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Twentieth Century Droughts and Agriculture: Examples from Impacts on Soybean Production in Kentucky, USA

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REPORT

Twentieth century droughts and agriculture: Examples from impacts on soybean production in Kentucky, USA

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Abstract Drought is a significant natural hazard that slowly evolves over time. Because of its character, drought is difficult to monitor and impacts are often poorly documented. Agriculture is one of the most sensitive sectors that are prone to drought. The objective of this research is to assess the impacts of drought on soybean production and revenue in Kentucky. Soybeans are one of Kentucky's most important commodities. In this study, impacts of 1930–1931, 1940–1942, 1952–1955, 1987–1988, 1999–2000, and 2007 droughts were considered. It was found that over the recent years, up to 56 % of the revenue from soybeans was lost due to drought. During the first half of the twentieth century, revenue loss reached up to 77 %. This research is valuable to the general public as well as planners and policy makers. Proper documentation of impacts of past droughts will help identify drought vulnerabilities and results in better risk management and mitigation.

Keywords Soybean · Drought · Agriculture · Impact assessment

INTRODUCTION

Drought affects more people than any other natural hazard, yet it is the most complex and least understood (Wilhite 1993; Cook et al. 2007). While the most commonly reported drought impacts are related to diminished agricultural production and water supply, other sectors, such as tourism and river navigation, also experience negative impact. The severity of a drought's impacts depends on a society's vulnerability at that particular time of occurrence. To fully understand societal vulnerability to drought, extensive documentation of every drought-sensitive sector is needed. The National Integrated Drought Information System (NIDIS) was created to enable more effective response in the U.S. by allowing decision makers to determine and prepare for potential impacts (NIDIS 2007). NIDIS is a drought risk information system that provides drought monitoring and prediction as well as communication of impacts. NIDIS recommends six steps for drought mitigation and preparedness. Drought impact assessment is the second step in this process and hence, signifies its importance. The analysis presented here assessed impacts of historical droughts on soybeans in Kentucky.

Climate models project a global increase in temperature over this century (IPCC 2013; Kirtman et al. 2013). Moreover, it is noted that during the twentieth century, there has been an increase in the frequency and intensity of drought in some regions while in others they decreased (Hartmann et al. 2013). Knowledge of future droughts, combined with a historical understanding of its impacts on agriculture, provides policy makers with the opportunity to develop a more proactive approach to drought management (Wilhite 1993). A large number of scientific researches related to drought assessments (Heim 2002) can be found. However, there is a lack of studies related to long-term historical economic impacts caused by past droughts. This research contributes to this goal.

Specifically, the purpose of this research is to assess the impacts of droughts on yield, production, price, and revenue for soybeans in Kentucky during significant drought years. This research did not attempt to develop any econometric model or conduct any trend analysis. The analysis is similar to that of Craft et al. (2013), which analyzed historical economic impacts of drought on corn production in Kentucky. The state significantly depends on its agricultural revenues, and droughts can cause severe economic hardship. Understanding the impacts of drought on Kentucky's soybean crop will allow planners and policy makers to make better decisions about drought mitigation.

BACKGROUND

Kentucky is ranked 14th out of 50 U.S. states in total output of soybeans (NASS 2014) and thus, a significant sector in the agricultural economy of the state. For the year 2012, soybeans were the fourth most important agricultural commodity in Kentucky contributing USD 741 million (14 %) of the state's farm receipts, and they are the state's second largest agricultural export (USD 448 million) (USDA ERS 2014). Thus, given the significance of soybeans to the state of Kentucky, anything that may harm the industry, including drought, can have significant impacts on the agricultural sector and the entire economy of Kentucky.

As noted above, drought is one of the most damaging, costly, complex, and naturally reoccurring natural hazards, which impacts multiple sectors of society (Andreadis et al. 2005; Pulwarty et al. 2007; Wardlow et al. 2009). Over the period 1980–2011, nationally, there were 16 droughts/heatwaves causing damages of USD 210.1 thousand millions (inflation adjusted to 2011 dollars) (Smith and Katz 2013). Although drought impacts many sectors of society, agriculture is often cited as the economic sector most susceptible to drought (Frederick and Schwarz 2000; Wu and Wilhite 2004; Horridge et al. 2005). For example, the U.S. Midwest drought of 2005 caused over one thousand million USD in damage, much of it in agricultural losses primarily to corn and soybeans; the 2000 drought extending over the south-central and southeastern U.S. caused over USD 4 thousand millions in damages with significant losses to agriculture and related industries; and the 1998 drought that extended from Texas/Oklahoma eastward to the Carolinas caused over USD 6 thousand millions in damages to agriculture and ranching (Lott and Ross 2006).

According to Palmer et al. (1996), drought is the single most important factor limiting the yield of soybeans. This claim is substantiated by a number of studies that examine the impact of drought on yield as well as other attributes on soybean plant growth and development throughout the world (Podesta et al. 1999; Liu et al. 2004; Oya et al. 2004; Samarah et al. 2006; Sinclair et al. 2007; Fraisse et al. 2008; Mishra and Cherkauer 2010; USDA ERS 2013). These studies investigated the impacts of drought and drought stress on soybeans in the USA, China, Korea, Paraguay, Brazil, Argentina, and Denmark.

