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## Research Article

# A Spatiotemporal Analysis of Sorghum in the United States

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Sorghum is a type of grain, forage, and sugar crop that has been grown in warm, arid climates around the world for 10,000 years. It is a drought-tolerant crop, and is among the most efficient crops in the conversion of solar energy and use of water. In the United States, South America, and Australia, sorghum grain is used primarily for livestock feed and ethanol production and is becoming popular in the human food sector because of its use in gluten-free food products. The U.S. sorghum belt stretches from South Dakota to southern Texas. From the mid-1950s to the mid-1980s, sorghum was harvested, on average, from more than 14 million acres of cropland. Today, the United States harvests just over 7 million acres, with most of those acres in Kansas (2.7 million) and Texas (2.25 million). This article provides a spatiotemporal analysis of sorghum grown in the United States over the past century to help understand farmers' decision making in response to changing markets, policy, and environmental variables. **Keywords:** agriculture, sorghum, United States.

Sorghum is a grain, forage, and sugar crop that is among the most efficient crops with respect to its use of water and conversion of solar energy. It is extremely drought tolerant and is used primarily for livestock feed and ethanol production. It is also gaining in popularity in the human food sector (mostly with respect to the growth in gluten- and GMO-free food products) in the developed world (Sorghum Checkoff 2015), but it has long been a dietary staple in arid regions around the world. Sorghum was one of two cereals, along with pearl millet, that was part of the African savanna agricultural complex, and along with wheat (Near Eastern complex) and rice (southern and eastern Asia) comprised the three major cereal agricultures of the Old World (Harlan 1977). Evidence of wild sorghum was widespread throughout much of Africa, and although it is not possible to locate a center for sorghum domestication, evidence suggests that the most probable area was in a zone that stretched from Lake Chad to east central Sudan (Harlan 1971) in the African Sahel. Evidence of sorghum from archaeological digs near the Egyptian–Sudanese border have been dated at 8,000 BC, and from there domestication spread throughout Africa and continued to India and China circa 2,000 BC (Harlan and Stemler 1976; Smith and Frederiksen 2000; Sorghum Checkoff 2015).

Although various reports suggest that a sorghum relative, broomcorn, was likely grown by Benjamin Franklin in the late 1700s (Smith and Frederiksen 2000), Martin (1936) suggested that the first sweet sorghum was introduced into the United States from France in 1853, having been introduced to France from China two years prior. Other sweet sorghums (used for syrup production as opposed to other cultivars grown for forage and grain) were introduced in later years from South Africa, with production

centered in South Carolina and Georgia. Syrup pressed from sweet sorghum has declined from over 24 million gallons in the 1890s to less than 1 million gallons today (Oklahoma State University Extension 2015), but new research has investigated the efficacy of sweet sorghum as a biomass source for ethanol production (Wang *et al.* 2012). Sudangrass, another type of sorghum, was introduced in 1909 from Sudan as a forage crop and was widely planted in Texas with encouragement from the Chillicothe, Texas Agricultural Field Station (Smith and Frederiksen 2000). Production of both sweet and forage sorghums in the United States are dwarfed when compared to grain varieties. The U.S. Department of Agriculture National Agricultural Statistics Service (USDA NASS) reported in 2014 that only 315,000 acres of sorghum—4.6 percent of the total acreage of all sorghums grown—was used for forage or silage (USDA NASS 2015), and the most recent report of sweet sorghum grown for syrup from the Census of Agriculture was in 1964, where it was reported that ~12,000 acres were harvested, yielding 1.1 million gallons of syrup.

Grain sorghum, originally known as guinea corn, came to the United States many years before sweet sorghums. Known as rural branching durra and white milo maize, this sorghum reached the West Indies on slave ships from Africa. However, the first grain sorghum to be successfully used for grain cultivation in the United States was white durra, which was introduced into California from Egypt in 1874. It soon reached the Great Plains and was known as Egyptian rice corn, and became popular in Kansas during the late 1880s (Smith and Frederiksen 2000), where H. W. Smith of Garden City, Kansas, was attributed as the original pioneer in sorghum plant breeding and hybridization (Quinby *et al.* 1958). Smith was committed to developing a

crop that could adapt to the harsh and volatile climate of the Great Plains and that could be harvested using the same large, mechanized implements that were used to grow the successful wheat crops of the region. Further hybridization of sorghum cultivars continued throughout the nineteenth and twentieth centuries at agricultural experiment stations throughout the Great Plains.

