the Southeast experienced wet conditions. This wetness diminished quickly in February, and by time spring arrived in 1930, all of Kentucky's climate divisions were experiencing dry conditions. The year of 1930 was a warm year, with mean annual temperatures for all of Kentucky's climate divisions ranging from 13.1-14.6°C. It was also a dry year with annual precipitation totals ranging from 671-837 mm. The Western division had the highest annual precipitation total of 837 mm, while the lowest value of 671 mm belonged to the Bluegrass division (Figures 6-17). Typically in Kentucky the warmer months receive the most precipitation, but during 1930 the precipitation was lower during June-August than it was during the winter months. High temperatures and dry conditions made this drought severe. The drought started out as moderate in April and May, and turned to severe in the Central division in June. During July conditions worsened, three of the climate divisions were in the extreme category while the Western division remained severe. By time August rolled around all four of Kentucky's climate divisions were in the extreme drought category and remained there throughout the remainder of the year.

The start of the new year in 1931 did not bring any relief for the dry conditions. Winter precipitation coupled with lower evaporation rates can often bring some relief for drought conditions, but that wasn't the case in January of 1931 (USDA Yearbook of Agriculture 1931). However, precipitation amounts did increase from February through April, but not enough to compensate for the dry spell or replenish ground water. By the end of April 1931, drought conditions started to lessen in severity. Finally, by time December came around, three of Kentucky's climate divisions, excluding the Eastern division, were receiving normal rainfall.

The warm and dry conditions of the 1930-1931 drought caused hardships for Kentucky farmers. During these years corn yield and production were extremely low. In fact, 1930 was the lowest year for corn yield in all four climate divisions and 1931 was in the lowest 15 years. Of the four, the Central division experienced the lowest yield of 0.60 metric tons per hectare. The year of 1930 was also the lowest production year for the Western and Central divisions. Production totals ranged from 196,575 metric tons in the

Central division to 236,175 metric tons in the Western division. For the Eastern division, 1930 was a moderate production year. As discussed previously, corn production has been decreasing in the Eastern division since the 1950s. Therefore it is not surprising that 1930 wasn't the lowest production year, since poor soils and mountainous terrain have contributed to low production in this area.

Low corn production due to the drought caused economic hardships for Kentucky farmers. During 1930, the state generated a total of $322,255,395 (2010 dollars) from corn. During the year of 1931, Kentucky generated $393,072,561; giving the drought of 1930-1931 a combined total of $715,327,956 in corn used for grain revenue. As Figure 21 shows 1930-1931 were very low corn revenue years for the state. The average corn revenue year from 1930-1939 generates $615,241,808. This means that the year of 1930 caused a $292,986,413 deficit from the decade average, and the year of 1931 caused a $222,169,247 deficit. The combined years of 1930-1931 caused a deficit of $515,155,660 in corn revenue for Kentucky. As discussed previously, technology was not as advanced in the 1930's as it is today. This lack of technology contributes to low yields and production during this time. It is expected for corn revenue to be lower in 1930-1931 than in recent years because of the advancement in technology, but we can hypothesize that drought also played a role in decreasing corn production and revenue during this time as well because of the deviation from the 1930-1939 average.

County-level corn yield data is illustrated in Figure 37. The map shows local variation in corn yield across the state. In the image, the dark maroon counties experienced the highest yields and the pale yellow counties experienced the lowest. It is obvious that corn yield varies from county to county and during 1930, counties in the west and south-eastern parts of the state had the highest yields.

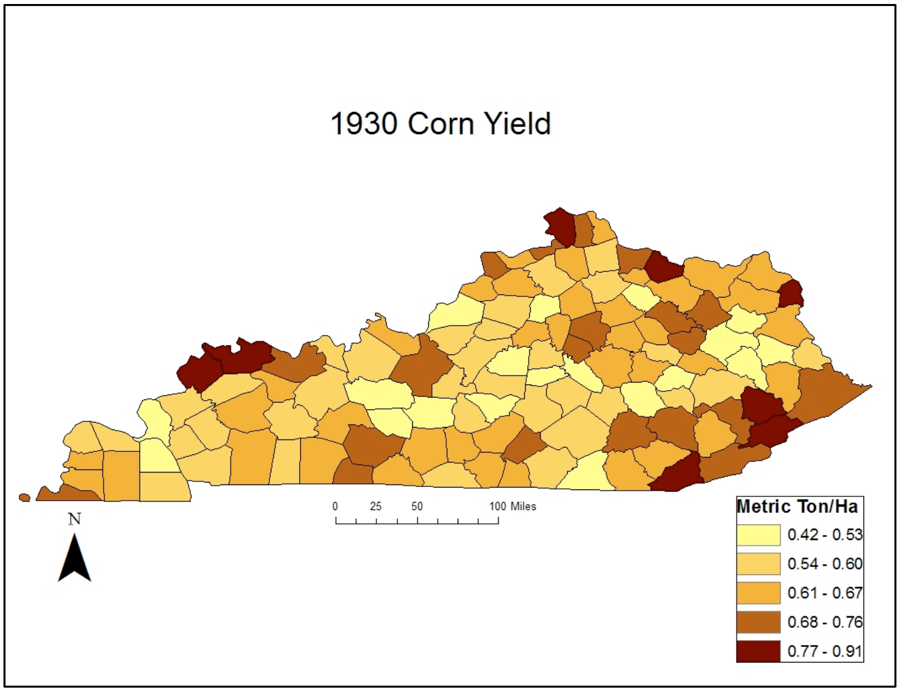


Figure 37. 1930 Kentucky Corn Yield. Source: NASS 2010.

The National Agricultural Statistics Service (NASS) does not have county-level soybean data avaliable for Kentucky before the year of 1981, making the local impacts of the 1930-1931 drought on soybeans difficult to determine. According to the USDA Yearbook of Agriculture (1930), soybeans were first introduced in the United States in 1804, but it wasn't until around 1920, that soybeans began to become appreciated. Production was beginning to reach commercial proportions in the US in 1930, and many farmers were starting to produce soybeans for oil, meal, industrial products, and human consumption. Since soybeans got a later start in terms of commercial production compared to corn, it is not surprising that annual county-level data was not collected until much later.

State level production data for soybean is avaliable through the NASS from 1929-2009. As disscussed previously, soybean production was flat until the mid-1960s. At that time, soybeans began to be a popular commodity because of its usage in many different products (Allmaras 1997). In 1930 soybean production was around 1,836 metric tons, which is 1,628 metric tons below the decade average. During 1931, production increased to 3,564 metric tons which is still low compared to recent times but is approximately 99 metric tons more than the decade average. Though price data is not avaliable for this time, it is expected that prices would be high due to scarcity.

County-level hay data is not avaliable until the 1970s, but state-level data production data is avaliable dating back until 1929. During this time period, the the year of 1930 was the second lowest hay production year for the state. That year Kentucky only produced 651,226 metric tons of hay. This amount is 649,049 metric tons lower than the decade average. During 1931, production increased from the previous year by a total of 672,087 metric tons. This gives the year of 1931 a production total of 1,323,313 metric tons, which is actually 23,037 tons higher than the decade average. Hay price data is not avaliable until 1949, making it difficult to determine hay revenue during this time period. However, an article was printed in the USDA 1931 yearbook about the impacts of the 1930-1931 drought on agriculture in the U.S. According to the article the drought spread from the Mid-Atlantic states to the Ohio and Mississippi valleys in the Spring of 1930. In June and July the drought spread to the southcentral states, especially those in the low

Mississippi valley. Precipitation in the spring and summer was the lowest on record for West Virgina, Kentucky, Indiana, Illinois, and Missouri. The drought did not come early enough in Kentucky to severely impact yields of wheat, oats, or barley. However, almost all nonirrigated crops growing late in the season were affected. Hay and pasturage were among the crops affected the most. It was estimated that hay production was down approximately 16 percent from 1929, and 10 percent from the average of the previous 5 years. Many farmers had little hay to sell and they had to stirctly ration hay for livestock feeding. The low production and poor quality brought a sharp decline in demand for many commodities, which forced farmers to sell at low prices. This developed into a world-wide economic depression that was felt by states experieincing the drought and those outside of the drought as well. Many farmers hoped that the scarcity of hay would result in a shortage of feed for livestock, which would reduce the supply of meat products and bring about a rise in the price of beef cows and cattle commodities. However, this trend had not yet been seen in the spring of 1931 (USDA 1931).

4.3.2 Drought of 1940-1942

During the fall of 1939, drought spread from the Midwestern and Northeastern United States into Kentucky. The annual PDSI for this year ranged from -0.71-0.62. The Eastern division had the most severe annual PDSI while the Bluegrass division was the only division with a positive annual PDSI. Some relief did come in the spring of 1940, but the drought quickly reintensified in the summer and fall. The drought reached its peak intensity in Kentucky in May of 1941, in which annual PDSI values ranged from -4.48 in the Western division to -3.60 in the Bluegrass division. In June of 1942 the drought finally came to an end and normal precipitation amounts were received across the state.

The years of 1940-1942 were among the 20 lowest years for corn yield across the state. Each climate division suffered low yields during this time period and the Western, Central, and Bluegrass divisions suffered low production as well. The year of 1940 was the most severe during the three year period in terms of corn yield; the Eastern division had the lowest average yield of 1.33 metric tons per hectare. The Central division had the second lowest average yield of 1.52 tons per hectare, closely followed by the Western division with 1.54 tons per hectare, and the Bluegrass division with 1.71 metric tons per hectare. Corn production did not fare much better, the year of 1940 was the 6th lowest production year for the Western division producing only 556,075 metric tons of corn. It was also in the 30 lowest years for corn production for the Central and Bluegrass regions producing 447,925 and 281,275 tons. The year of 1940 was actually a high corn production year for the Eastern division. In fact it was the 7th highest year for corn production from 1929-2009, producing 313,350 tons. As discussed previously, corn production in the Eastern climate division has decreased throughout time so it is not surprising that earlier years would be the highest production years for the climate division.

The years of 1941-1942 were slightly better years for corn than the previous. Average yields across the state ranged from 1.47-2.06 tons per hectare in 1941, and 1.62-2.06 tons per hectare in 1942. The Western division is the highest corn producing division for the state of Kentucky. During 1941 it only produced 663,825 metric tons.

This is 35,341metric tons less than the decade average production for the Western division of 699,166 metric tons. In the Central division, total production for 1941 was 14,986 metric tons lower than the decade average. The Bluegrass division produced 338,373 metric tons of corn during this year. This amount is 1,152 metric tons lower than the decade average. The Eastern divisions experienced higher than average corn production during this year. It produced 322,100 metric tons of corn that year, which is 14,436 metric tons greater than the decade average. These variations between climate divisions show how drought varies geographically and temporally.

Since corn production in the Western division deviates the most from its average, it is expected that the years of 1940-1942 would be ranked the lowest in terms of corn revenue in the Western division compared to the other divisions as well. Referring back to Figure 19, this assumption proves to be true. The year of 1940 is ranked as the 16th lowest corn revenue year for the Western division. During this year the Western division generated $252,797,256 from corn. This amount is $195,163,070 less than the decade average corn revenue amount for the Western division. For the other climate divisions, 1940 was ranked in the 40 highest corn revenue years and was even the 14th highest year for the Eastern division. Combined the state of Kentucky generated $726,750,911 (2010 dollars) in corn revenue.

In 1941 the state generated $950,007,600 (2010 dollars) from corn. This amount is $226,076,487 lower than the average for the 1940's. The year of 1942 generated $1,187,626,322; which is $11,542,235 higher than the average for that decade. It is likely that revenues during this year is higher than average because production was higher than average in the Bluegrass and Eastern divisions. Corn prices were also among their highest during this time. Although the Western and Central divisions suffered from low corn production due to the drought, the other half of the state had higher than average productions which allowed revenue to stay high. Also, many other states were affected by the drought and it is likely that Kentucky farmers could sale their corn at higher prices to out of state consumers.

As mention previously, soybean, hay, and beef cattle data are not available at the county level via the NASS before the 1970s; however, state totals are available for soybeans and hay. In the year of 1940, Kentucky produced 10,881 metric tons of soybeans. This amount is 24,802 metric tons lower than average production from 1940-1949. During the year of 1941, soybean production increased to 15,876 metric tons, a value that is 19,807 metric tons lower than average. As expected, soybean production increased even more during the dissipation of the drought. During the year of 1942, soybean production increased to 32,508 metric tons, which is still 3,175 metric tons less than the average from 1940-1949.

Kentucky generated $7,601,467 from soybean in 1940. This is the lowest revenue year on record from 1940-2009. This amount is $25,906,461 lower than the average soybean revenue for the 1940s. During 1941, soybean revenue nearly doubled, generating a value of $14,901,055. Though this value is a major increase from 1940, it is still $18,606,073 below the average for that decade. Soybean revenue continued to increase during 1942, generating $25,949,511; which is $7,558,417 lower than the decade average.

During the year of 1940 Kentucky produced 1,666,159 metric tons of hay. This value made 1940 the 12th lowest hay production year in Kentucky from 1929-2009. This value is 394,635 metric tons less than the average for that decade. Hay production improved during 1941 to a value of 1,790,418 metric tons. Though this is an improvement from the previous year, this value is still 270,376 metric tons less than the decade average. As the drought came to an end hay production continued to increase. During 1942 hay production was the highest amount during the three year drought period. During that year the state produced 2,191,312 metric tons of hay, which is 130,517 metric tons higher than the average for the 1940's.

4.3.3 Drought of 1952-1955

The drought of 1952-1955 had a long duration for many states in the southern U.S. By June 1952 the drought had spread across all of Kentucky. Kentucky's temperatures were high throughout June and July, and most stations reported temperatures higher than 37.7°C (US Department of Commerce 1952). Some relief did come to Kentucky in the spring of 1953, but did not last long. The drought reintensified that summer and did not dissipate in Kentucky until February 1955. Figures 58-73 show monthly PDSI values for the 1952-1955 drought. In Kentucky, all climate divisions started out moderately – mostly moist during the spring of 1952. By time summer occurred, this pattern changed to a midrange pattern that developed into a moderate drought by September 1952. Two months later and all of Kentucky except the Eastern division were in a severe drought. This pattern continued into spring of 1953. Some relief did arrive during June 1953 but the drought ramped back up during the fall and by December 1953, all of Kentucky was in an extreme drought.

The majority of Kentucky remained in a state of extreme drought for most of 1954. During October 1954, the Western and Central division fell to the severe drought category and the Eastern division fell to a moderate drought. This left the Bluegrass division as the only division still experiencing an extreme drought. Conditions improved during 1955, but at the end of the year, the Western and Eastern divisions were back into a severe drought episode.

In 1952 Kentucky produced 1,460,200 metric tons of corn. This amount ranks 1952 as the 7th lowest production year for corn in Kentucky. As discussed previously, when production is low, prices are expected to be high. The year of 1952 is no exception to this assumption, the price of corn during this year was approximately \$549/metric ton (2010 dollars). This amount is the 10th highest price for corn in Kentucky from 1929-2009. During this year the state generated \$802,292,288 from corn. This amount is \$36,464,082 less than state average from 1950-1959, and is a \$408,121,064 decrease from the previous year of 1951.

The short drought relief in the spring of 1953 did slightly help corn production. During this year the state produced 1,777,650 metric tons of corn. This is a 317,450 metric ton increase in production from 1952. Prices during the year of 1953 decreased from the previous year due to higher production. The average price of corn in Kentucky during 1953 was approximately \$489.81/metric ton. This amount is \$60.18 lower than the 1952 price, but it is still among the top 20 highest corn prices for Kentucky. During 1953, Kentucky generated \$870,710,746 from corn. This is a \$68,418,468 increase from 1952, and \$31,954,376 larger than the decade average.

Corn production did not improve much during the last two years of the drought. Yields remained low for all climate divisions and production did not fare much better. During the year of 1954, total production was less than the previous year. There was no relief from the drought this year like there was during 1953 which caused production to be lower. During this year Kentucky produced 1,777,650 metric tons of corn. This amount is 21,260 metric tons lower than the decade average. Though production was less during this year, prices were slightly lower than the previous year. The average price of corn during 1954 was $473.21/metric tons. Though it is expected that prices are higher during lower production, the price and production of corn in 1954 was lower than in 1953. This could be because the quality of corn was very poor as the drought's duration lagged on, that farmers could not sell corn at a higher price during 1954. During this year the state generated $762,431,670 from corn, the lowest revenue value for the years of 1952-1955 and $76,324,699 less than the decade average.

During the last year of the duration of the drought, the state produced 1,976,550 metric tons of corn. As expected, production was the highest during this year because of the offset of the drought. Prices were also at their lowest during the drought with a value of approximately $422.92/metric ton. During this year the state produced $835,922,526 from corn, making it the second highest revenue year from 1952-1955. The year of 1953 generated the most revenue during the drought. Though production was lower in 1953 than in 1955, prices in 1953 were higher, which resulted in higher revenue. Though 1955 was the second highest revenue year during the drought, it is still $2,833,843 less than the decade average.