The USDA ERS (2013) study reports that during the 2012 drought in the U.S., soybean yields were the lowest since 2003. Mishra and Cherkauer (2010) examined the impact of drought periods between 1916 and 2007 on corn and soybeans in the Midwestern U.S. states of Illinois and Indiana and found that corn and soybean yields were strongly correlated with drought indices. Fraisse et al. (2008) studied soybean yields in Paraguay over the period from 1982 to 2007 comparing yields during El Niño years with La Niña years. Their results showed statistically significantly lower precipitation levels during planting and blooming during La Niña years relative to El Niño years, and soybean yields were up to 37 % lower during La Niña years. In Argentina, Podesta et al. (1999) studied the relationship between yield anomalies of major crops, including soybean, in an El Niño Southern Oscillation (ENSO) phase. With respect to soybean, they found a clear association between lower precipitation levels and lower yields. All of these studies confirm that drought poses significant adverse impacts on soybean production.

The purpose of this study is to document and describe drought impacts on soybean in Kentucky. The research examines relationships between drought episodes, soybean prices, and associated revenues of the state's soybean production. As noted above, agricultural revenues are significant to the economy of Kentucky, and thus, drought episodes can cause severe economic hardship. Therefore, it is useful to estimate the impact of drought on soybean production in Kentucky so that policymakers, public managers, and farmers can improve decision making in order to mitigate the adverse impacts of drought. Assessing the impacts of past droughts on Kentucky's soybean production will help reduce future drought vulnerability.

DATA AND METHODOLOGY

In order to quantify the economic impacts of drought (in U.S. dollars) on soybeans in Kentucky, several datasets were utilized. The commodity data were obtained from the National Agricultural Statistics Service (http://www.nass.usda.gov/). Since this research is focused on drought impacts, the original county-level data were organized into Kentucky's four climate divisions: Western, Central, Bluegrass, and Eastern (Fig. 1). Climatological drought severity can vary among these climate divisions. Hence, aggregation of soybean data by climate division permits direct comparison between drought and soybean production, yield, and revenue among these regions (e.g., Wilhite et al. 1987; Sonmez et al. 2005; Quiring 2009). Once the county-level data were aggregated into the appropriate climate divisions, the yield data were compared with the production data. The county-level soybean data cover the period of 1972–2009. However, state-level soybean data are available from 1929 to 2009. Having a long range of data allows for better comparison and analysis. It was expected that during drought years, the analysis would show changes in yield and production.

Annual price data for each commodity came from the National Agricultural Statistics Service. This source has price data dating back to 1940s for soybeans. Prices were

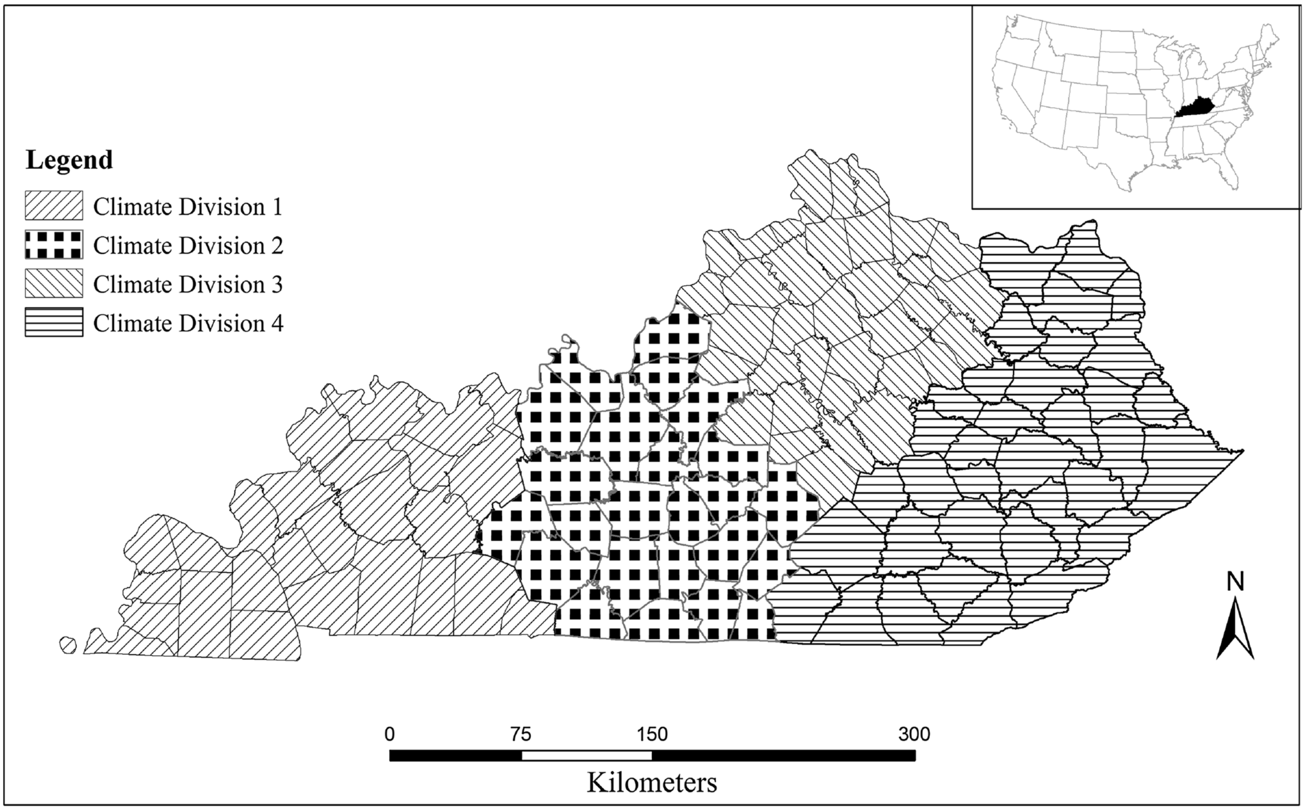

Fig. 1 Kentucky climate divisions

normalized to 2010 U.S. dollars by using the U.S. Department of Labor, Bureau of Labor Statistics, Consumer Price Index (CPI-U) (e.g., Craft et al. 2013). First, a price index was created for each year as follows:

$$\text{Price index} = \frac{\text{Current CPI-U}}{\text{2010 CPI-U}}.$$

The price index for each year was then used to calculate the "real" or normalized price for each year as follows:

$$\text{Real price} = \frac{\text{Current price}}{\text{Price index}}.$$

The 2010 real price of soybeans for each year was multiplied by the production for the same year in order to determine soybean revenue.

This study used Palmer Drought Severity Index (PDSI) to determine severe droughts for different climate divisions of Kentucky. The PDSI data were obtained from the National Oceanic and Atmospheric Administration (NOAA) (NOAA 2010). It is the most popular, and perhaps most widely used, measure of drought. The PDSI is based on a scale of −6.0 to 6.0 where positive values suggest wet conditions, while negative numbers signify dry conditions (Palmer 1965). This index takes precipitation, evapotranspiration, and soil moisture into account (Alley 1984). Hence, PDSI is a more robust measure compared to simple rainfall anomaly data. Moreover, no historical soil moisture data are available for Kentucky and for the U.S. Note that some of the longest soil moisture datasets are only little longer than two decades old. PDSI is widely used by many governmental agencies such as the U.S. Department of Agriculture (USDA) and the NOAA (Svoboda et al. 2002). The PDSI is used throughout the United Stated as well as other areas of the world (Kogan 1995; Hu and Willson 2002).

The PDSI was developed to determine multi-month long dry or wet spells [NDMC (2013)]. As a result, this index may not be suitable for detecting short-term dry or wet conditions. It is also found that this approach often underestimates runoff during summer and autumn seasons (e.g., Rushton and Ward 1979). Other limitations include omission of frozen ground or snow melt (Alley 1984). The challenge with this scale is that it was derived based on a study which was focused on central Iowa and western Kansas and may not be applicable to other regions.

Diaz (1983) identified ≥ 3 consecutive months of PDSI ≤ -2.0 as moderate drought, while a major drought defined as ≥ 6 consecutive months. He also suggested that a drought comes to an end when the index returned to positive values. Diaz (1983) also noted that this type of classification works well for droughts in the eastern United States. When this criterion was applied to Kentucky composite PDSI data, six drought episodes were selected for the analysis: 1930–1931, 1940–1942, 1952–1955, 1987–1988, 1999–2001, and 2007. They also represent multi-year droughts (1930–1931, 1940–1942, and 1952–1955) and the three worst recent droughts (1987–1988, 1999–2001, and 2007).

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 soybeans was determined, the revenue during that year was compared to the decadal average. For example, the state total revenue for soybeans during the significant drought year of 1940 was determined and compared to the average revenue of that decade (1940–1949). A decadal average was used to account for the change in technology over time. Also, this was done to determine if revenue was lower during a significant drought year compared to neighboring years.

RESULTS AND DISCUSSION

In Kentucky, soybeans are usually planted around mid-May, when temperatures are usually warm and precipitation is plentiful (Egli 2008). Figure 2 shows the soybean production and yield for the entire state from 1929 to 2009 and that soybean production remained generally unchanged until the 1960s. Up to this time, soybeans in Kentucky were mostly used for forage or grain. Farmers began to increase planting of soybeans in the 1940s in response to societal demand (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.

The years with the highest prices occurred in the 1940s and again 1970s (Fig. 3a). However, Kentucky soybean revenue stayed relatively unchanged from 1940 through the 1950s (Fig. 3b) mainly due to low production during this period (Fig. 2). Once soybeans became a desired commodity, the demand increased and it led to significantly increased revenue. So it is not surprising that the annual soybean revenues increased dramatically in the late 1960s and stayed the highest during 1970s and early 1980s due to high soybean prices as well as high production (Fig. 3). Thereafter in the mid-1980s, soybean revenues began to decline and level off due to the gradual decline of soybean prices (Fig. 3a).

Figures 4 and 5 show soybean yield and production of Kentucky's four climate divisions, respectively. Due to unavailability of data, historically significant drought years before 1972 could not be included for county and division level assessments. We were only able to examine the more localized impacts of drought on soybean for the 1988, 1999–2001, and 2007 droughts.

Analysis shows, overall, the Western division had the largest annual soybean production throughout the period (1972–2009), when compared with the other three climate divisions (Fig. 4). All four climate divisions reported noticeable reduction in yield and production during the 1988, 1999–2001, and 2007 droughts (Figs. 4, 5). For the Western division, the lowest soybean production year