This article reports spatial and temporal changes in U.S. sorghum production at the county, state, and national scales from circa 1930 to the present, with specific eras of increased and decreased production highlighted. Yield data were also used to compile a risk assessment analysis that compared planting and harvesting sorghum and corn that can be used to help aid in farmers' decision-making efforts with regard to which crop they should focus their agricultural production endeavors on. Data reported in this article were obtained from the USDA NASS Quick Stats 2.0 interactive data query tool (USDA NASS 2015) and from the USDA's quinquennial Census of Agriculture through manual data entry or the downloading of data from the Desktop Data Query Tool 2.0 (USDA 2015).

## U.S. Sorghum Production

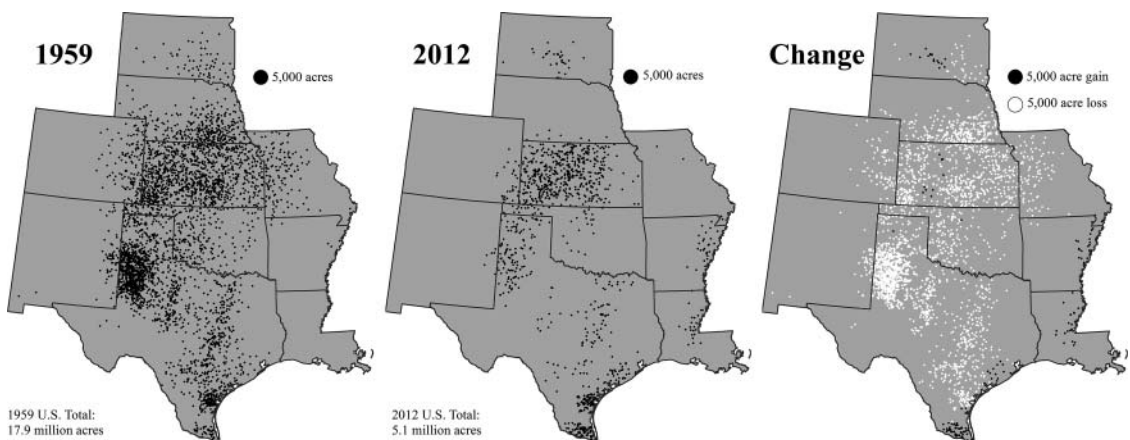
Farmers harvested 6.7 million acres of sorghum in the United States in 2014—6.4 million acres for grain and 315,000 acres for silage (USDA NASS 2015). This acreage was down from historic highs in the mid to late 1950s, when U.S. farmers harvested nearly 22 million acres. In 1990 farmers harvested just below 10 million acres; 36 percent of the U.S. sorghum crop was exported; 62 percent was used for livestock feed; and 2 percent was used for food, alcohol (e.g., ethanol), and other industrial uses. By 2014 U.S. farmers were growing 3 million fewer acres of sorghum than

in 1990—a 30 percent reduction—but with 56 percent of the crop being exported, 25 percent used for livestock feed, and nearly 19 percent being used for food, alcohol, and other industrial uses (USDA Economic Research Service (ERS) 2015a).

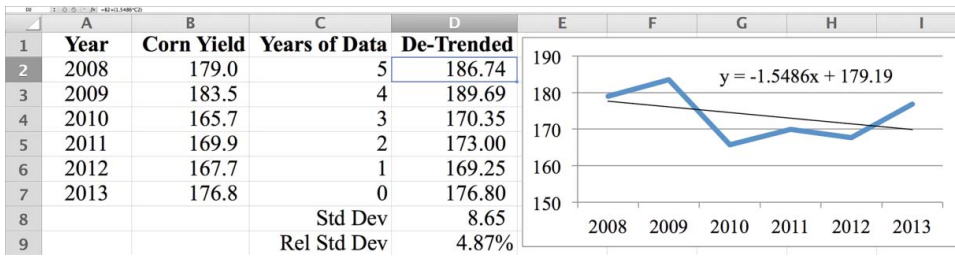
In the late 1950s, sorghum was commonly grown in the Plains states of Nebraska, Kansas, Texas, Oklahoma, and Missouri, with smaller areas of production found in Colorado, South Dakota, and New Mexico (Figure 1). Mirroring national production trends, sorghum production plateaued during a period from the late 1950s to the 1980s, at which time all major sorghum-growing states began a precipitous decline, with only a few small areas where sorghum production remained constant or new areas where localized acreage has expanded (e.g., far south Texas, central South Dakota, and in the Arkansas and Louisiana portions of the Mississippi Delta).