Soybean production for the drought of 1952-1955 was extremely low. Data is not available at the county-level during this time but state totals are available. During the year of 1952, the state produced 47,304 metric tons of soybeans. This amount is 23,292 metric tons below the decade average and resulted in the state generating $42,555,151.

This amount is $18,369,498 lower than the revenue of the previous year and $8,920,535 lower than the average from 1950-1959. Conditions worsened during 1953, that year the state produced 38,637 metric tons of soybeans. The total production for that year decreased 8,667 from the previous year, and 31,959 metric tons from the average. Luckily, production increased during the remaining two years of the drought. In 1954, the state produced 57,915 metric tons. This year the state generated $47,377,945 from soybeans. Though this is an increase from the previous two years, revenue for that year was $4,097,741 below the average. Production continued to increase during the last year of the drought. During 1955 the state produced 65,124 metric tons of soybeans. However, the increase in production caused prices to drop to its lowest price during the four year drought period. Revenue for that year totaled $45,622,618, which is $5,053,068 below the decade average. This value is also slightly lower than the previous year due to the drop in price.

Hay production during 1952-1955 was extremely low for the state. Of these years the year of 1952 experienced the lowest production total. During this year the state only produced 1,634,414 tons of hay. This value ranks 1952 as the 10^{th} lowest year for Kentucky hay production from 1929-2009. During this year the state generated $406,168,223 in hay revenue. This amount is $26,361,340 higher than the decade average. Production increased by 127,887 metric tons during 1953 from the previous year. That year the state produced 1,762,301 tons of hay, which is 292,326 metric tons lower than the 1950's decade average. Revenue decreased from the previous year but still remained above the decade average by $23,530,947. Hay production continued to increase for the remaining two years of the drought while revenue began to decrease.

During 1954 Kentucky produced 1,762,301 metric tons of hay and 2,258,430 tons in 1955. Though these totals are a vast improvement from the previous two years, the production total for 1954 is still 292,326 less than the decade average. Prices decreased during this year due to the increase in production and revenue fell $5,547,019 below the decade average. During 1955, the drought began to dissipate and Kentucky experienced above the decade average production. Since there was an abundance of hay available that year, prices decreased and revenue dropped to $25,391,463 below the decade average.

4.3.4 Drought of 1987-1988

The drought of 1987-1988 started along the west coast and extended into the northwestern United States. By the beginning of 1988, the drought intensified over the Great Plains and spread to most of the eastern part of the U.S. In Kentucky, the drought reached its peak during the summer of 1988. That summer was particularly hot and dry across the state and conditions did not improve until the fall season of that year (NOAA 1992). The 1980s drought is known as the most costly in U.S. history. The loses of energy, ecosystems, water, and agriculture are estimated to cost around $39 billion (Riebsame et al. 1991).

During the year of 1987, Kentucky produced 2,960,822 metric tons of corn. This was a 533,603 metric ton decrease from the production during 1986. Though production was lower than the previous year, 1987 was a high year for corn production in Kentucky. In fact, 1987 is in the top 30 years for highest corn production from 1929-2009. During this year the state generated $459,016,157 from corn. This amount is $204,037,240 lower than the average corn revenue for the 1980s. The year of 1987 was among the lowest corn price years with a value of $142.32/metric ton. It is likely that since production was high, there was a higher supply of corn than demand which caused prices and revenue to be low.

The drought of 1987-1988 intensified during the summer of 1988. Since the drought was more severe during 1988, it is expected that corn would be impacted more than in 1987. During 1988 corn yield and production was much lower than in 1987. This year the state produced 2,004,958 metric tons of corn, a 955,863 ton decrease from the previous year. The lower production caused prices to increase to $203.41/metric ton, a $48.38 increase from 1987. However, the increase in price could not make up for the lower production and the state only generated $407,828,506 from corn. This amount is a $51,187,650 decrease from the revenue of 1987 and $255,225,590 decrease from the decade average.

Corn quality during the growing season of 1987 and 1988 can be seen in Tables 3-4. The majority of corn quality during the year of 1987 was classified as being in good condition. There was also a high percentage of corn that was considered to be in fair condition throughout the year. During weeks 36 and 37, corn quality experienced a higher percentage of corn in poor condition. As the drought intensified into 1988, the percentage of excellent corn condition diminished. In fact, Kentucky corn was only considered to be in excellent condition during weeks 21 and 22 of that year. During the 27th week of that year, 50% of corn quality was considered to be very poor in Kentucky and 0% was considered to be excellent or good. The majority of corn stayed in the poor quality region until week 32 when 53% of corn was considered to be fair, but still 0%

was considered excellent and only 5% was considered to be good. As time progressed and the end of the growing season approached, there was a higher percentage of fair quality corn for Kentucky, but the percentage of excellent and good quality corn remained low.

Table 3. 1987 Corn Quality. Source: NASS 2009.

Week #	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
% Excellent	4	2	9	4	10	7	14	26	29	22	15	17	7	12	6	9	11
% Good	47	52	58	46	48	55	53	59	55	60	66	59	65	68	67	63	62
% Fair	44	42	33	45	37	37	31	13	15	18	18	21	25	18	23	18	21
% Poor	3	4	0	5	5	1	2	2	1	0	1	2	1	1	2	8	6
% Very Poor	2	0	0	0	0	0	0	0	0	0	0	1	2	1	2	2	0

Table 4. 1988 Corn Quality. Source: NASS 2009.

Week #	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
% Excellent	3	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
% Good	62	43	27	8	3	2	0	0	3	5	8	5	4	6	6	14
% Fair	32	43	62	60	42	30	12	16	22	31	38	53	42	44	43	37
% Poor	3	9	9	22	38	27	38	49	53	46	42	33	37	39	41	39
% Very Poor	0	1	2	10	17	31	50	35	22	18	12	9	15	13	10	10

County-level corn yield data during 1988, is illustrated in Figure 38. Several counties in the eastern part of the state are left blank because county-level data is not available for those counties during that year. The map shows that the counties with the highest corn yields during 1988 occurred in the western part of the state. There is also a cluster of counties in central-Kentucky, where corn yield is higher than neighboring counties. Counties in the northern and eastern part of the state experienced yield totals much lower than the rest of the state.

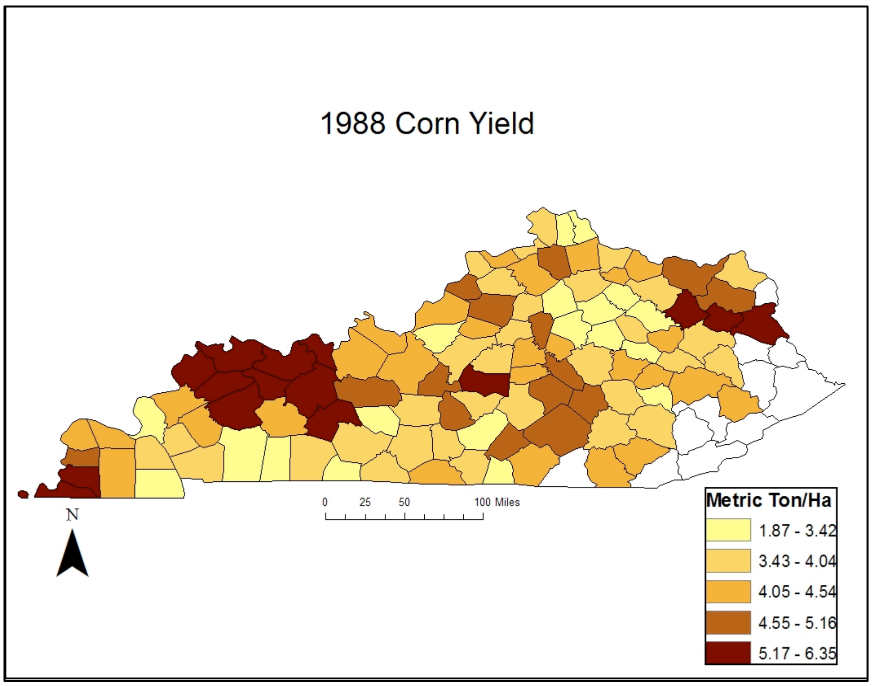


Figure 38. 1988 Kentucky Corn Yield. Source: NASS 2010.

Kentucky soybean during the drought of 1987-1988 has a similar story to that of Kentucky corn in terms of yield and production. During 1987 the state produced 735,136 metric ton of soybean. This year was among the seven lowest soybean production years for Kentucky from 1972-2009. The year of 1988 was even worse in terms of soybean production, with a total of only 650,012 metric tons. During 1987, the state generated $367,536,002 from soybean, which is $196,569,985 less than the decade average. Though production was lower in 1988 than in the previous year, prices were approximately $560/metric ton higher. The higher price made total revenue for 1988 higher than in 1987. During 1988, the state generated $367,536,002 in soybean revenue, a value that is $164,138,263 less than the decade average.

During the year of 1987, soybean quality was mostly considered to be in good or fair condition (Table 5). During weeks 35-41 soybean quality began to diminish and during week 38, 35% of soybeans were considered to be in poor condition and 10% were in very poor condition. As the drought progressed into 1988, 0% of soybeans were in excellent condition until weeks 36 and 37 (Table 6). During weeks 26 and 27, 0% of soybeans were in excellent or good condition. These are the only two weeks in which there were 0% of soybeans in good condition. Soybean quality reached its poorest conditions during week 27. During that week 44% of soybeans were considered to be in poor condition, and 22% were in very poor condition. Very poor conditions continued until around week 34, when the percentage of poor soybean quality decreased. Though conditions did improve towards the end of the growing season, the majority of soybeans remained in the fair condition category.

Table 5. 1987 Soybean Quality. Source: NASS 2009.

Week #	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
% Excellent	1	1	8	1	11	12	7	4	8	3	0	0	0	0	0	3	0	0
% Good	36	55	37	48	60	54	52	58	58	50	53	33	18	19	14	9	15	8
% Fair	52	35	52	50	28	31	41	38	33	42	40	52	52	48	41	53	48	45
% Poor	11	9	3	1	1	3	0	0	0	5	6	14	26	30	35	25	29	39
% Very Poor	0	0	0	0	0	0	0	0	1	0	1	1	4	3	10	10	8	8

Table 6. 1988 Soybean Quality. Source: NASS 2009.

Week #	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
% Excellent	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4
% Good	24	3	4	0	0	5	16	25	34	37	13	28	39	27	31
% Fair	55	53	39	42	34	53	58	64	62	47	61	63	57	61	57
% Poor	17	32	43	38	44	31	25	10	3	16	14	9	4	8	7
% Very Poor	4	12	14	20	22	11	1	1	1	0	12	0	0	3	1

Hay production during the 1987-1988 drought was below the average. During 1987, Kentucky produced 3,932,299 metric tons of hay. This value is actually 572,863 metric tons above the average for that decade. As the drought intensified so did the impacts on Kentucky hay. In 1988, the state produced 3,447,235 metric tons of hay. This amount is 485,063 metric tons lower than the previous year and 87,800 metric tons above the decade average. Since production was greater during 1987, prices were lower. During that year the average price of Kentucky hay was $112.63/metric ton. As conditions worsened into 1988 and production decreased, farmers were able to sale their hay at higher prices. During 1988 the average price of hay increase to approximately $143/metric ton.

During the year of 1987, beef cattle production was its second lowest value between 1986 and 2008. During that year, the state produced 9,952,000 head of beef cows. This value is 110,612 head less that the average. Production did increase during 1988 with a value of 1,015,200 head; but remained 90,612 head below the average. Also during the year of 1988, 43,000 beef cows died. The deaths of these beef cows are likely due to heat exhaustion and scarcity of feed due to decreased hay production. Though we could not determine the revenue of beef cows without knowing their weights, we can conclude that drought cost Kentucky beef cows farmers money by causing beef cows mortalities.

4.3.5 Drought of 1999-2001

The year of 1999 started out as a moderately dry year for Kentucky and conditions quickly intensified into the summer and fall. By November 1999, most of Kentucky was in the severe drought category, while the Bluegrass division was experiencing an extreme drought. Dry conditions continued across the state until some relief came during the fall of 2000. However this relief did not last long, as the Bluegrass division progressed into a severe drought and other divisions were in a moderate drought during the spring of 2001. Finally the drought began to dissipate and wetter conditions prevailed during the fall and winter of 2001.

During the 1999-2001 drought, the year of 1999 suffered the lowest corn production. That year the state of Kentucky produced 3,090,255 metric tons of corn. This amount is 243,166 metric tons below the decade average. The year of 2000 was better for corn production with a total of 3,990,843 metric tons, but conditions worsened for 2001 with a total of 3,893,383. Though 1999-2001 were significant drought years, production was much higher than years in the past. This is mainly due to the improvement in technology, and more advanced seeds that are drought resistant. High production resulted in low prices, during these years Kentucky corn prices were among their five lowest. As a result, corn revenue was among the 13 lowest years in Kentucky. During 1999 the state generated $341,225,957 from corn, a value that is $152,233,141 below the average for the 1990's decade. The year of 2000 had higher production and a slightly lower price, with a difference of approximately $6.00/metric ton. During this year the state generated $418,280,202 from corn, a $89,820,712 decrease from the decade average. The last year of the drought had lower production than the previous but more than in 1999. During 2001 Kentucky produced 3,983,383 metric tons of corn. Prices during this year were extremely low with an average of $102.46/metric ton. This low price made the year of 2001 the 8th lowest corn revenue year for Kentucky, with a total of $398,915,971. This amount is $109,184,944 below the average corn revenue from 2000-2009.

Corn quality during 1999 started out in mostly excellent and good condition until week 30, when quality started to decrease. During weeks 30-37 the percentage or corn in excellent condition decreased from approximately 20% to around 5%. The percentage of good quality corn also decreased, and more corn was considered to be fair, poor, or very poor. During 2000, the percentage of corn in excellent condition increased from the end of the growing season of the previous year. During this year most weeks experienced 20-35% of excellent quality corn. However, there was still around 20% of corn that was only in fair condition throughout most weeks and all of the weeks had corn in the poor quality range. It seems that soybean conditions did improve from the previous year, since only 6 weeks during 2000 had soybeans in very poor condition. During 2001, the majority of soybeans in excellent condition ranged from 20-30%. This year, the majority of soybeans were in good or fair conditions, but all weeks experienced poor quality and some experienced very poor quality. As the weeks progressed soybean quality did improve and by the end of the growing season, approximately 80% of soybeans were in excellent or good condition (Tables 7-9).

Table 7. 1999 Corn Quality. Source: NASS 2009.

Week #	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
% Excellent	29	22	21	25	19	32	27	25	20	5	4	4	3	5	8	6	8
% Good	55	56	57	55	59	52	56	56	49	48	30	34	34	30	38	35	38
% Fair	14	20	17	17	19	14	13	16	22	28	43	38	38	40	32	36	29
% Poor	2	1	5	3	2	1	3	2	8	14	17	17	20	18	17	15	15
% Very Poor	0	1	0	0	1	1	1	1	1	5	6	7	5	7	5	8	10

Table 8. 2000 Corn Quality. Source: NASS 2009.

Week #	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
% Excellent	19	26	23	19	24	34	32	40	33	28	24	30	30	31	36	36	31	33
% Good	61	55	60	59	49	47	42	43	43	46	45	46	45	45	42	42	43	45
% Fair	17	17	14	19	24	17	13	14	18	20	23	19	20	19	18	17	21	18
% Poor	3	2	3	3	2	2	3	3	6	5	7	4	4	4	4	5	5	4
% Very Poor	0	0	0	0	1	0	0	0	0	1	1	1	1	1	0	0	0	0

Table 9. 2001 Corn Quality. Source: NASS 2009.

Week #	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
% Excellent	8	11	16	20	28	25	21	21	21	23	29	28	30	32	29	29	34	33
% Good	44	54	58	55	56	57	59	58	47	54	53	45	47	50	51	47	47	47
% Fair	37	28	21	23	14	15	16	17	17	22	14	17	20	17	17	16	17	17
% Poor	8	5	4	2	2	3	4	4	4	6	3	2	4	2	3	3	2	2
% Very Poor	3	2	1	0	0	0	0	0	0	2	0	0	1	1	1	0	1	1

Soybean yield and production were also low during the year of 1999. The average yield during that year was approximately 1.41 metric tons per hectare, which is 0.61 metric tons per hectare lower than the average. Total production for the year of 1999 was 655,279 metric tons. Though it is expected that prices would be high during this year due to low production, prices were extremely low, at a value of $253.17/metric ton. Perhaps, this is due to very poor quality and though soybeans were scarce in Kentucky, the poor quality kept farmers from being able to raise prices. Low production and prices resulted in the year of 1999 being the lowest soybean revenue year for Kentucky from 1980-2009. During that year the state only generated $165,897,035 from soybean, causing a $210,101,810 deficit from the 1990's decade average.