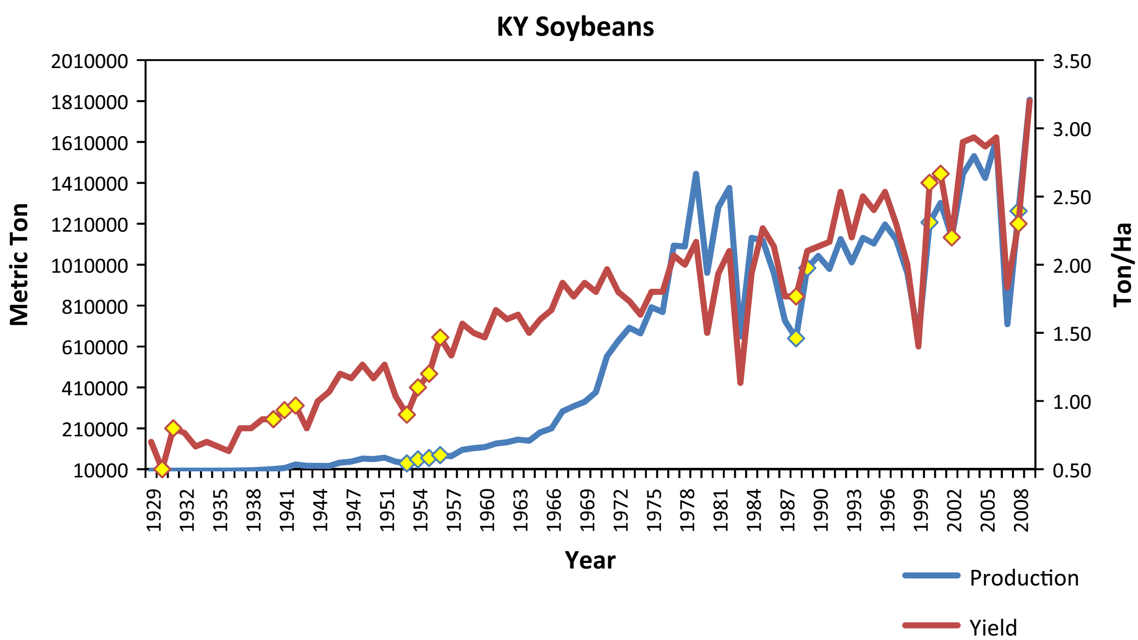

Fig. 2 Kentucky soybean production and yield. Drought years are shown by *yellow diamonds* in this and following figures. *Data source* NASS (2010)

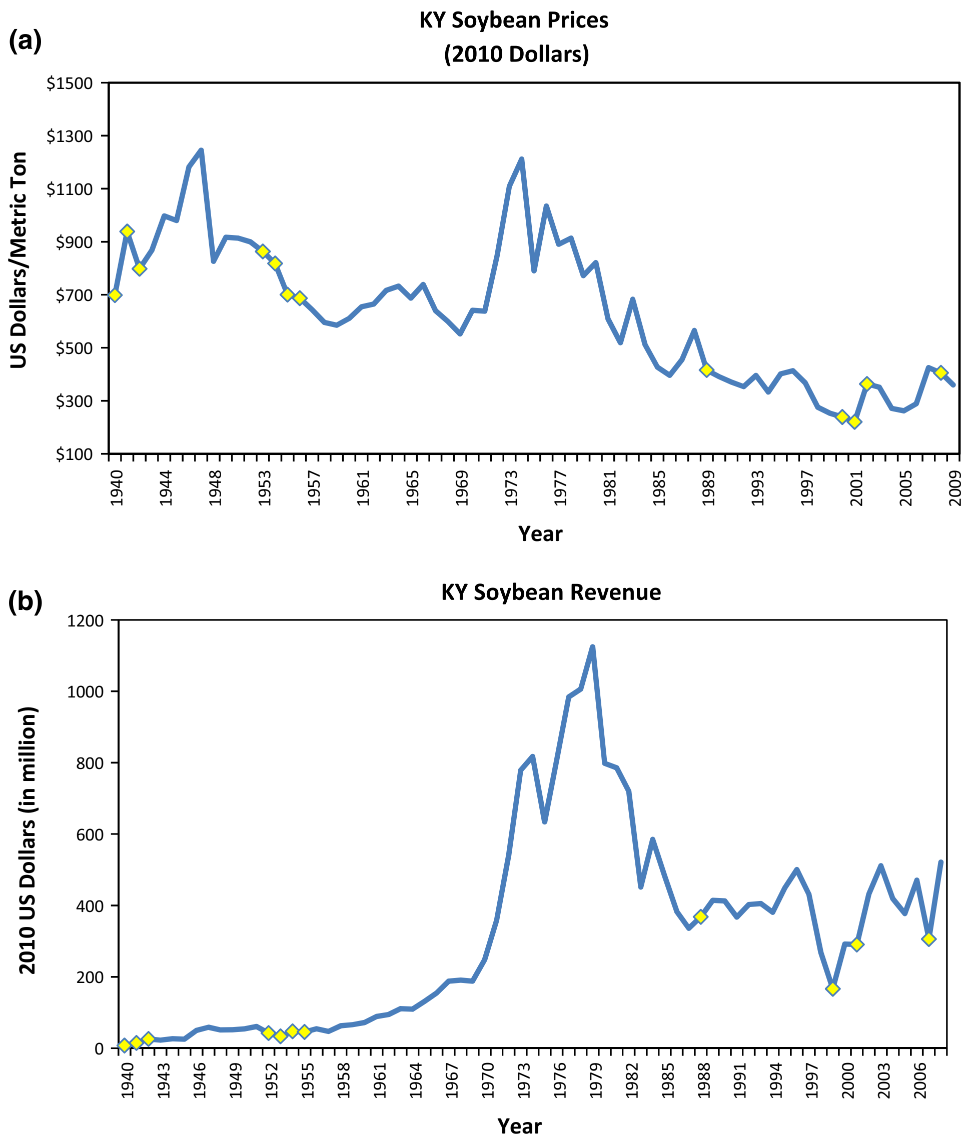

Fig. 3 **a**, **b** Kentucky soybean price and revenue. *Data source* NASS (2010)

occurred in 2007, which was one of the most recent significant drought years in Kentucky. In 2007, Western division produced only 538 039 metric tons of soybeans which was 717 336 metric tons less than 2006. For the other climate divisions, 1972–1976 were among the lowest soybean production years. Again this is likely due to the fact that soybeans were a fairly new commercial crop to these divisions.