Sorghum's decline across most of the ten-state study area has been driven largely by technological advancements and economic competitiveness with respect to other crops—especially corn and to a lesser extent cotton in the Texas panhandle—coupled with the widespread adoption of irrigation across much of the region. Seed companies, after World War II, focused their attention on crops such as corn, soybeans, and to a lesser extent wheat, rather than on sorghum (R. W. Elmore, personal communication June 17, 2015). New, advantageous, yield-enhancing traits such as drought tolerance and pest resistance were introduced into corn, soy, and wheat varieties and gave them an economic benefit over sorghum. New varieties, coupled with subsequent increases in market demand for corn and soybeans, drastically reduced acreage devoted to growing sorghum.

Historically, the U.S. sorghum export market has been dominated by Mexico, Japan, and to a lesser



**Figure 1** Acres of sorghum grown for grain or silage/fodder in 1959, 2012, and the change in acres between the two years. Sorghum grown in these ten states accounts for over 95 percent of all sorghum acres grown in the U.S. in both dates. Source: USDA Census of Agriculture 1959, 2012.



**Figure 2** An example (using corn yield for Thayer County, NE from 2008–2013) of de-trending the yield data: data downloaded from NASS Quick Stats (column B), the number of years of data found in the dataset starting at 0 with the most current year (column C), and the resulting de-trended data (column D). The equation used for cell D2 is shown in the equation box at the top of the figure:  $=B2+(-1.5486*C2)$ . The value of -1.5486 comes from the coefficient for the yield trend variable in the equation shown in the associated line graph. Standard deviation and relative standard deviation values were calculated in Excel. (Color figure available online.)

extent, sub-Saharan Africa. Recently, however, unusually strong demand from China, seeking a cheaper substitute for corn to use to feed livestock, has increased the price and marketability of U.S.-grown sorghum (USDA ERS 2015b). Sorghum, unlike corn, does not face import quotas and other constraints that often delay or restrict shipments of corn and distillers dried grains (DDGs, a by-product of the ethanol industry used as a supplement to livestock feed) from entering countries such as China, and as such, demand for U.S. sorghum surged. In 2014 China was the principal buyer of U.S. sorghum and could account for more than 90 percent of the 350 million bushels of sorghum the United States could export during the 2014–2015 marketing year (USDA ERS 2015b). The strong increase in demand pushed U.S. sorghum prices higher, resulting in a premium over corn (only the fourth time it has occurred since 1981–1982) that could persist for the second consecutive marketing year.

## Risk Assessment

### National Risk Assessment

Widmar and Gloy (2014) reported on a study they conducted on yield variations between sorghum and corn from the late 1920s to the present. They wanted to investigate the historical variations in corn and sorghum yields to test a risk assessment model they had developed to understand some of the decision-making rationale that farmers might have used to decide whether or not to plant corn or sorghum. To accomplish this, Widmar and Gloy detrended yield values for corn and sorghum (in a process similar to adjusting monetary units for inflation) to adjust for yield increases caused by technological improvements, and to show the impacts of the natural variations that affect crop production, namely weather and climate (Figure 2).

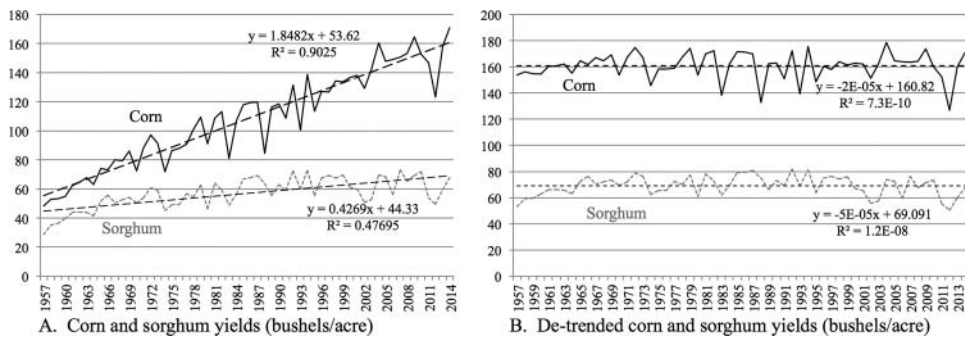
Nationally, corn yields have always been higher than sorghum; today, the average yield for sorghum at

the national scale is 37.5 percent of corn's annual yield, whereas in 1929, sorghum's yield was 55.3 percent of the average corn yield (USDA NASS 2015). The yield gap between the two crops was nearly parallel through the 1930s and 1940s, but began to widen in the late 1950s when more effort was put forth after World War II to find ways to increase per-acre yield in more common and lucrative crops such as corn and soybeans. From 1957 to 2014, corn experienced a yield growth rate of about 1.8 bushels per acre per year, whereas sorghum increased at a rate of 0.4 bushels per acre per year, creating nearly an 80-bushel advantage for corn (Figure 3A). Two of sorghum's major advantages over corn are its ability to consume less water per bushel and its exceedingly high tolerance for drought. To this end, Widmar and Gloy (2014) posited that if sorghum cannot surpass corn based on yield, perhaps it could outcompete corn with respect to yield risks.