The years of 2000-2001 were much better in terms of soybean yield and production for Kentucky. The average yield in 2000 was approximately 2.62 metric tons/hectare and approximately 2.69 metric tons/hectare in 2001. Production increased significantly from 1999 to 2000. During 2000 Kentucky produced 1,216,920 metric tons of soybean, a 561,641 metric ton increase from the previous year. The year of 2001 fared even better for soybean production, with a total of 1,311,771 metric tons. However, the increase in production did not yield significantly higher revenues. During 2000-2001, prices remained low and revenues were among lowest years in recent times. The state generated $290,661,270 from soybean in 2000 and $289,284,792 in 2001. These totals put the year of 2000 at $133,950,171 below the average from 2000-2009, and the year of 2001at $135,326,649 below the average.

Soybean quality during 1999 started out as mostly in excellent or good quality. As time progressed conditions started to worsen and the percentage of soybeans in excellent condition began to diminish. By week 30, only around 4% of soybeans were in excellent condition, and the percentage of soybeans in fair and poor conditions began to increase. Some weeks even experienced over 20% of soybeans in very poor condition. This trend continued through the beginning of the growing season in 2000. The percentage of excellent condition soybeans decreased from the beginning of 1999. During that year the majority of soybeans stayed in good quality but most weeks experienced around 20% of soybeans in fair quality. During this year, every week had soybeans in the poor quality category and 6 weeks experienced very poor quality. Those weeks that did experience very poor quality, only ranged from 1-2%. This is a big improvement from the previous year, when several weeks experienced over 20% of very poor quality soybeans. Conditions during 2001 started out slightly poorer than the previous year. During 2000, almost every week had soybeans in very poor condition. However, towards the end of the growing season, conditions did improve and the percentage of corn in excellent condition increased to around 35% (Tables 10-12).

Table 10. 1999 Soybean Quality. Source: NASS 2009.

Week #	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
% Excellent	21	21	23	17	29	30	27	15	4	3	2	0	2	1	1	3	1	2
% Good	60	54	58	57	52	50	51	54	42	26	19	13	12	16	8	15	11	15
% Fair	18	19	16	23	16	16	17	26	34	39	41	39	32	30	29	24	27	25
% Poor	1	5	2	3	2	3	4	5	15	24	28	32	33	28	33	31	36	35
% Very Poor	0	1	1	0	1	1	1	0	5	8	10	16	21	25	29	27	25	23

Table 11. 2000 Soybean Quality. Source: NASS 2009.

Week #	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
% Excellent	14	12	14	21	28	33	30	26	25	22	29	24	27	26	30	23	26	23	25
% Good	67	69	67	58	54	52	52	51	47	42	47	52	48	48	47	45	43	48	50
% Fair	17	16	17	19	15	14	17	20	23	28	20	19	20	21	20	26	28	26	23
% Poor	2	3	2	2	3	1	1	3	4	6	3	4	5	5	2	5	3	2	2
% Very Poor	0	0	0	0	0	0	0	0	1	2	1	1	0	0	1	1	0	1	0

Table 12. 2001 Soybean quality. Source: NASS 2009.

Week #	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
% Excellent	11	13	18	16	18	15	16	17	20	23	33	35	33	26	27	31	27	35	35
% Good	54	53	57	61	62	55	55	53	50	54	47	39	41	42	43	45	44	41	41
% Fair	29	29	18	19	14	23	22	22	18	19	16	19	22	24	24	19	23	18	17
% Poor	5	4	6	3	4	5	5	6	9	4	3	6	4	7	5	4	5	5	5
% Very Poor	1	1	1	1	2	2	2	2	3	0	1	1	0	1	1	1	1	1	2

Similar to corn and soybean, the year of 1999 was the worst for hay yield and production during the three year drought. The average hay yield in 1999 was approximately 4.48 metric tons/hectare, and the total production was 4,295,289 metric tons. The average yield for this year was approximately 0.68 metric tons/hectare below the average, while production was 452,505 metric tons less than the 1990's decade average. Prices during this year were moderately low with a value of $105.97/metric ton.

During 1999 the state generated $455,171,772 from hay revenue. This value is $41,796,584 less than the average from 1990-1999.

Average yield and production did increase drastically during 2000. The average yield during this year was 5.68 metric tons/hectare and production totaled 5,584,254 metric tons. Higher yield and production decreased prices to $93.89/metric ton. Revenue also increased drastically with a total of $524,305,597 from hay which is $79,156,797 above the decade average. However, hay conditions worsened during 2001. Average hay yield dropped to 5.31 metric tons/hectare, and production decreased to 5,040,707 metric tons. Prices also dropped to $79.58/metric ton, making the year of 2001 the lowest price year during the drought. Low production and price made the year of 2001 a low hay revenue year in Kentucky. During this year the state generated $401,139,457 from hay, a value that is $44,009,343 below the average from 2000-2009.

Beef cattle production was its highest during the drought of 1999-2001 during the year of 1999. That year the state produced 1,102,900 head of beef cattle. This value makes the year of 1999, the 17th lowest beef cattle production year from 1986-2008. As the drought intensified, conditions worsened for beef cows. During 2000, beef cattle production dropped 54,900 head from the previous year. The year of 2000 was the 7th lowest beef cattle production year for Kentucky with a value of only 1,048,000 head. This production total is 57,812 head less than the average beef cattle production year. As the drought finally came to an end in 2001, beef cattle production did increase but still remained lower than in 1999. During 2001, the state produced 1,057,600 head of beef cows. Though this value is 9,600 head more than the previous year, it is still 48,212 head less than the average production year.

The year with the most beef cattle deaths during the 1999-2001 drought occurred in 1999. Though production was high that year, 43,000 beef cows died, decreasing the production total substantially. During the years of 2000 and 2001, 38,000 and 36,000 beef cattle perished. This gives the drought of 1999-2001 a combined total of 117,000 head of beef cattle lost. During these years the number of beef cows sold was high. It is likely that farmers could not afford to feed their entire inventory and were forced to sell of their herds at lower prices before they died and no profit could be made.

4.3.6 Drought of 2007

The drought of 2007 brought dry conditions to the majority of the Southeast, west, and upper Great Lakes for the most of the year. During the summer, the drought encumbered the Mid-Atlantic States and several short lived dry-episodes occurred in the Ohio Valley, the Northeast, and the northern Plains (NOAA 2007). Drought conditions worsened across Kentucky during June 2007. Most locations across Kentucky experienced lower than normal precipitation totals with the largest deficits occurring over the southeastern part of the state. Soil moisture across the state was rated as 70 percent short or very short by the USDA. Hot and dry conditions continued until fall of 2007 when relief finally came to the bluegrass state (NOAA 2007). By December 2007, the Western and Central divisions were experiencing wet spells while the Eastern division dropped from an extreme to moderate drought classification.

Though conditions during 2007 were hot and dry, corn yield and production were not impacted too severely. During that year the average corn yield for the state was approximately 8.03 metric tons/hectare and total production was 4,266,843 metric tons. This amount is 355,917 metric tons above the decade average. The following year of 2008 suffered more severe impacts with decreased yield and production. Though corn yield and production were not severely affected at the state level, the Bluegrass and Eastern climate divisions did experience negative impacts. In the Bluegrass division, corn production during 2007 totaled 192,020, making it the 10^{th} lowest production year for that division. In the Eastern division corn production totaled 53,929, which ranks as the 6^{th} lowest corn production year in that division. Since the overall state total was not severely impacted and production was high, prices were moderate with an average value of $174.08/metric ton. This value was however approximately $37.00 higher than the price in 2006. In terms of revenue, high total production and moderate prices kept revenue above average. During 2007 the state generated $742,771,942 from corn, a value that is $234,671,028 higher than the decade average.

County-level corn yield data during 2007 is shown in Figure 39. During the year of 1999, counties in the western part of the state experienced higher yields compared to the rest of the counties. Many counties in eastern Kentucky are represented as clear in the map because data is not available for those counties during 2007. This is likely because not enough corn is being produced in those counties to be documented. Though western counties had the highest yields during that year, several counties in central Kentucky also experienced high yields.

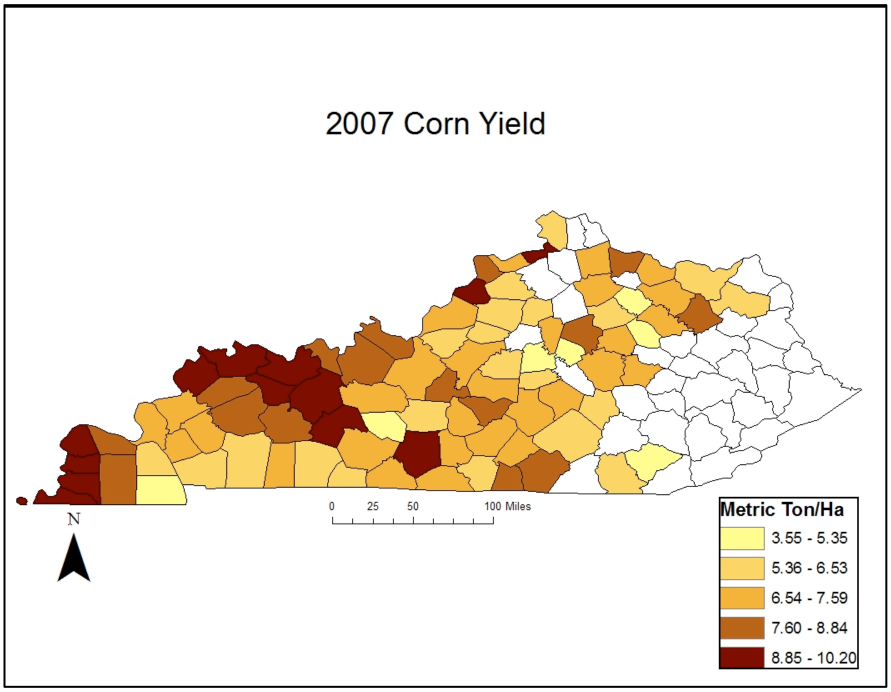


Figure 39. 2007 Corn Yield. Source: NASS 2010.

Corn quality during 2007 started out as mostly in excellent or good condition, but quickly declined as time and the drought progressed (Table 13). Most weeks experienced a higher percentage of corn in good or fair condition than in excellent. Also every week experienced corn in poor condition, and all weeks except one had very poor corn conditions. It is obvious that the hot and dry condition did impact corn quality as the drought intensified. During weeks 34 and 35, only 6-7% of corn was in excellent condition, and 7-15% was considered in very poor condition. Conditions did improve by the end of the growing season, and during week 37, the percentage of excellent condition corn increased to 25% and very poor condition corn decreased to 6%.

Table 13. 2007 Corn Quality. Source: NASS 2009.

Week #	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
% Excellent	25	19	16	13	6	9	16	16	20	23	26	22	9	9	6	7	14	25
% Good	57	54	43	51	37	40	44	43	36	36	35	42	45	43	42	32	38	34
% Fair	17	23	31	22	31	30	20	24	25	24	25	21	26	24	27	27	24	22
% Poor	1	3	8	11	20	14	11	11	10	10	8	9	14	17	18	19	17	13
% Very Poor	0	1	2	3	6	7	9	6	9	7	6	6	6	7	7	15	7	6

Unlike corn, total soybean production was low during the year of 2007. During that year the state produced 719,173 metric tons of soybean, a value that is 634,130 metric tons lower than the average from 2000-2009. Low production raised prices to their highest value seen since 1988. The scarcity of soybeans rose prices to an average cost of $425.37/metric ton. Though prices were high that year, revenue was still low. The state generated $305,914,538 from soybean in 2007. The low revenue puts the year of 2007 at $118,696,904 below the decade average.

Soybeans in 2007 started out as mostly in good condition but as the drought progressed, conditions started to worsen (Table 14). Towards the beginning of the growing season most weeks experienced 15-25% of excellent quality soybeans. This number quickly decreased to around 0-8% during week 32 till the end of the growing season. During 2007, every week experienced poor and very poor soybean conditions. Towards the beginning of the growing season the percentage of soybeans with very poor quality ranged from 2-10%. During weeks 33-40, 15-28% of soybeans were in very poor condition. It is likely that the hot and dry conditions made it difficult for soybeans to grow and decreased their quality. As mentioned previously, prices of soybeans were high during 2007 due to low production, but revenue remained low as well. Since soybean quality was impacted, it is likely that many farmers could not sell them, even though they were scarce that year.

Table 14. 2007 Soybean Quality. Source: NASS 2009.

Week #	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
% Excellent	16	13	6	11	20	17	24	27	29	15	8	6	0	1	2	3	4	4	6
% Good	48	50	45	39	41	43	35	39	40	49	38	28	21	15	18	20	18	17	22
% Fair	28	27	29	33	25	25	22	23	20	20	28	34	42	35	40	39	36	26	25
% Poor	6	8	16	12	8	10	12	6	8	10	19	22	22	21	22	19	23	26	24
% Very Poor	2	2	4	5	6	5	7	5	3	6	7	10	15	28	18	19	19	27	23

Hay yield was extremely low during the year of 2007. In fact, 2007 is the lowest hay yield on record since 1964. Hay production was also low that year, with a total of 3,612,870 metric tons. This value is 1,462,881 metric tons lower than the decade average. Hay revenue during 2007 was upon the lowest years for all four climate divisions and was even the lowest year for revenue in the Western division. For the state total, the year of 2007 was the 9th lowest revenue year from 1949-2009. That year the state generated $362,948,954 from hay, a value that is $82,199,846 below the decade average.

Beef cattle production was high during the year of 2007. During that year the state produced 1,205,700 head of beef cattle, making 2007 the 3rd highest beef cattle production year. Since production was high, beef cattle prices were lower than average.

During 2007, the average price of a beef cow was $47.73/cwt. This price is $1.90/cwt less than the previous year and $17.55/cwt less than the average price. However, production would have been higher if the 44,000 beef cows that died that year were not lost. The year of 2007 was the 6th highest year for beef cattle deaths in Kentucky. As discussed previously, hay production was extremely low during 2007 which forced farmers to ration their feed for livestock. Also, during 2007 only 580,000 beef cows were sold. This is the 5th lowest number of beef cows sold in Kentucky during 1988-2008. It is likely that the demand for beef cattle that year was low because there was not enough hay to feed them. Buyers could not afford to increase their herd and those interested in beef cows for consumption were probably turned off by the diminished body compositions of the cows.

Chapter 5
Conclusion

Drought research is vital if we are to ever understand the relationship between drought and society. Since drought impacts are poorly documented, they are often underestimated (Hayes et al. 2004). It is important that drought impact studies, like this research, are continued in order to decrease drought vulnerabilities in the future. Several organizations including the NDMC, NIDIS, and the Western Governors' Association have noted the need for better documentation of drought impacts. The explicit goal set forth by NIDIS is to enable society to respond to periods of drought by improving monitoring, prediction, risk assessment, and communication (The National Integrated Drought Information System Implementation Plan 2007). This research contributes to this goal by documenting drought impacts on agriculture and aiding in the quest for more efficient drought management.

Over 13,993,121 acres of land in Kentucky is farmland. This accounts for over 55% of the total land in Kentucky (USDA 2007). Kentucky agriculture generates billions of dollars annually. During periods of drought this number can decrease significantly. In this research, four of Kentucky's most valuable commodities were examined. These commodities were corn, soybeans, hay, and beef cattle. Each of these commodities' yield and production were examined over time in order to compare their values during significant drought years vs. non-significant drought years.

Corn was the first commodity examined in this research. The corn data dated back to 1929, which provided a long time scale. This availability of data made it easier to determine the pattern of corn yield and production over time. It also allowed several significant drought years to be examined that ranged from 1930-2007. Plotting the data proved that corn yield and production has been increasing steadily throughout time. This is due to improved crop management and the advancement of technology (Sunding and Zilberman 1999). However, the Bluegrass and Eastern divisions have experienced decreased corn yields in recent years because less corn is being planted in those regions. The results of this research also concluded that yield and production decreased during periods of drought. This decrease in yield and production made corn more scarce and impacted corn prices. During drought periods corn prices were among their highest values. From these results, Kentucky corn revenue could be determined and analyzed. The results indicated that during significant drought years, corn revenue was usually lower than neighboring years, meaning that drought has a negative relationship with revenue.

Table 15 is a summary of the corn results found in this research. In the table, the yield, production, and price data are compared to a decade average. For example, corn yield in 1930 was 0.76 metric tons per hectare less than the decade average. The year of 1930 experienced the lowest corn yield and price compared to the decade average of all of the significant drought years. The significant drought year whose production deviated the most from the decade average occurred during 1988. During that year, corn production was 1,067,418 metric tons lower than the decade average.

Drought Year	Yield (Ton/Ha)	Production (Ton)	Price (2010 Dollars)
1930	-0.76	-820,762	$31.27
1931	0.30	477,037	-$222.69
1940	-0.45	-296,095	-$185.33
1941	-0.20	-53,620	-$123.94
1942	-0.04	87,300	-$40.87
1952	-0.68	-338,710	$84.33
1953	-0.21	-21,260	$24.70
1954	-0.50	-187,685	$8.09
1955	0.13	177,640	-$42.18
1988	-1.10	-1,067,418	-$20.72
1999	-0.36	-243,166	-$38.32
2000	-0.45	83,917	-$22.12
2001	0.30	-13,542	-$24.47
2007	-0.58	355,917	$47.14

Table 15. Drought Years' Corn Results. Source: NASS 2010.