Due to unavailability of the division level data for pre-1972 period, we only estimated soybean revenues from 1972 to 2009 for the four climate divisions (Fig. 6). During this period, 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. This is expected as this year also had the third lowest price during the period of 1940–2009 (USD 253.17 ton^{-1}). Data suggest that 1999 was a particularly 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 lowest revenue (USD 5 674 833) year for the Bluegrass and Eastern divisions occurred in 1972. This amount was USD 2 612 337 less than the revenue of 1973. The Eastern division also experienced its lowest revenue (USD 2 164 131) in 1972. Production in 1972 was fairly low which probably contributed to low revenues. Other low revenue years occurred in 1987–1988, 1991, 2000–2001, and 2007. Hot and dry conditions occurred in 1987 which was a precursor to the severe drought of 1988. Though prices during 1987–1988 were among the highest,

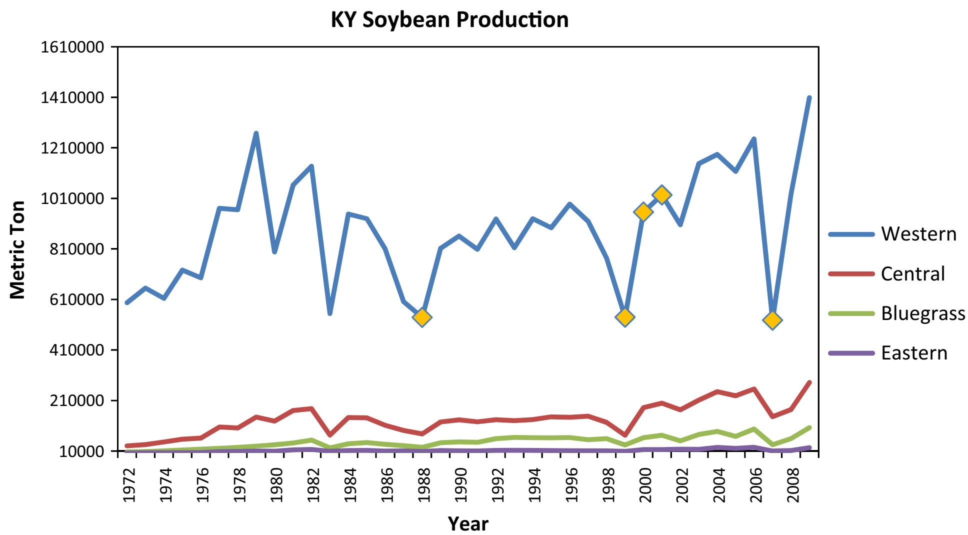

Fig. 4 Kentucky soybean production by climate division. *Data source* NASS (2010)

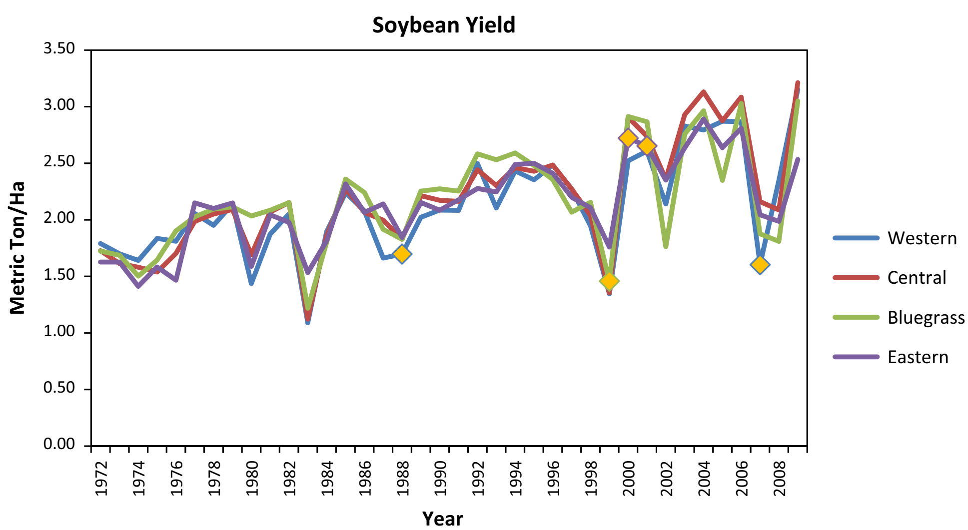

Fig. 5 Kentucky soybean yield by climate division. *Data source* NASS (2010)

decreased productivity and quality resulted in low revenues (Tables 1, 2, 3, and 4).

The year of 1999 was among the lowest 10 soybean revenue years for all four climate divisions. During this year, revenue ranged from USD 3 551 932 to USD 265 461 248 across the state. The year of 1999 was also in the lower 20 production years for all climate divisions. Overall, Western division observed the highest production and the Eastern division the lowest. Annual mean temperature in 1999 was among the 20 highest years for all four climate divisions. Precipitation totals ranged from 870 mm (mean = 1149 mm) in the Bluegrass division to 1042 mm (mean = 1209 mm) in the Western division. Annual PDSI values during this year were also in the negatives for the Western, Central, and Bluegrass divisions.

Below, we present further detailed analysis of each of the drought episodes and their impacts on soybeans.

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 U.S. in 1930. During this time, the Ohio Valley and regions of the Southeast experienced wet conditions. This wetness diminished quickly in February, and by the time spring

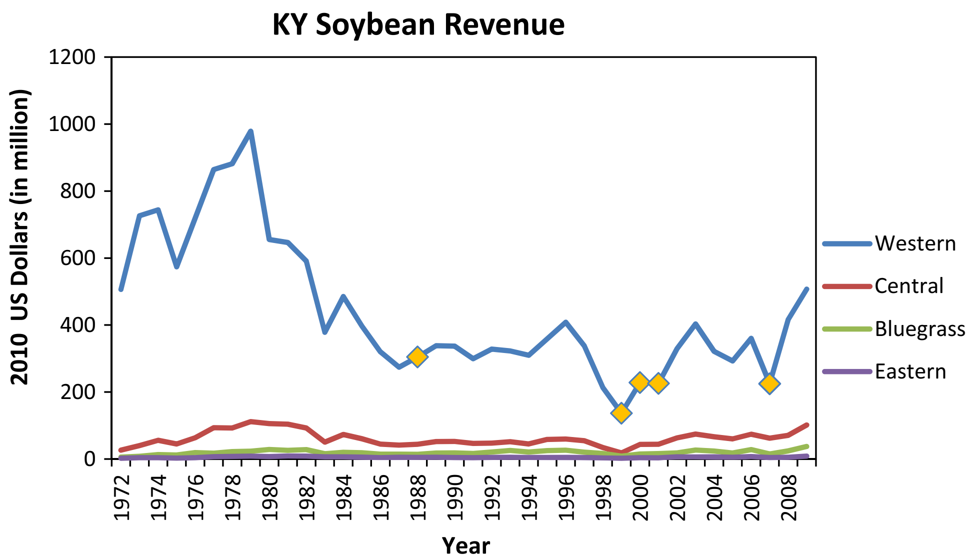

Fig. 6 Kentucky soybean revenue by climate division. *Data source* NASS (2010)

Table 1 Soybean quality of 1987. *Data 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 2 Soybean quality of 1988. *Data 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

arrived in 1930, all of Kentucky's climate divisions were experiencing dry conditions with annual precipitation totals ranging from 671 to 837 mm. The Western division had the highest annual precipitation, total of 837 mm, while the lowest (671 mm) was observed in the Bluegrass division. The drought started out as moderate (PDSI −2.0 to −2.9) in April and May, and turned to severe (PDSI −3.0 to −3.9) in the Central division in June. In July, the conditions worsened and three of the climate divisions were in the extreme category (PDSI < −4.0), while the Western division remained under the severe category. By August, all four climate divisions were in the extreme drought category and remained there for the rest of the year.

The start of 1931 did not bring any relief for the dry conditions. By the end of April 1931, drought severity started to improve. Finally, by December, all climate divisions, except the Eastern division, were receiving normal rainfall. During 1930–1931, crop yield and production were extremely low. In 1930, soybean production was 1836 metric tons, which was 1628 metric tons (47 %) below the decadal average. Since data for 1920s were not available, decadal average from 1930s was used for this purpose and the following calculation. During 1931, production increased to 3564 metric tons which was still low compared to this time period but was approximately 99 metric tons (3 %) more than the decadal average. As noted above, due

Table 3 Changes in soybean yield, production, and price (ton^{-1}) compared to decadal averages in Kentucky during significant drought years. *Data source* NASS (2010)

Drought year	Yield (metric ton ha^{-1})	Production (metric ton)	Price (2010 dollars)
1930	−0.22	−1628	N/A
1931	+0.08	+99	N/A
1940	−0.18	−24 802	−USD 231.90
1941	−0.11	−19 807	+USD 8.08
1942	−0.08	−3175	−USD 132.25
1952	−0.22	−23 292	+USD 137.34
1953	−0.36	−31 959	+USD 101.17
1954	−0.15	−12 681	+USD 55.79
1955	−0.05	−5472	−USD 61.71
1988	−0.10	−34 2333	+USD 25.02
1999	−0.82	−38 7702	−USD 102.47
2000	−0.04	−14 8419	−USD 75.35
2001	+0.02	−52 299	−USD 93.64
2007	−0.82	−55 3149	+USD 111.16

Table 4 Soybean revenue during drought years. Data source: NASS (2010)

Drought years	Revenue deficit compared to decadal average (2010 dollars)	Percent change
1930	N/A	N/A
1931	N/A	N/A
1940	−USD 25 906 461	−77
1941	−USD 18 606 873	−56
1942	−USD 7 558 417	−23
1952	−USD 8 920 535	−17
1953	−USD 18 114 955	−35
1954	−USD 4 097 742	−8
1955	−USD 5 853 069	−11
1988	−USD 164 250 344	−29
1999	−USD 210 644 043	−56
2000	−USD 113 551 421	−28
2001	−USD 114 731 591	−28
2007	−USD 57 880 972	−14

to the absence of county-level data prior to 1972, divisional level assessment was not possible for 1930–1931.

Drought of 1940–1942

During the fall of 1939, mild drought spreads from the Midwestern and Northeastern U.S. into Kentucky. Some relief to drought condition did come in the spring of 1940, but the drought quickly reintensified in the summer and fall. The drought reached to 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 (statewide mean = 1200 mm) was received across the state.