After determining how much each significant drought year's yield, production, and price deviated from the decade average, revenue was investigated. Table 16 is a summary table of each significant drought years' revenue compared to a decade average. A negative number means that the value is less than the decade average and a positive value means the number is larger than the decade average. For example, in 1940 corn revenue was $447,741,450 less than the decade average. According to the results, Kentucky experienced its lowest corn revenue during the 1940-1942 drought. The revenue during the year of 1940 deviated the most from the decade average. The second lowest revenue year occurred during 1930. During that year, Kentucky corn revenue was $292,986,413 below the decade average. The year of 2007 experienced the highest corn revenue of the significant drought years. That year revenue was $234,671,028 above the decade average. This proves that even though 2007 was a significant drought year, technology has become so advanced that it is still possible to have a successful agricultural economy.

Drought Year	Revenue (2010 Dollars)
1930	-$292,986,413
1931	-$222,169,247
1940	-$447,741,450
1941	-$224,484,762
1942	+$13,133,960
1952	-$36,464,081
1953	+$31,954,376
1954	-$76,324,700
1955	-$2,833,844
1988	-$255,225,591
1999	-$152,233,133
2000	-$89,820,713
2001	-$109,184,944
2007	+$234,671,028

Table 16. Drought Years' Corn Revenue Results. Source: NASS 2010.

In this research, Kentucky soybeans were also investigated. Soybean data was only available from 1972-2008 at the county level. However, it was available from 1929-2008 at the state level. Results show that like corn, soybean yield and production have been increasing throughout time due to the advancement in technology and the variety of products that are made from soybean oils (Allmaras 1997). Results also showed that during significant drought years, soybean yield and production were lower than neighboring years. This suggests that drought has a negative impact on Kentucky soybean yield and production.

As expected, the price of soybeans increased during periods of drought. The low yield and production totals allowed farmers to sell their soybeans at higher prices than usual. During drought periods the demand for soybeans was higher than the supply which drove up prices. Multiplying the production of soybeans of each year by the price determined revenue for that year. Results showed that revenue was typically lower than neighboring years during periods of drought.

A summary of the soybean results can be seen in Tables 17-18. The results from this research indicate that the years of 1999 and 2007 experienced the lowest soybean yields compared to a decade average. During those years soybean yield was 0.82 metric tons per hectare less than the decade average. These years were also the lowest production years of the significant drought years. During 1999, soybean production was 387,702 metric tons less than the decade average and during 2007, production was down 553,149 from the decade average. Since production was significantly lower than average during these years, it is no surprise that prices were among their highest. During the year of 2007, prices were over $111.00 more than the decade average.

Drought Year	Yield (Ton/Ha)	Production (Ton)	Price (2010 Dollars)
1930	-0.22	-1,628	N/A
1931	+0.08	+99	N/A
1940	-0.18	-24,802	-$231.90
1941	-0.11	-19,807	+$8.08
1942	-0.08	-3,175	-$132.25
1952	-0.22	-23,292	+$137.34
1953	-0.36	-31,959	+$101.17
1954	-0.15	-12,681	+$55.79
1955	-0.05	-5,472	-$61.71
1988	-0.10	-342,333	+$25.02
1999	-0.82	-387,702	-$102.47
2000	-0.04	-148,419	-$75.35
2001	+0.02	-52,299	-$93.64
2007	-0.82	-553,149	+$111.16

Table 17. Drought Years' Soybean Results. Source: NASS 2010.

Soybean revenue results are summarized in Table 18. Since price data is not available prior to 1940, the significant drought years' 1930-1931 revenue could not be determined. Results showed that during the year of 1999, Kentucky experienced its lowest soybean revenue year compared to a decade average. That year, soybean revenue was $210,644,043 less than the decade average. It should be mentioned that every significant drought year experienced soybean revenues less than the decade average.

Among the worst, the years of 1998, 2000, and 2001, soybean revenue was over $100,000,000 less than the decade average.

Drought Years	Revenue (2010 Dollars)
1930	N/A
1931	N/A
1940	-$25,906,461
1941	-$18,606,873
1942	-$7,558,417
1952	-$8,920,535
1953	-$18,114,955
1954	-$4,097,742
1955	-$5,853,069
1988	-$164,250,344
1999	-$210,644,043
2000	-$113,551,421
2001	-$114,731,591
2007	-$57,880,972

Table 18. Drought Years' Soybean Revenue Results. Source: NASS 2010.

The third commodity examined in this research was hay. State level hay data ranges from 1929-2009. As expected, results show that hay yield and production have increase throughout time. A summary of the hay results is shown in Tables 19-20. Results showed that the drought of 2007 was particularly difficult for hay yield and production. During that year hay yield was 1.52 metric tons per hectare lower than the decade average and production was 1,513,781 metric tons less. However, prices during 2007 were only $13.81 above the decade average which contributed to revenue being over $82,000,000 below the decade average.

Drought Year	Yield (Ton/Ha)	Production (Ton)	Price (2010 Dollars)
1930	-0.88	-649,049	N/A
1931	+0.10	+23,037	N/A
1940	-0.21	-394,635	N/A
1941	-0.08	-270,376	N/A
1942	0.21	+130,517	N/A
1952	-0.48	-420,213	+$59.50
1953	-0.32	-292,326	+$40.26
1954	-0.26	-292,326	+$23.76
1955	+0.19	+203,802	-$31.67
1988	-0.72	+87,800	+$8.24
1999	-0.52	-452,505	+$1.22
2000	+0.50	+457,652	+$6.59
2001	+0.05	-85,894	-$7.71
2007	-1.52	-1,513,781	+$13.16

Table 19. Drought Years' Hay Results. Source: NASS 2010.

Drought Year	Revenue (2010 Dollars)
1930	N/A
1931	N/A
1940	N/A
1941	N/A
1942	N/A
1952	+$26,361,340
1953	+$23,530,947
1954	-$5,547,019
1955	-$25,391,463
1988	+$49,010,953
1999	-$41,796,584
2000	+$79,156,797
2001	-$44,009,343
2007	-$82,199,846

Table 20. Drought Years' Hay Revenue Results. Source: NASS 2010.

Drought impacts need to be documented if we are to ever understand the relationship between drought and society. From this research, it can be concluded that Kentucky's agriculture is vulnerable to drought and impact assessment is of vital importance. Results of this research show that during significant drought years, Kentucky corn, soybeans, hay, and beef cattle production and yields decrease significantly. These decreases cause negative impacts on Kentucky's economy. The significant drought years of Kentucky have caused billion dollar deficits in revenue from corn, soybeans, and hay alone. These huge amounts account for only three of Kentucky's commodities. It is hard to imagine the enormous deficit value that would result if all of Kentucky’s agricultural commodities were included in this study.

Future research needs to include more than just these four commodities if a true understanding of droughts’ impacts on Kentucky’s agriculture is to be established. Also, agriculture is just one of many sectors that are affected by drought. Water resources, public health, tourism, recreation, wildlife, timber, etc. all need to be examined and impacts of drought on these sectors need to be documented. Without completing an impact assessment of drought on all of these vulnerable sectors, drought risks cannot be reduced in the future. Hopefully, this research will contribute to the quest for more efficient drought monitoring and help policymakers implement plans that will decrease Kentucky’s agricultural economy vulnerability to future droughts.

APPENDIX

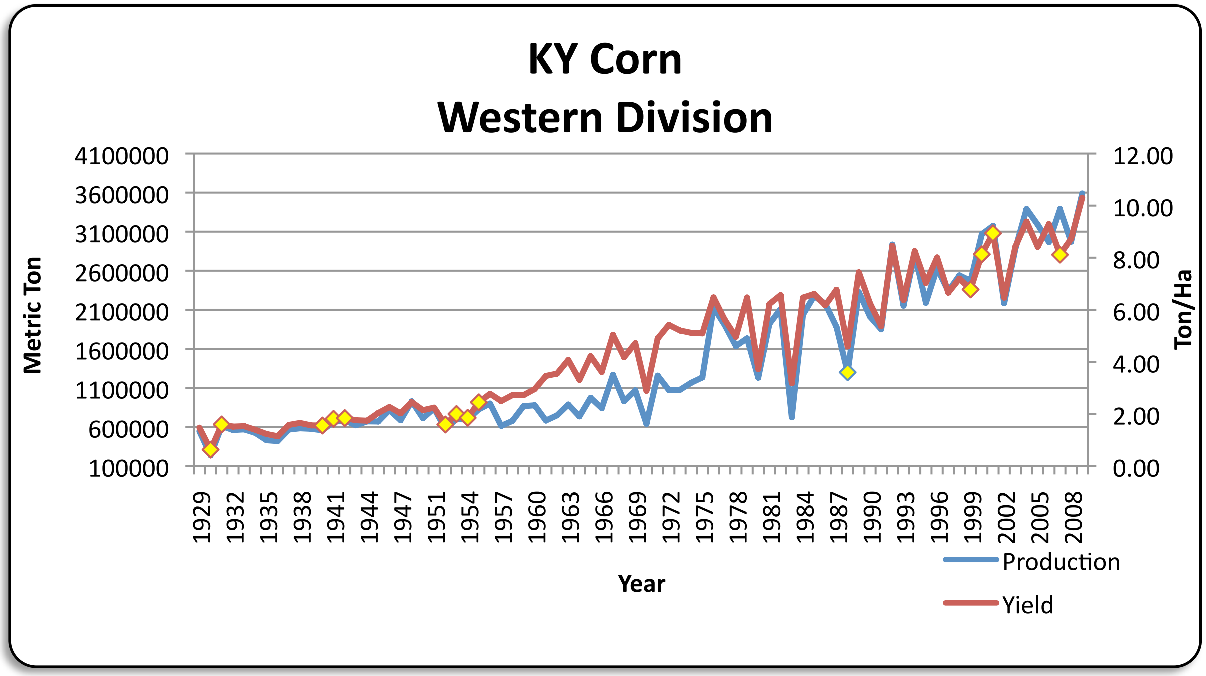


Figure 40. Kentucky Corn Yield and Production for the Western Division. Source: NASS 2010.

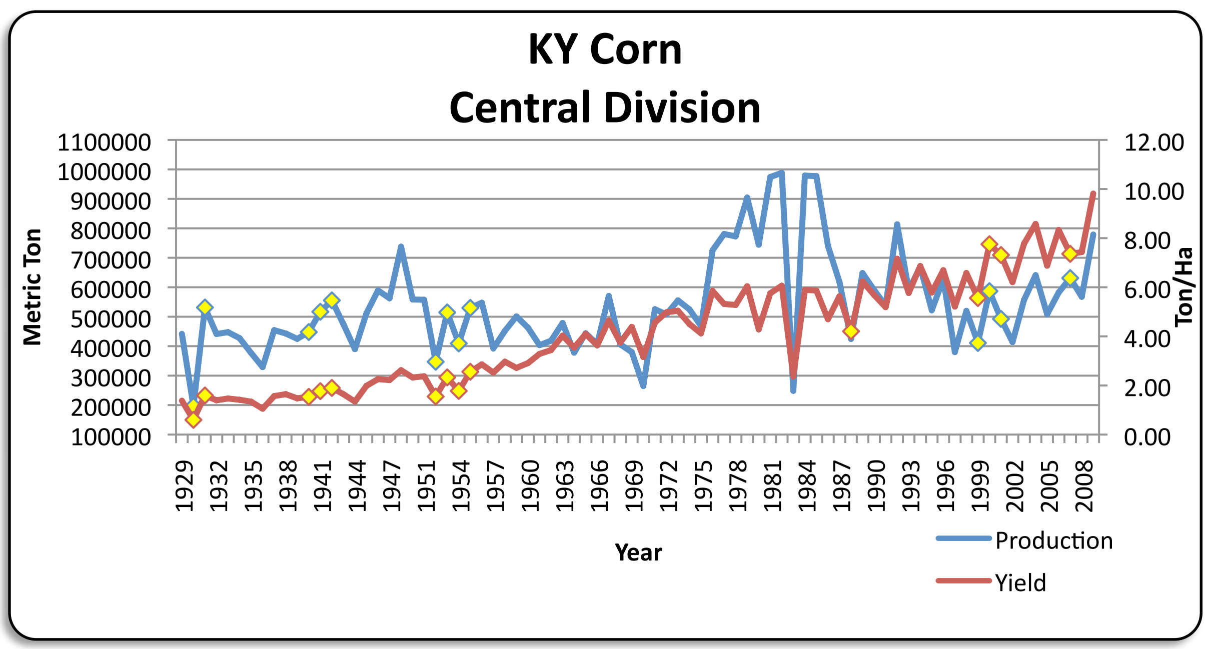


Figure 41. Kentucky Corn Yield and Production for the Central Division. Source: NASS 2010.

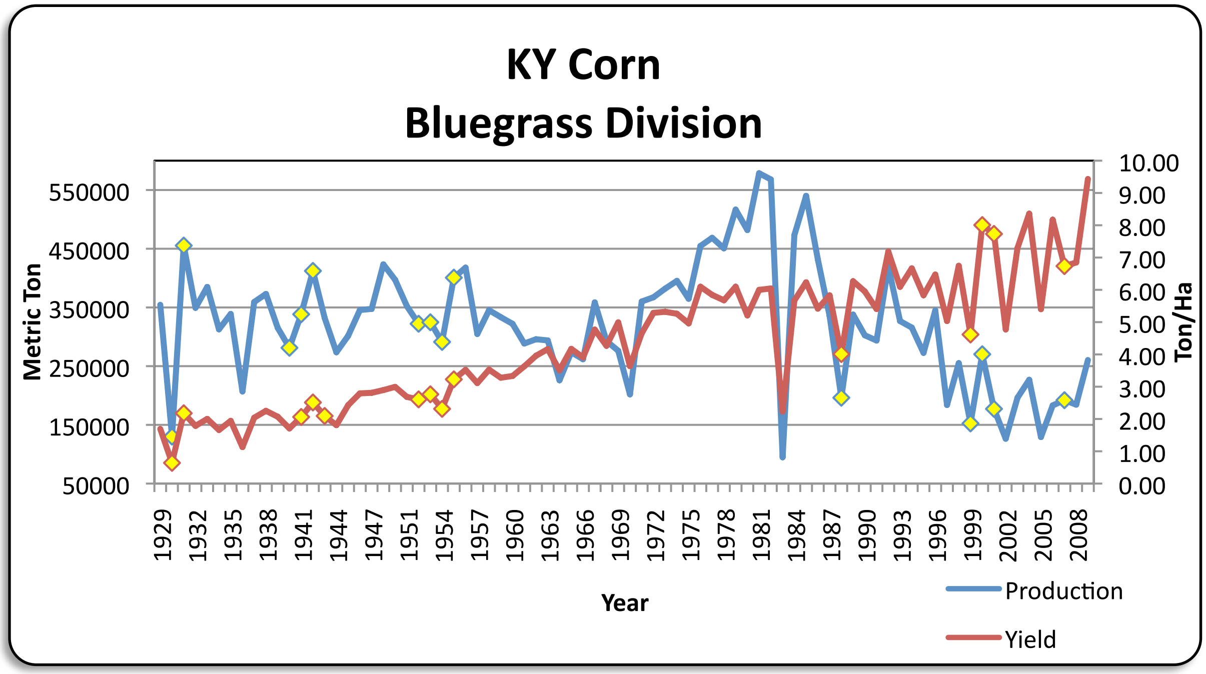


Figure 42. Kentucky Corn Yield and Production for the Bluegrass Division. Source: NASS 2010.