The 1940–1942 drought years had significant impacts on crop yields [e.g., on corn (Craft et al. 2013)]. Kentucky produced 10 881 metric tons of soybean in 1940 (Fig. 2). This was 24 802 metric tons (70 %) lower than average production for the decade of 1940–1949 (Table 3). During the year of 1941, soybean production increased to 15 876 metric tons, which was 19 807 metric tons (56 %) lower than average (Fig. 2; Table 3). As expected, soybean production increased with alleviation of drought condition. For example, during the year of 1942, soybean production increased to 32 508 metric tons, which was still 3175 metric tons (9 %) less than the average from the period of 1940–1949 (Fig. 2; Table 3).

Kentucky obtained USD 7 601 467 revenue from soybean in 1940 (Fig. 3b). This was the lowest revenue year on record from 1940 to 2009 and was USD 25 906 461 (77 %) lower than the average soybean revenue for the 1940s (Table 4). In 1941, soybean revenue nearly doubled to USD 14 901 055 (Fig. 3b). Though this was a significant increase from 1940, it was still USD 18 606 073 below the decadal average (Table 4). Soybean revenue continued to increase during 1942, generating USD 25 949 511 which was USD 7 558 417 lower than the decadal average (Fig. 3b). Revenue loss from 1941 and 1942 was 56 and 23 % lower than decadal average, respectively (Table 4).

Drought of 1952–1955

By June 1952, the drought had spread across all of Kentucky and continued to increase its severity. Drought conditions continued until February 1955. By September 1952, moderate drought condition prevailed, and by November, the whole of Kentucky except the Eastern division was in a severe drought. This pattern continued into the spring of 1953. Drought severity was reduced during June 1953 but the severity returned during the fall, and by December 1953, the whole of Kentucky was in an extreme drought.

Kentucky soybean production during drought of 1952–1955 was very low. In 1952, the state produced 47 304 metric tons of soybeans (Fig. 2). This was 23 292 metric tons (33 %) below the decadal average, and total revenue from soybean was USD 42 555 151. It was USD 18 369 498 lower than the revenue of 1951 and USD 8 920 535 (17 %) lower than the 1950–1959 average (Table 4). In 1953, soybean production was 38 637 metric tons, which was 45 % lower than decadal average. Production increased during the remaining two years of the drought. In 1954, the state produced 57 915 metric tons of soybeans and generated USD 47 377 945 revenue. Though this was an increase from the previous two years, revenue for 1954 was USD 4 097 741 (8 %) below the decadal average (Table 4). In 1955, the state produced 65 124 metric tons of soybeans. However, the increase in production caused prices to decrease to the lowest level during the four-year drought period. Revenue for 1955 totaled USD 45 622 618, which was USD 5 853 069 (11 %) below the decadal average (Table 4).

Drought of 1987–1988

The drought of 1987–1988 started in the western U.S. in 1987, and by the beginning of 1988, the drought intensified over the Great Plains and spreads to most of the eastern part of the U.S. In Kentucky, the drought reached to its peak during the summer of 1988. The 1987–1988 drought is known as the most costly in the U.S. history. The losses of energy, ecosystems, water, and agriculture were estimated to be USD 39 thousand millions (Riebsame et al. 1991).

In 1987, Kentucky produced 735 136 metric tons of soybeans (Fig. 2). This year was among the seven lowest soybean production years for Kentucky for the period from 1972 through 2009. Since the drought was more severe during 1988, soybean production declined to 650 012 metric tons, 2 % lower than 1987. In 1987, the state generated USD 367 536 002 (Fig. 3b) in soybean revenue, which was USD 196 569 985 less than the decadal average. Although the production was lower in 1988 relative to 1987, prices were approximately USD 560 metric ton^{-1} higher. This helped to generate revenues of USD 399 967 724 in 1988, which were slightly higher than that of 1987. However, this was still USD 164 250 344 (29 %) lower than the decadal average (Table 4).

During week 34 of 1987 through week 35 of 1988, 0 % of soybeans were identified as being in excellent condition which indicates the severity of the drought (Tables 1, 2). Soybean quality reached to its poorest conditions during week 27 of 1988, when 44 % of soybeans were considered to be in poor condition and 22 % were in very poor condition. This continued until around week 34, when the percentage of poor soybean quality decreased. Though the conditions did improve toward the end of the growing season, the majority of soybean remained in the fair condition category.

Drought of 1999–2001

The year of 1999 started out as a moderately dry year for Kentucky, and drought conditions quickly intensified during 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 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 severity began to alleviate and improved conditions prevailed during the fall and winter of 2001.

Soybean yield and production were low during the year of 1999. The average yield in 1999 was approximately 1.41 metric tons ha^{-1}, which was 0.61 metric tons ha^{-1} lower than the decadal average. Total production for the year of 1999 was 655 279 metric tons (Fig. 2). Prices were low at a value of only USD 253.17 metric ton^{-1} (Fig. 3a). Perhaps, this was due to very poor soybean quality. Low production and prices resulted in 1999 being the lowest soybean revenue year for Kentucky between 1980 and 2009. In 1999, the state only generated USD 165 897 035 (Fig. 3b) from soybeans, which was USD 210 644 043 (56 %) lower than the decadal average (Table 4).

The years of 2000–2001 were better in terms of soybean yield and production. The average yield in 2000 was approximately 2.62 metric tons ha^{-1} and approximately 2.69 metric tons ha^{-1} in 2001 (Fig. 3a). 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 was better with a production of 1 311 771 metric tons. However, the increase in production did not result in significantly higher revenues. During 2000–2001, prices remained low and revenues were among the lowest in recent times. The state generated only USD 290 661 270 from soybean in 2000 and USD 289 284 792 in 2001 (Fig. 3b). These totals put the year of 2000 at USD 113 551 421 and the year of 2001 at USD 114 731 591 below the average for the decade.

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 (not shown). By week 30 of 1999, approximately 4 % of soybeans were in excellent condition, and the percentage of soybeans in fair and poor conditions began to increase. About 29 % soybeans were reported to be in poor and very poor conditions around this time period (not shown). The quality of soybeans improved through 2000–2001 and larger percentages were reported to be in good and excellent condition during these years compared to 1999.

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 encompassed the Mid-Atlantic States, and several short-lived dry-episodes occurred in the Ohio Valley, the Northeast, and the northern Plains (NOAA 2007a). 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. Hot and dry conditions continued until the fall of 2007 when relief finally came to the state (NOAA 2007b). By December 2007, the Western and Central divisions were experiencing wet spells, while the Eastern division moved from an extreme to moderate drought classification.

Total soybean production was 719 173 metric tons, 553 149 metric tons (44 %) lower than the decadal average (Fig. 2). Low production raised prices to their highest value (USD 425.37 metric ton^{-1}) seen since 1988 (Fig. 3a). Although the price was high, revenue was still low due to overall low production. The state generated USD 305 914 538 from soybean in 2007 (Fig. 3b) and it was USD 57 880 972 below the decadal average.

Soybeans in 2007 started out as mostly in good condition but as the drought progressed, quality started to decline (not shown). Toward the beginning of the growing season, most weeks experienced 15–25 % of excellent quality soybeans. This number quickly declined to around 0–8 % during week 32 and remained there until the end of the growing season. During 2007, every week experienced poor and very poor soybean conditions. Toward the beginning of the growing season, the percentage of soybeans with very poor quality ranged from 2 to 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 resulted in lowering of quality. As mentioned previously, even though soybean prices were high during 2007, due to low production, revenue remained low.

CONCLUSION

Since drought impacts are poorly documented, they are often underestimated (Hayes et al. 2002). Drought impact studies, like this research, are useful because it allows societies to lower drought vulnerabilities in the future by quantitatively documenting magnitude of crop losses. It is possible to generally understand or climatologically assess whether a particular drought is severe or moderate, etc. However, policymakers typically request for monetary evaluation of losses during and after a drought, before allocating public funds and also for providing guidance in planning for future droughts. Policymakers also, justifiably, request for assessments (including monetary) in the historical drought context. These types of assessment allow a political entity (e.g., Kentucky) to be, monetarily and otherwise, prepared for droughts (proactive vs. reactive). Possibilities of future droughts cannot be eliminated. However, by proactively allocating resources (which typically requires public funds), hardship on the inhabitants and local/regional economies can be minimized. Note that crop and resultant economic loss not only affect farmers, but also affect local, regional, and national economies. In addition, this type of assessment helps in long-term planning. For example, whether the Commonwealth of Kentucky will invest more in research and promotion of a certain crop or management practices (e.g., irrigation).

In addition, 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 (NIDIS 2007). This research contributes to this goal by documenting drought impacts on agriculture and aiding in the quest for more efficient and informed drought management. In this research, soybean yield, production, and revenues were examined for significant drought years.

State-level soybean data are available for the years 1929–2008; however, county-level data are only available from 1972 to 2008. Due to this unavailability, division level assessment of impacts of drought on soybeans was not possible prior to 1972. Results from the state level did show that soybean yield and production have been increasing throughout the period of record due to the advancement in technology. We also found that during the significant drought years, soybean yield and production were lower than neighboring years. This suggests that drought indeed has a negative impact on Kentucky's soybean yield and production.

Typically, the price of soybeans increased during periods of drought. The low yield and production totals allowed farmers to sell their soybean at higher prices than usual. During drought periods, the demand for soybeans was often higher than the supply which forced prices to increase. Soybean prices also declined during some droughts, especially during severe droughts, when soybean quality was low. Results also show that revenue was typically lower than neighboring years even with higher prices during periods of drought.

The findings from this research indicate that the years of 1999 and 2007 experienced noticeably low soybean yields compared to their respective decade average (Tables 3, 4). During these years, soybean yield was 0.82 metric tons ha^{-1} less than the decadal average. These 2 years were also the lowest production years of the significant drought years. In 2007, production was 553 149 metric tons lower from the decadal average. As a result, prices were over USD 111 higher ton^{-1} compared to the decadal average. In 1999, not only was production down (387 702 metric tons less than the decadal average) but also the price (USD 102.47 lower ton^{-1} than the decadal average). This was likely due to the lower quality of soybeans (not shown). Therefore, compounded with low production, it (low quality) further drove down the revenue (not shown) and made 1999 the most costly drought in terms of soybean revenue loss (>USD 200 million) since 1940. Since price data are not available prior to 1940, the significant drought years' 1930–1931 revenue could not be determined. It should be mentioned that each drought year since 1980s, excluding 2007, experienced more than USD 100 million annual revenue loss compared to their respective decadal average (Table 4).

From this research, it can be concluded that Kentucky's soybean crop is vulnerable to drought, and impact assessment is of vital importance. Results show that during significant drought years, soybean production, yields, and revenue decrease significantly and resulted in negative impacts on Kentucky's economy. Future research needs to include more commodities and other sectors that are affected by drought. Otherwise, drought impacts and risks assessment will remain incomplete, and the economy will remain vulnerable to future droughts.

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