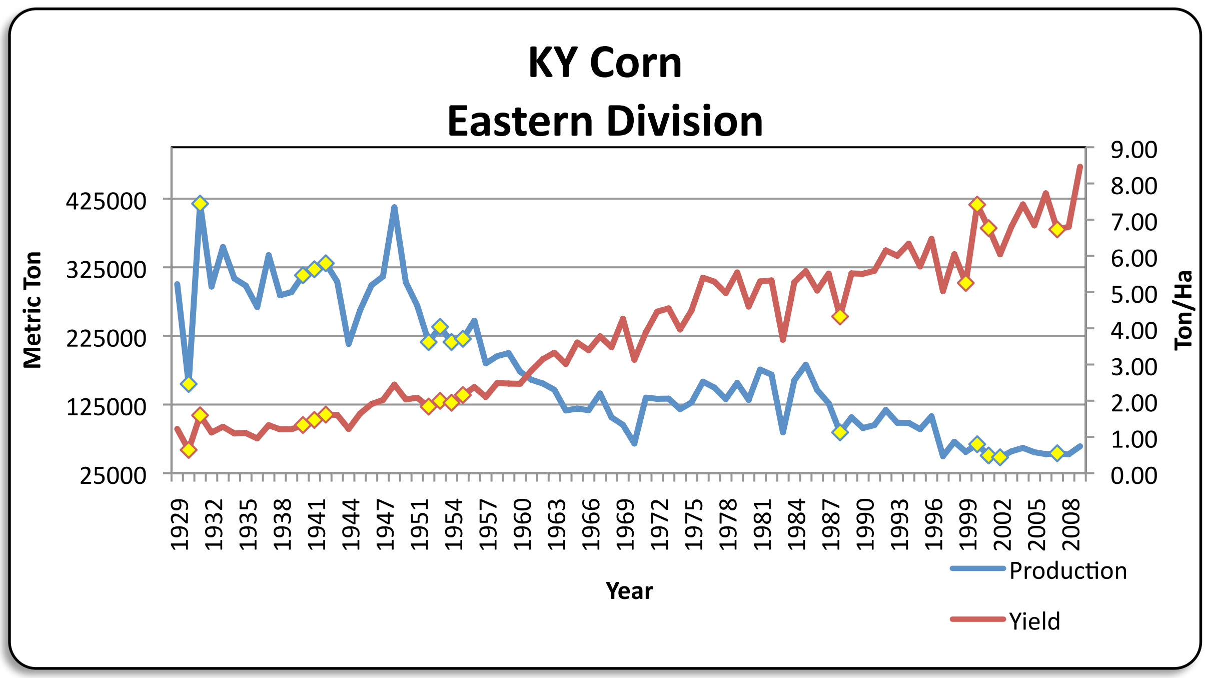


Figure 43. Kentucky Corn Yield and Production for the Eastern Division. Source: NASS 2010.

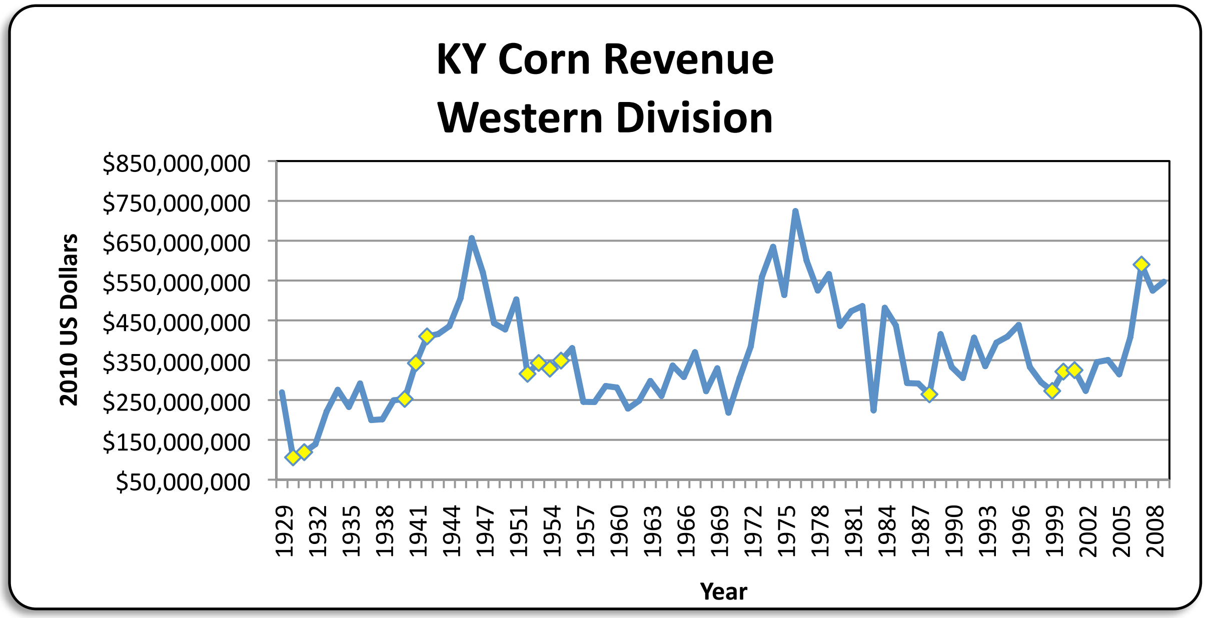


Figure 44. Kentucky Corn Revenue for the Western Division. Source: NASS 2010.

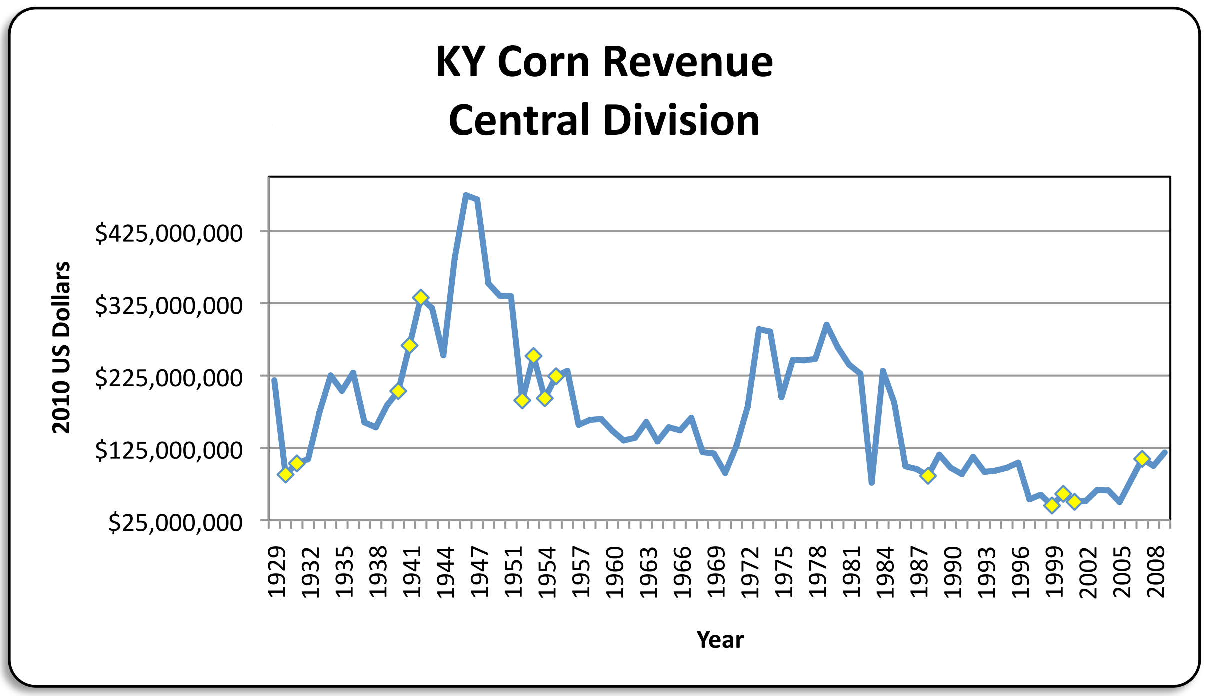


Figure 45. Kentucky Corn Revenue for the Central Division. Source: NASS 2010.

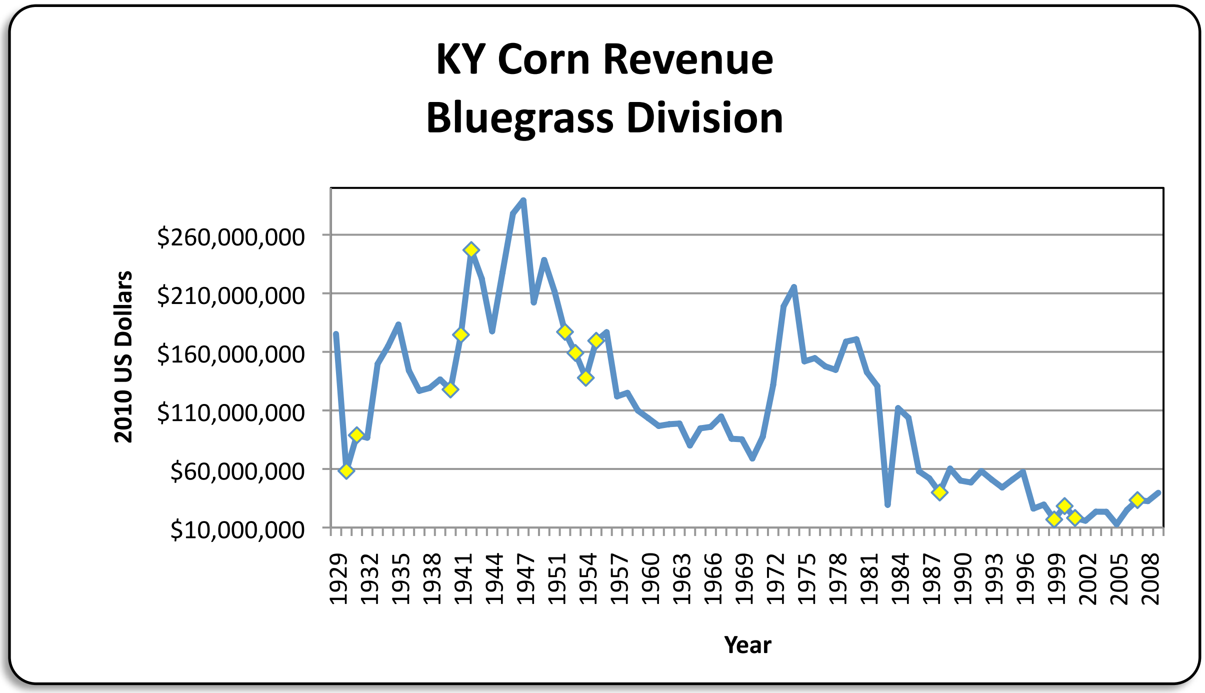


Figure 46. Kentucky corn revenue for the Bluegrass division. Source: NASS 2010.

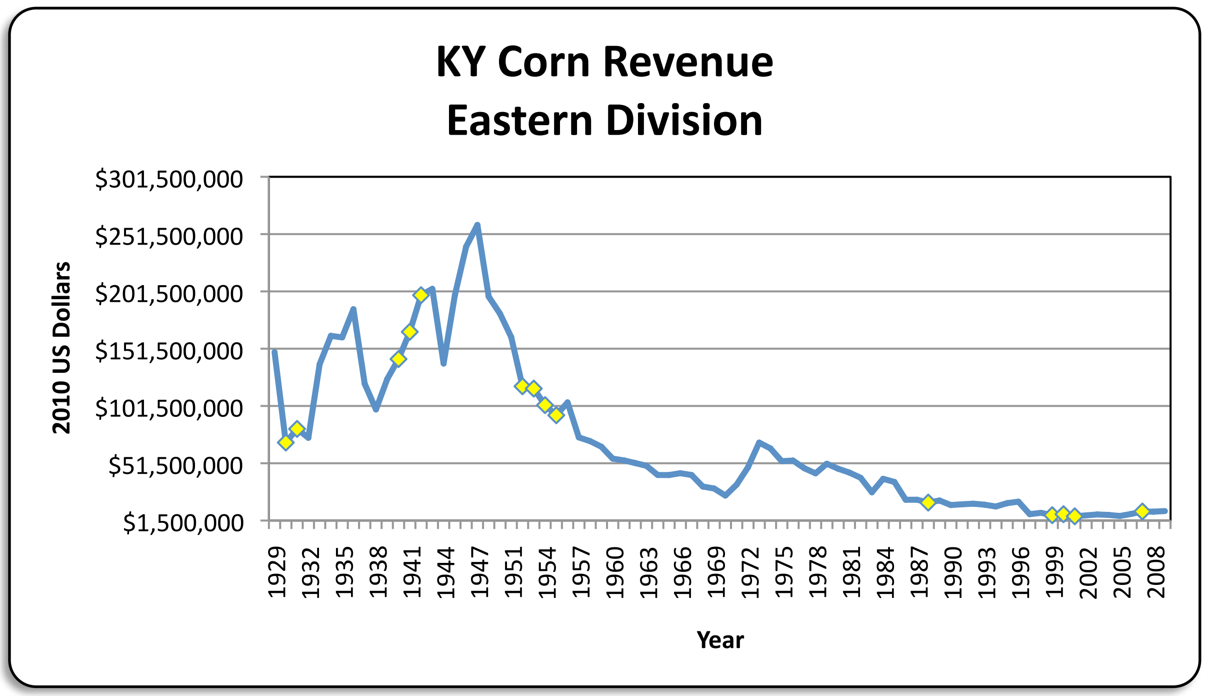


Figure 47. Kentucky Corn Revenue for the Eastern Division. Source: NASS 2010.

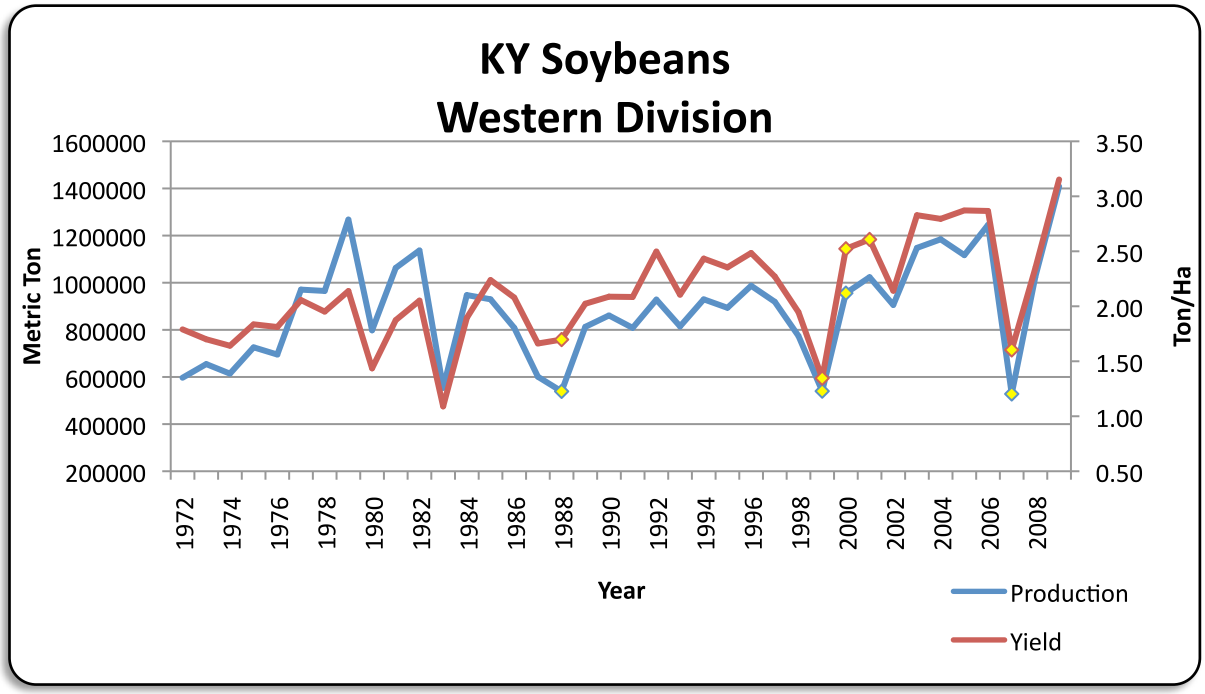


Figure 48. Kentucky Soybean Yield and Production for the Western Division. Source: NASS 2010.

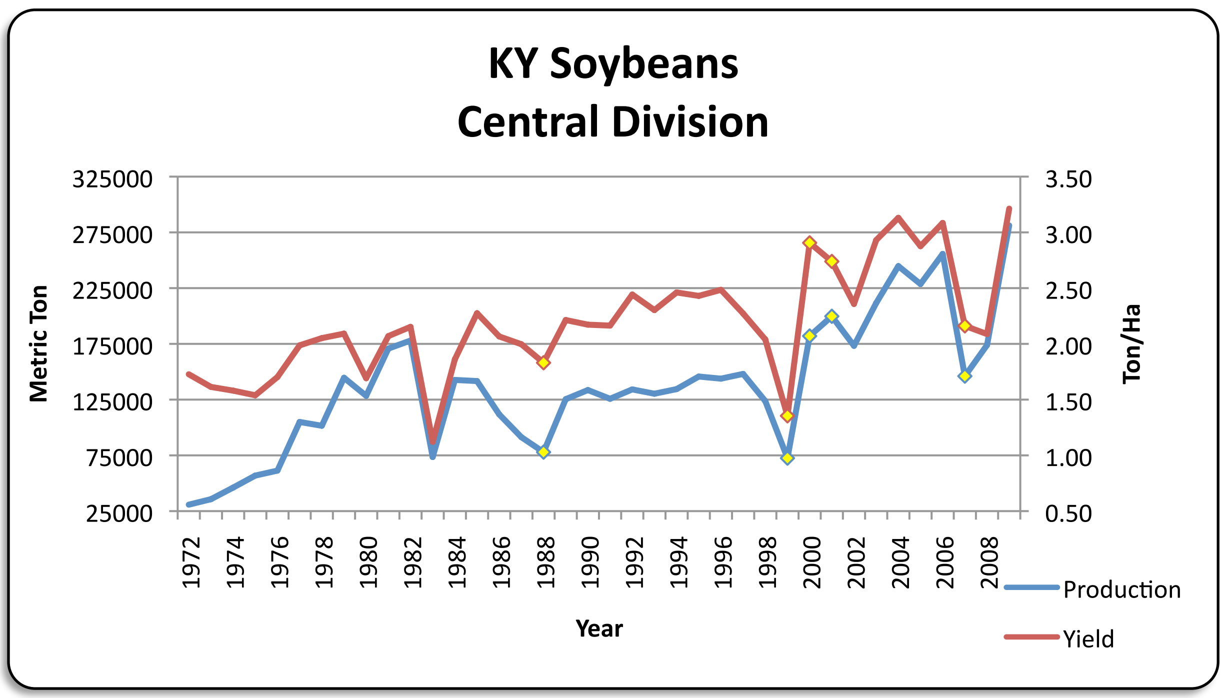


Figure 49. Kentucky Soybean Yield and Production for the Central Division. Source: NASS 2010.

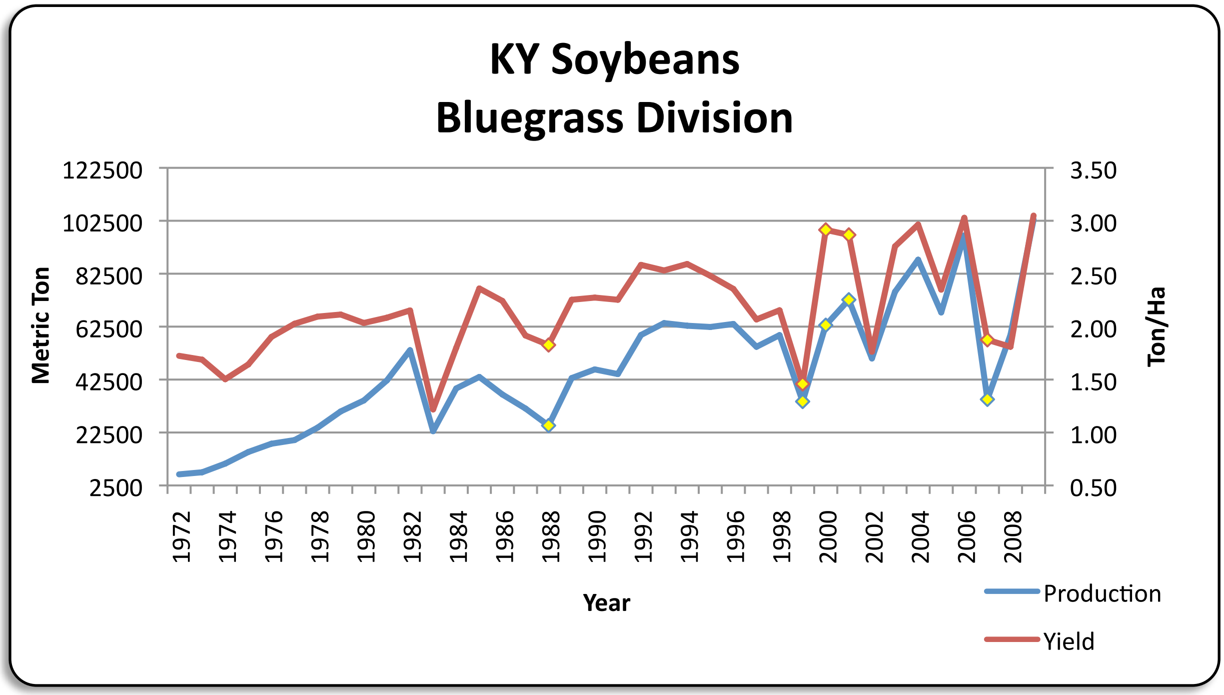


Figure 50. Kentucky Soybean Yield and Production for the Bluegrass Division. Source: NASS 2010.

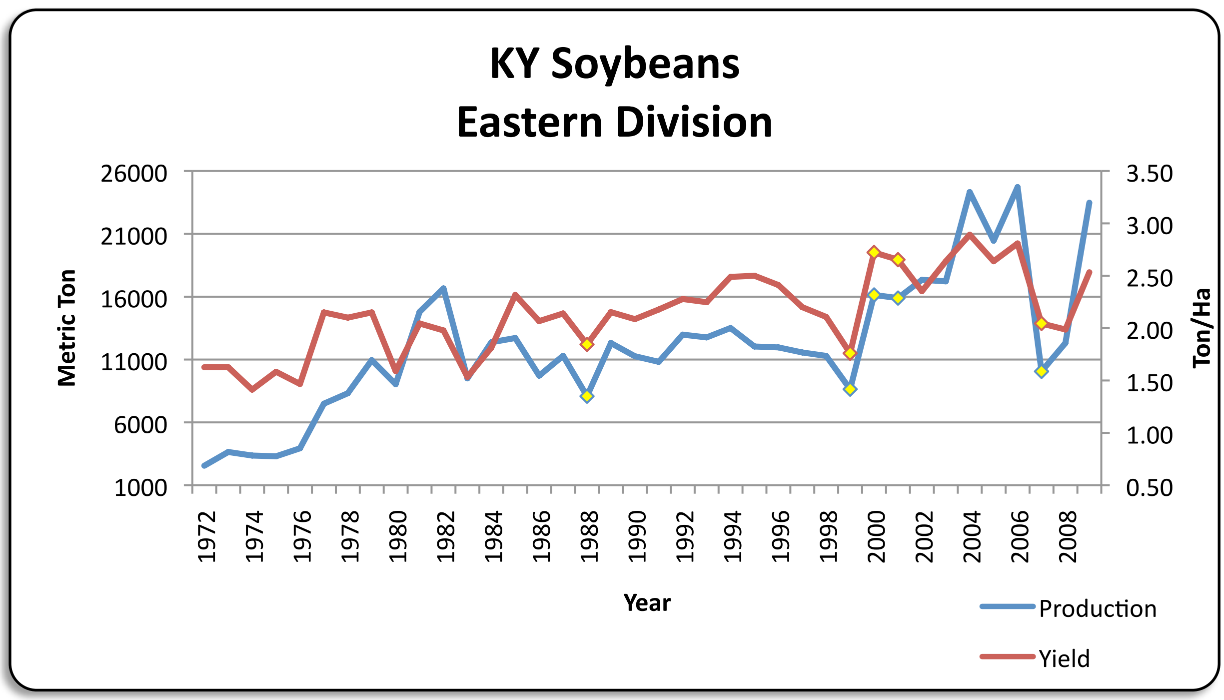


Figure 51. Kentucky Soybean Yield and Production for the Eastern Division. Source: NASS 2010.

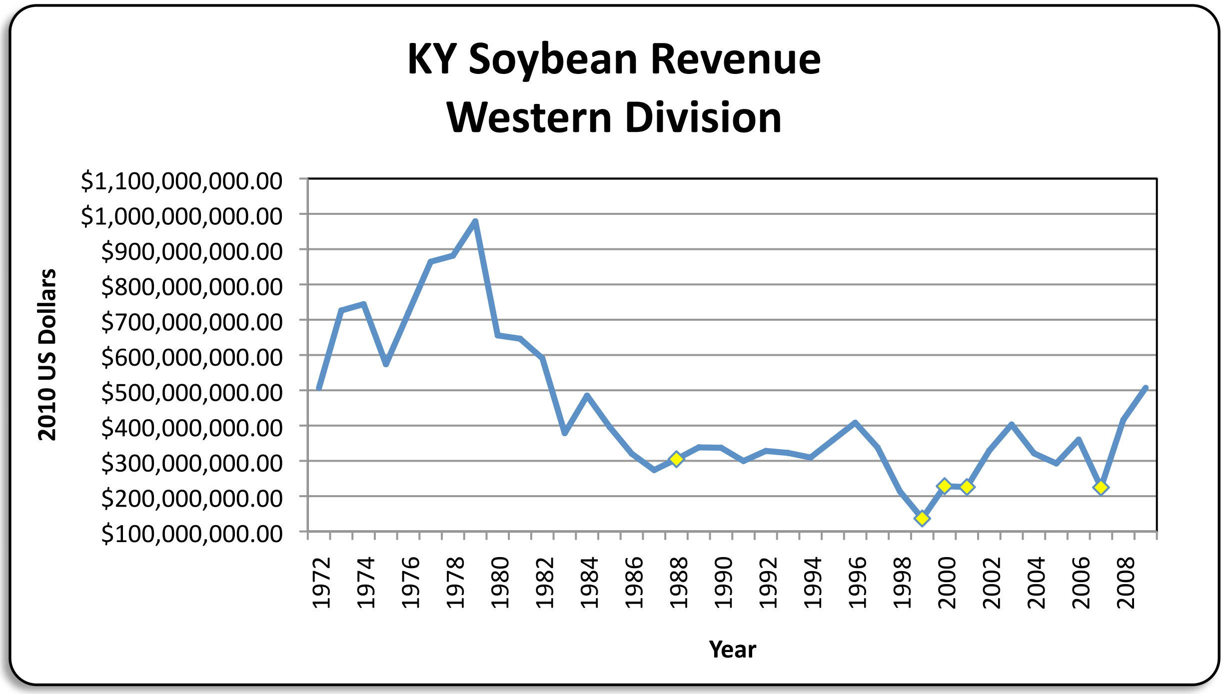


Figure 52. Kentucky Soybean Revenue for the Western Division. Source: NASS 2010.

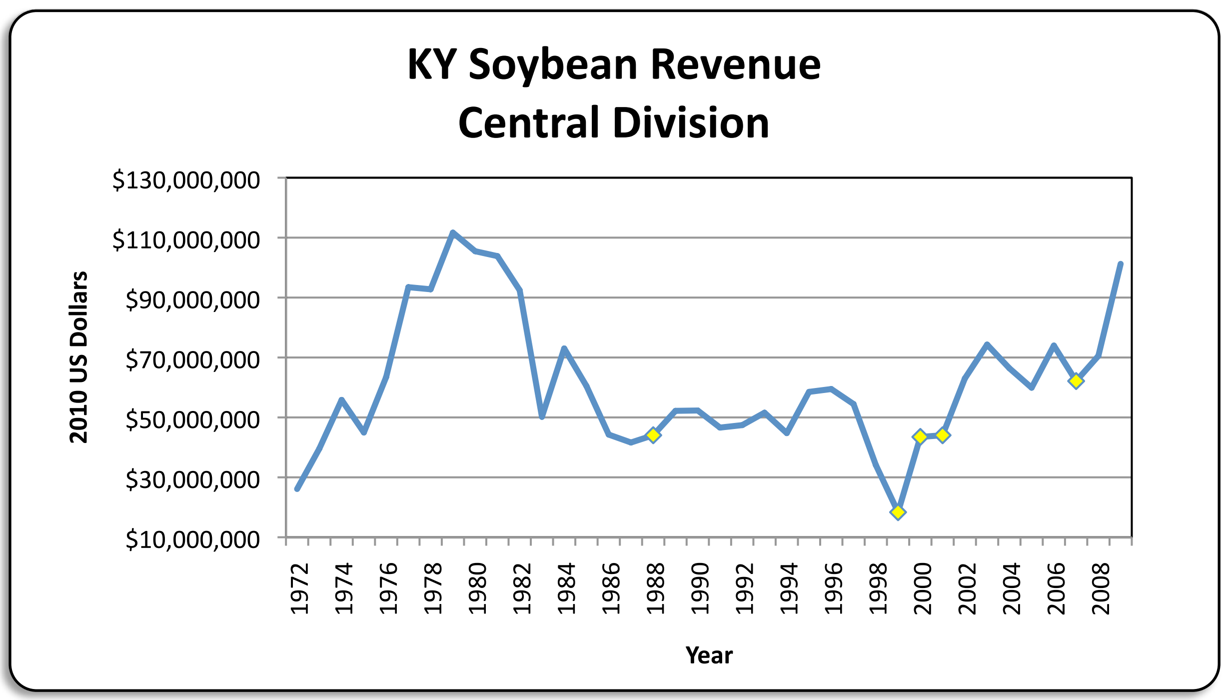


Figure 53. Kentucky Soybean Revenue for the Central Division. Source: NASS 2010.

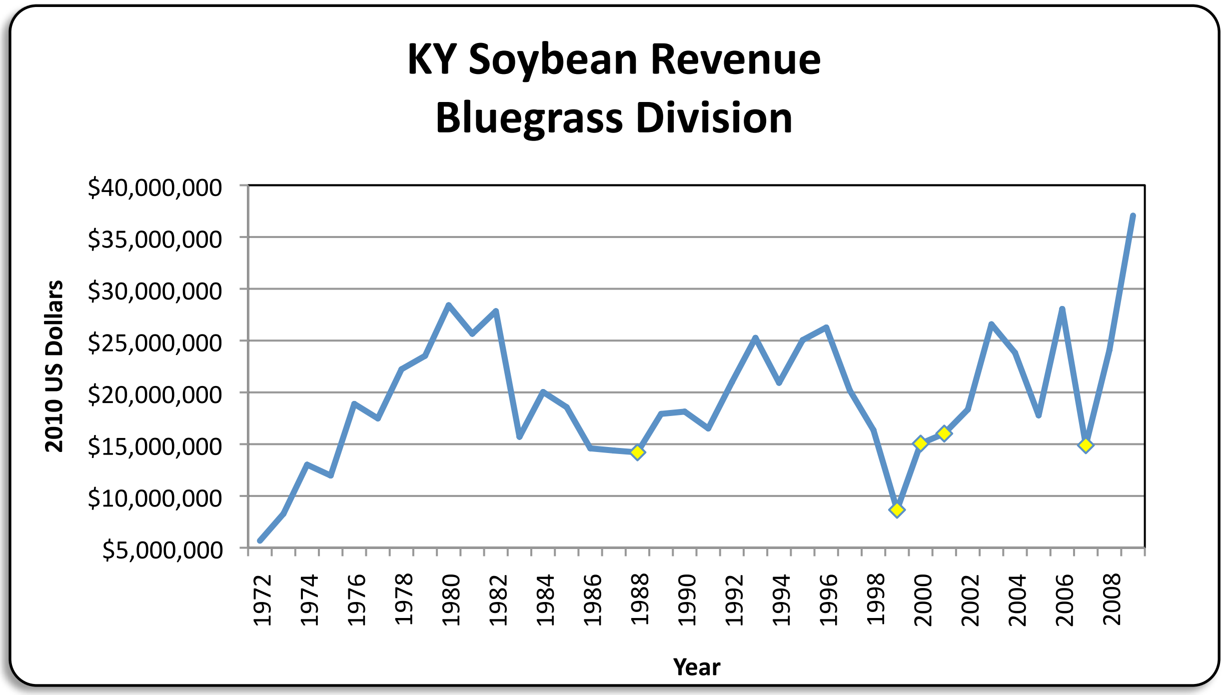


Figure 54. Kentucky Soybean Revenue for the Bluegrass Division. Source: NASS 2010.

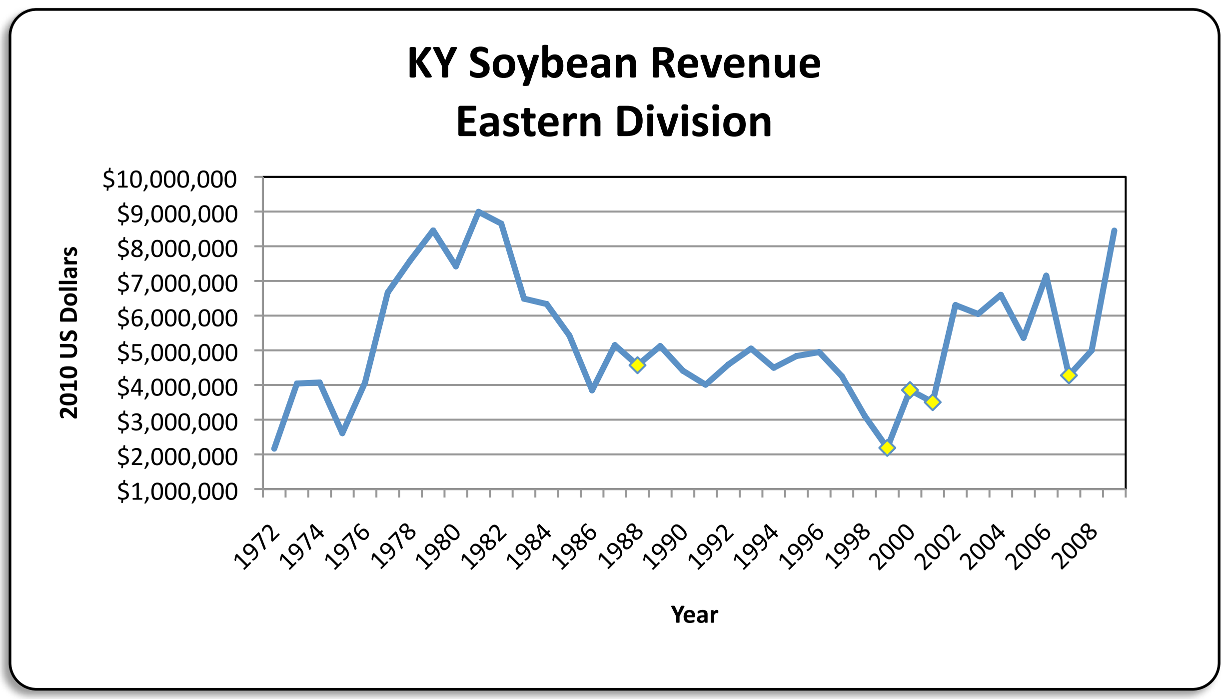


Figure 55. Kentucky Soybean Revenue for the Eastern Division. Source: NASS 2010.

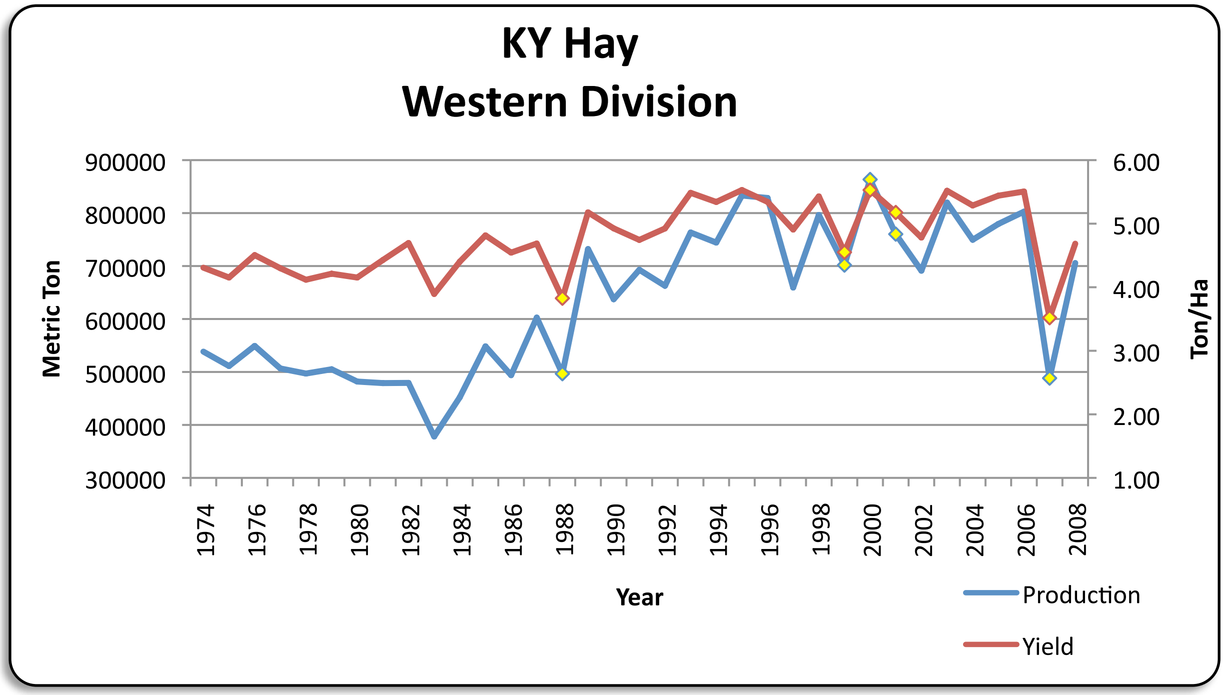


Figure 56. Kentucky Hay Yield and Production for the Western Division. Source: NASS 2010.

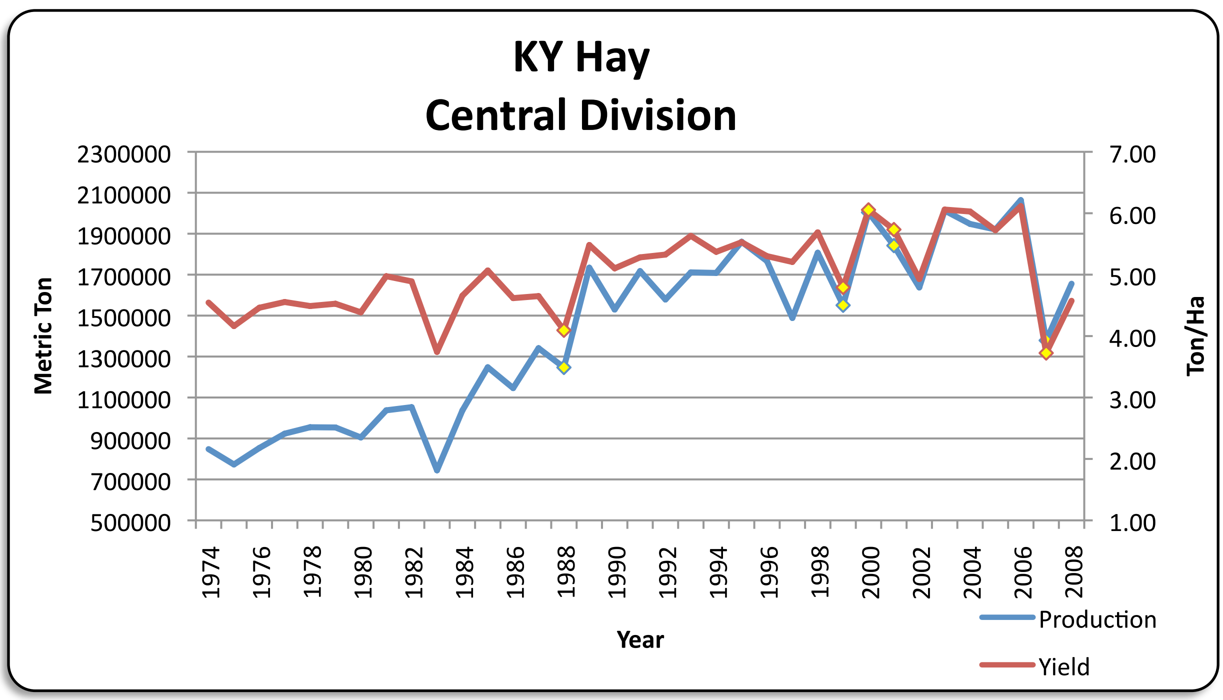


Figure 57. Kentucky Hay Yield and Production for the Central Division. Source: NASS 2010.

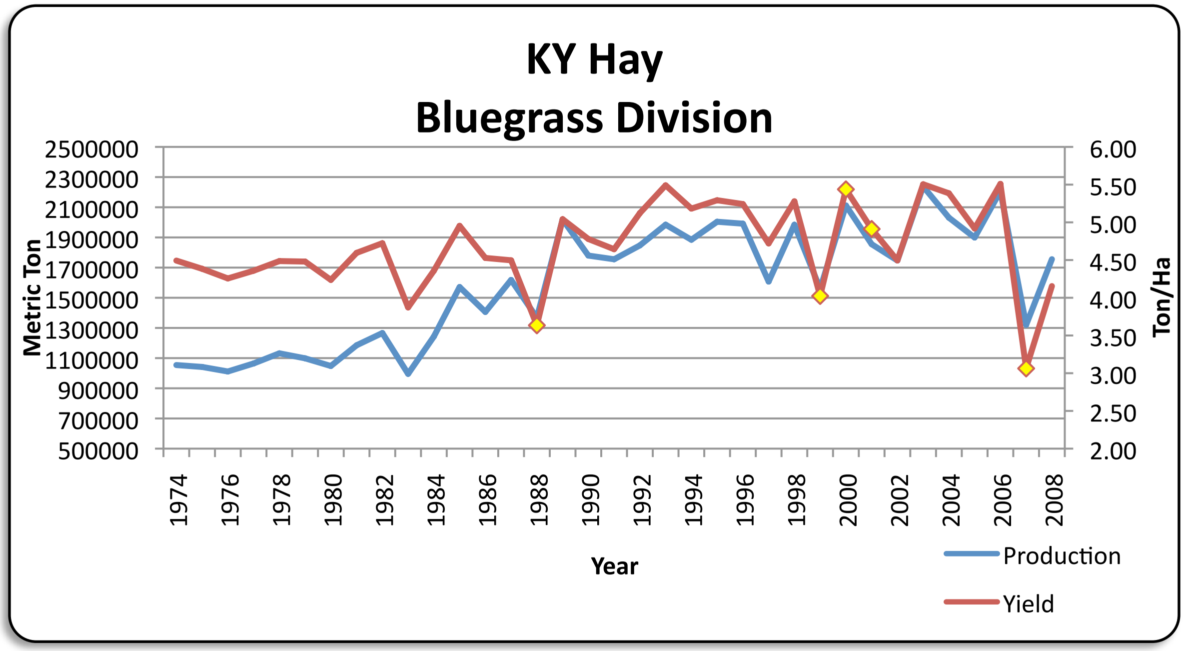


Figure 58. Kentucky Hay Yield and Production for the Bluegrass Division. Source: NASS 2010.

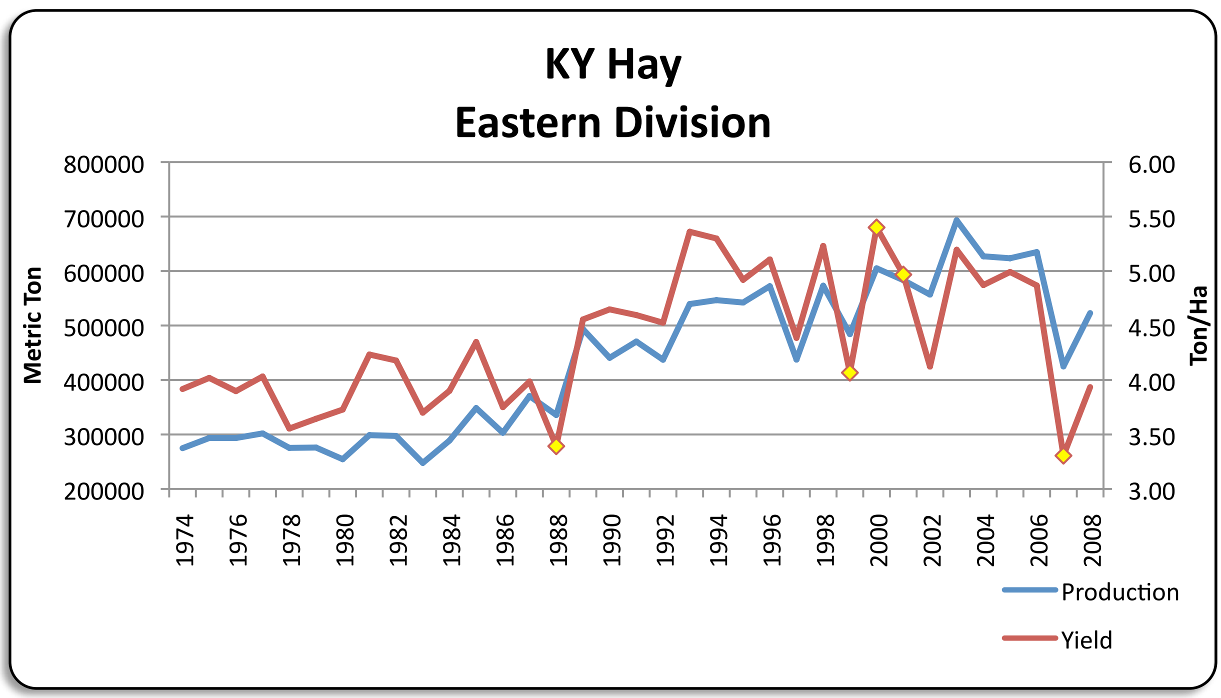


Figure 59. Kentucky Hay Yield and Production for the Eastern Division. Source: NASS 2010.

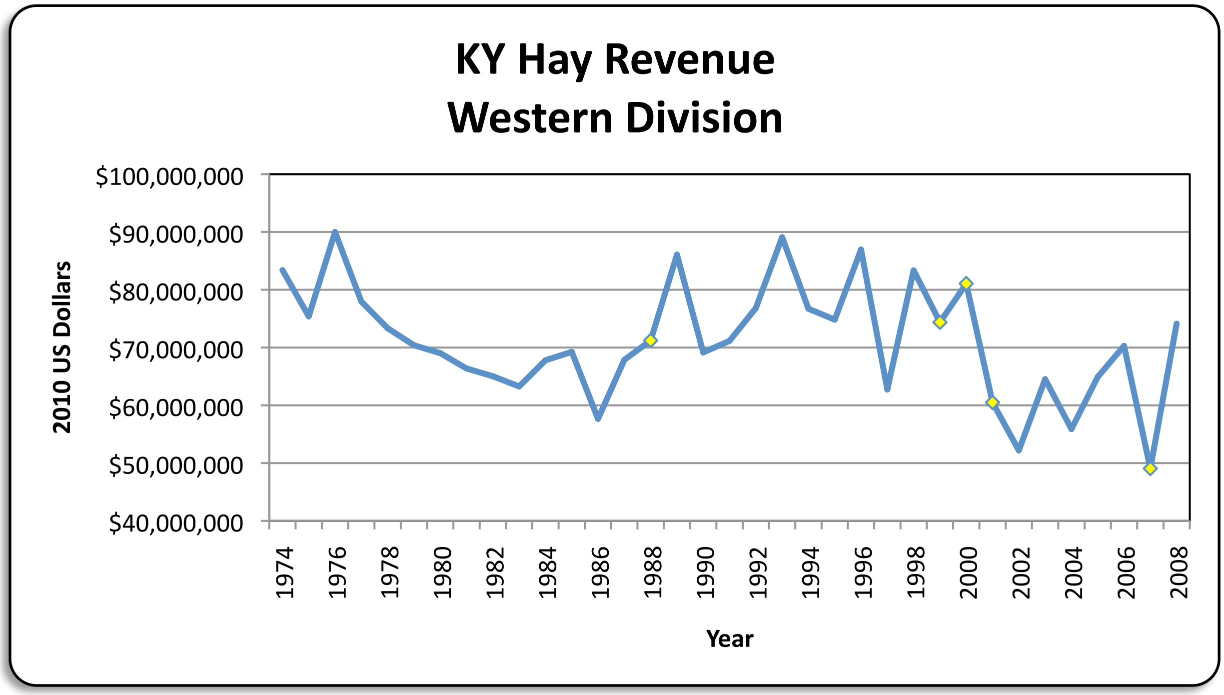


Figure 60. Kentucky Hay Revenue for the Western Division. Source: NASS 2010.

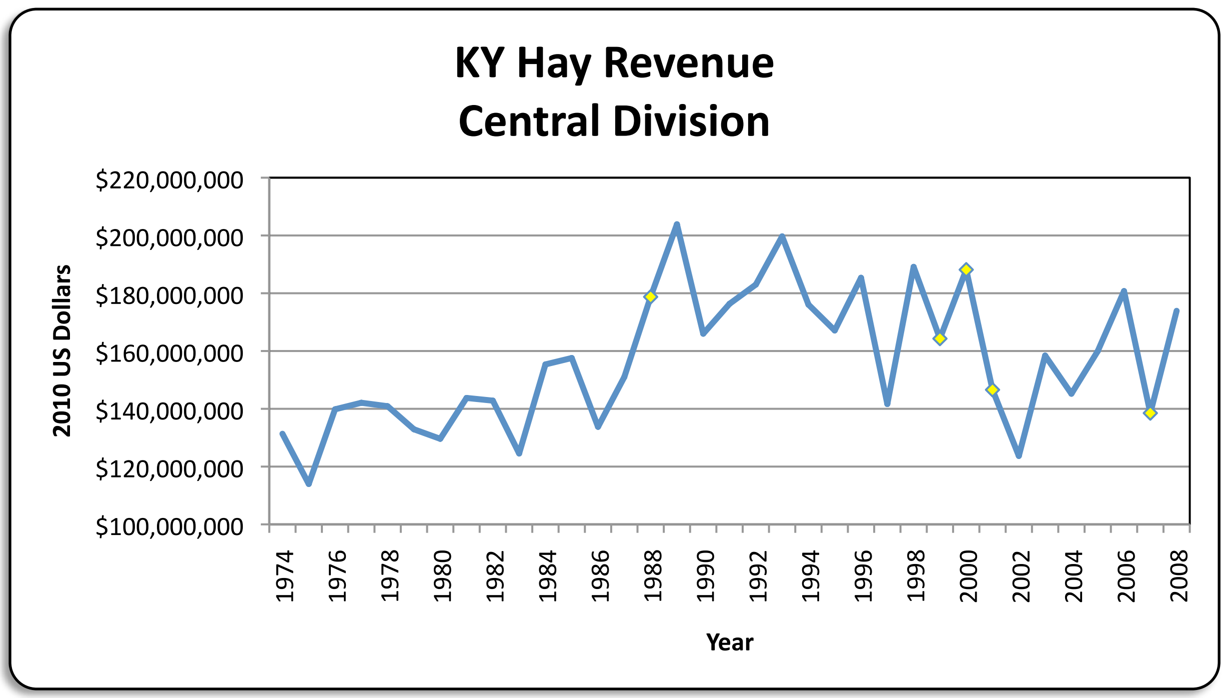


Figure 61. Kentucky Hay Revenue for the Central Division. Source: NASS 2010.

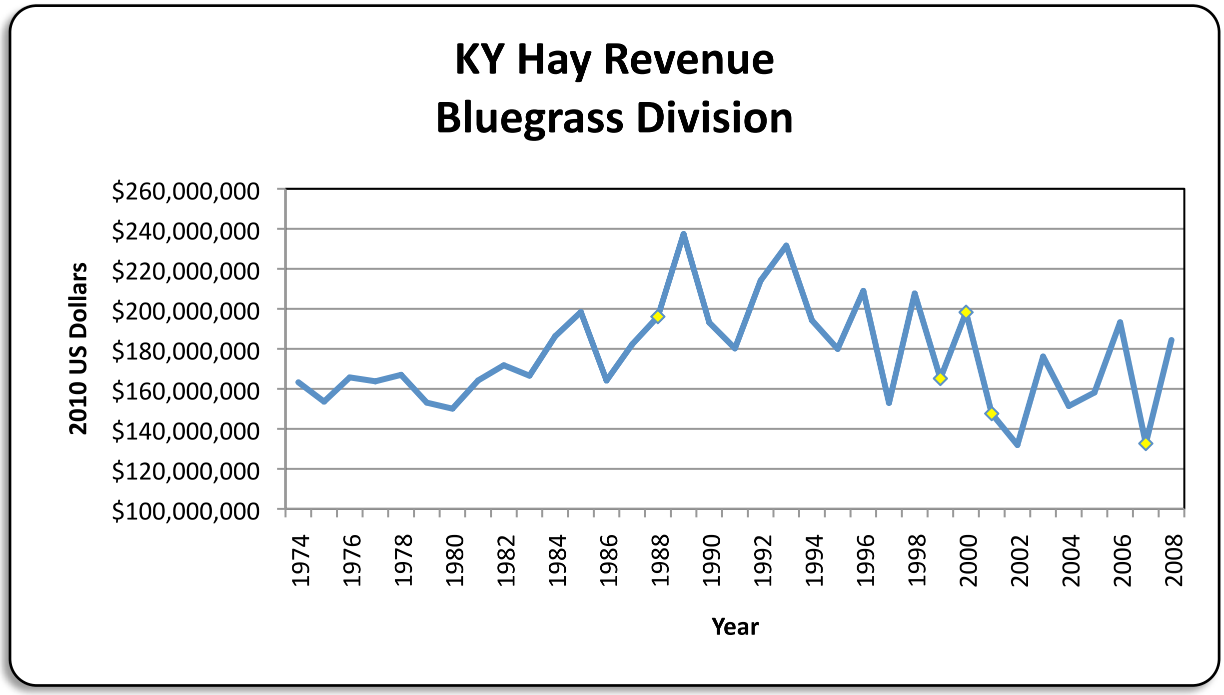


Figure 62. Kentucky Hay Revenue for the Bluegrass Division. Source: NASS 2010.

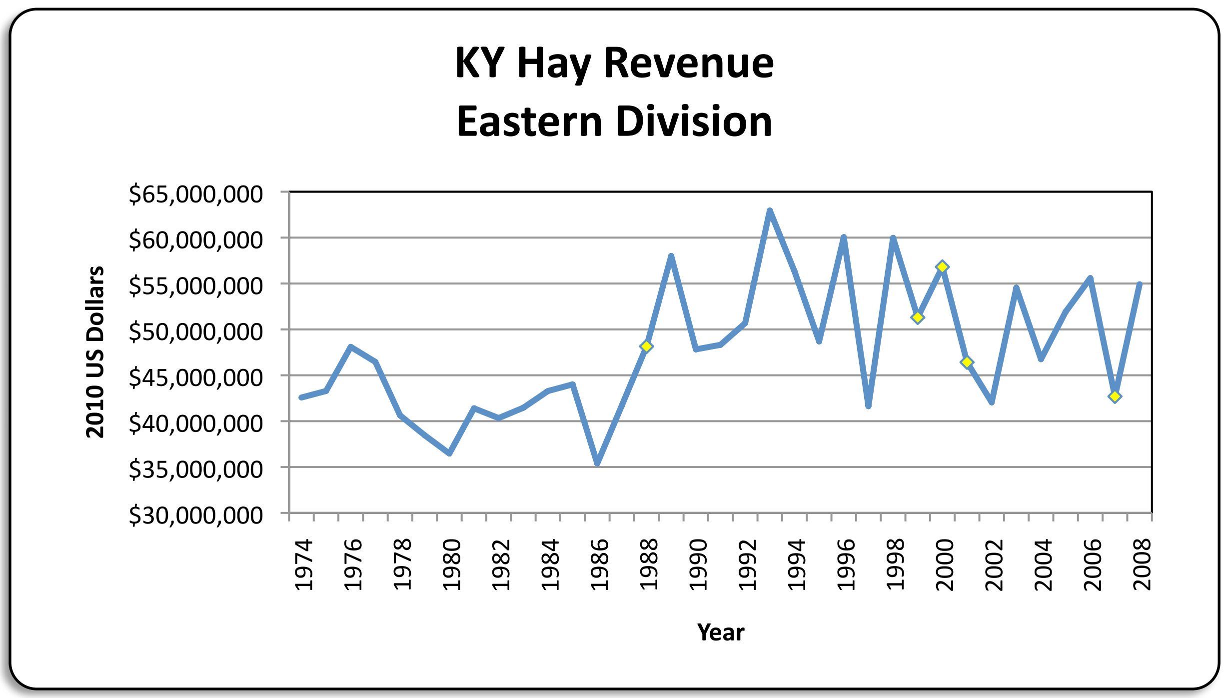


Figure 63. Kentucky Hay Revenue for the Eastern Division. Source: NASS 2010.

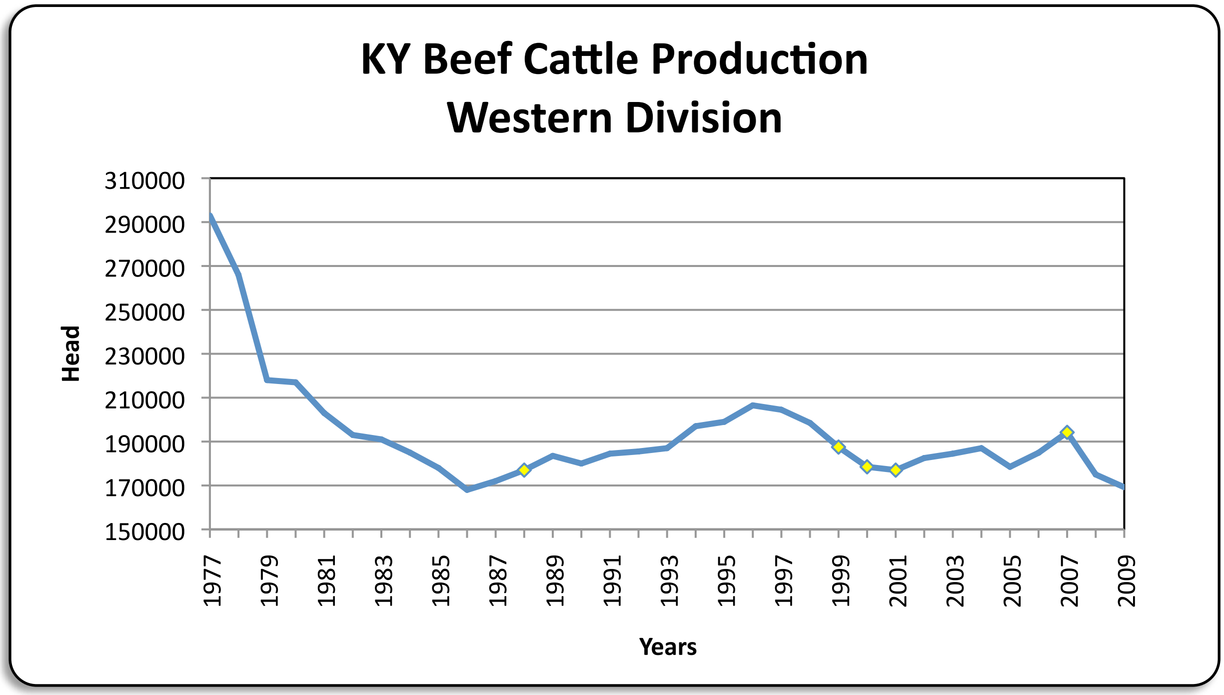


Figure 64. Kentucky Beef Cattle Production for the Western Divison. Source: NASS 2010.

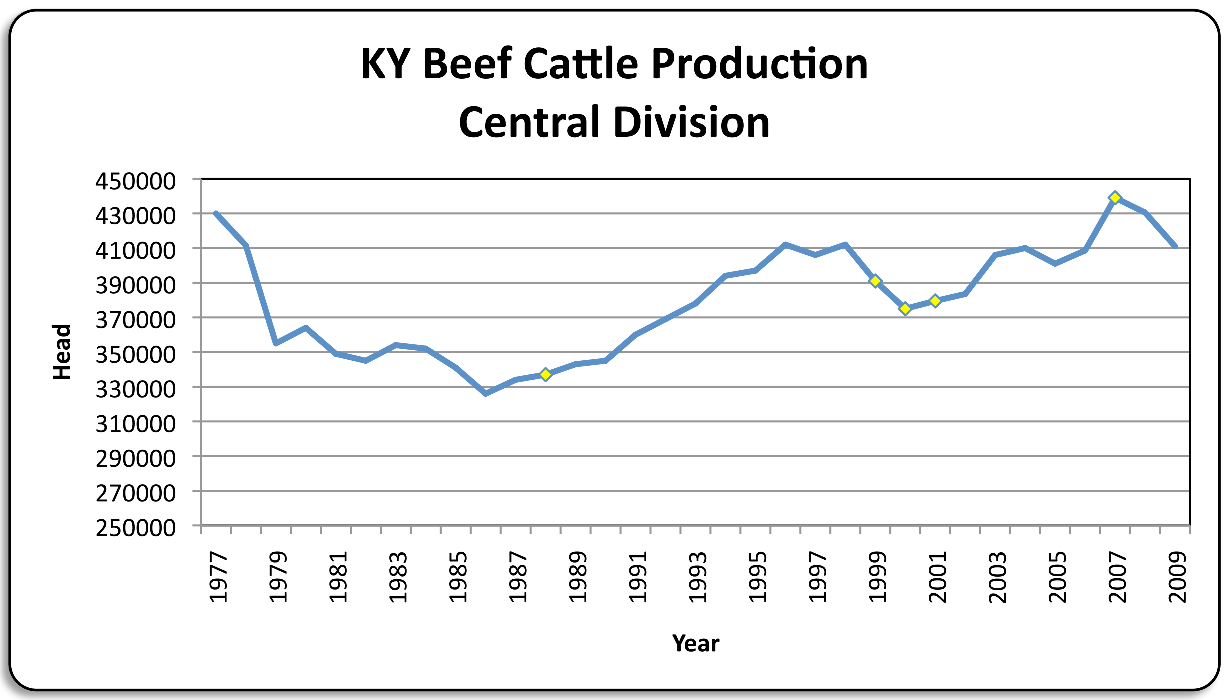


Figure 65. Kentucky Beef Cattle Production for the Central Division. Source: NASS 2010.

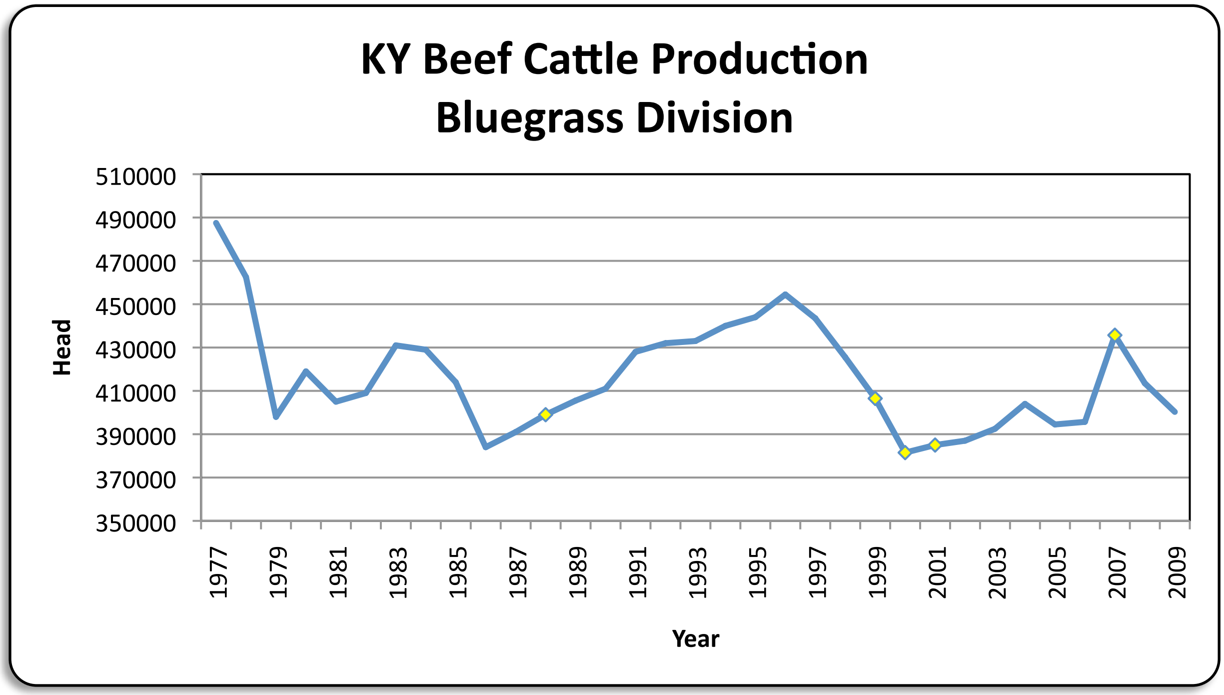


Figure 66. Kentucky Beef Cattle Production for the Bluegrass Division. Source: NASS 2010.

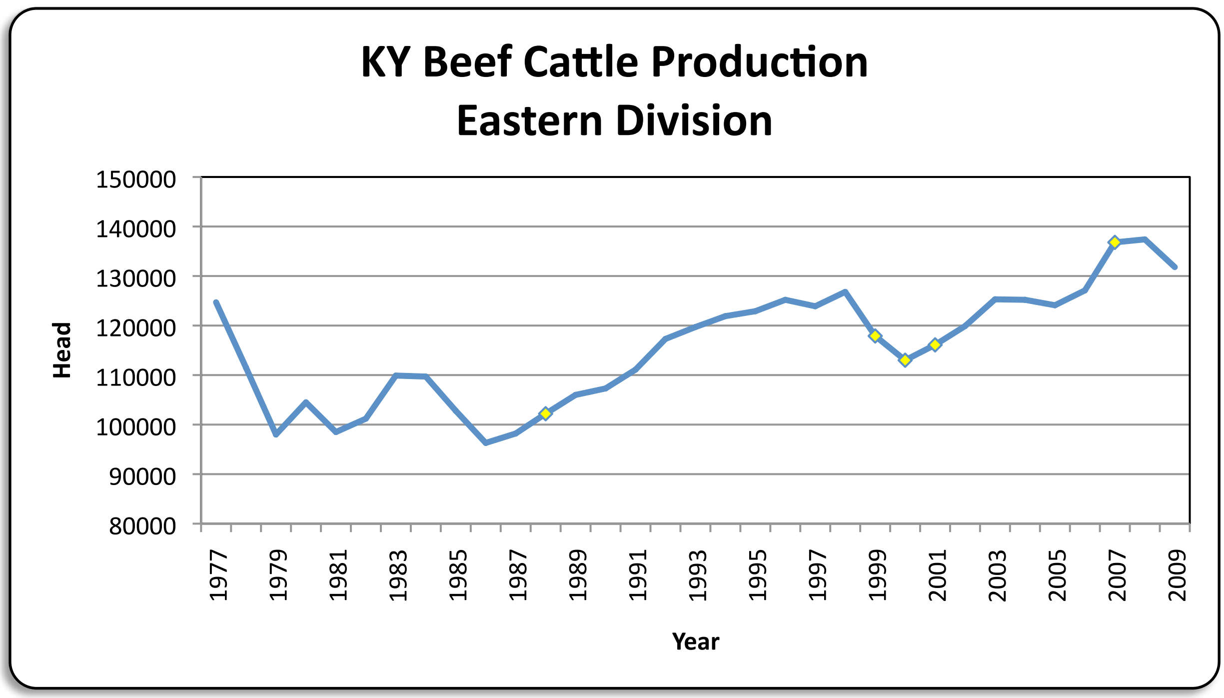


Figure 67. Kentucky Beef Cattle Production for the Eastern Division. Source: NASS 2010.

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