From 1957 to 2014, the detrended yield graph (Figure 3B) shows that annual corn yields were slightly more than 160 bushels per acre, whereas sorghum's detrended annual yields were just over 69 bushels per acre. At first glance, corn's annual yields appear to be more turbulent, with the differences between the mean yield and each year's actual (detrended) yield being greater than those associated with sorghum. From this, one could surmise that corn was indeed more risky to plant than sorghum. For the detrended yields since 1957, the standard deviation (SD)—a measure of yield variation—for corn is 10.3 bushels, whereas sorghum is 7.5.

However, it is important to note that corn and sorghum have different means to compare their standard deviations to. If these standard deviations are made relative to their respective means, we find that the relative standard deviation (RSD) for corn is 6.4 percent and sorghum is 10.9 percent (showing that sorghum is, in fact, the riskier crop to grow for the nation as a whole). Widmar and Gloy (2014) concluded:

The implications for these results are that, across the U.S., you can expect sorghum yields to have more variation relative to their mean,



**Figure 3** Yield trends for corn and sorghum, 1957 to 2014 (A), and de-trended yields (B). Source: USDA ERS, 2015a.

and are more risky, than corn yields. And while this does not discount the research suggesting that sorghum might be more drought tolerant, it highlights an important point that a crop with more drought tolerance does not necessarily have less yield risks.

#### State- and County-Level Risk Assessment

Although Widmar and Gloy's (2014) assessment of risk comparing corn and sorghum at the national scale is telling, it does not take into account the major variations in growing conditions found throughout the various regions of the country where both corn and sorghum could be harvested, nor does it take into consideration irrigated versus dryland farming practices. Therefore, the next logical step was to assess risk at more local scales. Due to the availability of yield data for corn and sorghum at the state and county scales, Widmar and Gloy's temporal study period was changed from 1957 through 2014 to 1972 through 2013. Data for corn and sorghum were also segmented into nonirrigated and irrigated categories. Irrigating corn will always make it the less risky and more lucrative crop to grow, if there is sufficient access to water. However, farmers who grow dryland corn, either by choice or having been forced to as water availability has declined, are susceptible to the same natural conditions as those who grow sorghum—a crop that is not heavily irrigated (only 6.7 percent of sorghum grown in Kansas was irrigated in 2012).

At the national scale, sorghum ( $RSD = 11.47$ ) remains the more risky crop to plant compared to corn ( $RSD = 7.33$ ), using the shorter temporal study period from 1972 through 2013. Irrigated and nonirrigated data for sorghum and corn were not available for analysis at the national scale. At the state scale using Kansas and Nebraska as examples, corn outcompetes sorghum in both instances (11.74 to 17.97 and 7.10 to 16.01, respectively), with the same being true for selected counties within both states—Ford County, Kansas, and Thayer County, Nebraska. The only scenario in which growing sorghum was less risky than growing corn was when both were grown in dryland (nonirrigated) farming conditions. Nonirrigated

sorghum had a lower relative standard deviation than nonirrigated corn at both the state and county scales.

Kansas State University agronomist Kraig Roozeboom (personal communication June 19, 2015) studied sorghum and corn yields in counties from western Kansas, eastern Colorado, and southwestern Nebraska. Sorghum yields were, on average, 43.8 bushels per acre and corn yields were 43.1 bushels per acre from 2000 to 2006. Further east (an area with more rainfall) and on experimental test plots managed by Kansas State University, 1990 to 2003 average dryland sorghum and corn yields were 109 and 102 bushels per acre, respectively. Using production data and estimated costs of inputs needed to grow both dryland corn and sorghum, Roozeboom concluded that, taking into account variability in yields across the study area, if corn yields were 80 to 90 bushels per acre or more, sorghum yield would likely be less, whereas if corn yields were less than 80 to 90 bushels per acre, sorghum yields would be higher. With respect to economic profitability, if corn yields were 75 to 95 bushels per acre or less, sorghum would be the more profitable crop to grow (given market prices and input costs for both corn and sorghum). Corn yields higher than 75 to 95 bushels per acre would make corn the more profitable dryland crop to grow.

#### Conclusion

Sorghum is a drought-tolerant, energy-efficient crop grown in arid regions around the world. Found in the arid western and southern plains of the United States, sorghum's abundance on the agricultural landscape has diminished as other crops such as corn have become—by and large—more economically advantageous to produce. In these arid regions where irrigation is not present to augment precipitation deficits, sorghum has been shown to outcompete corn with respect to per acre yield (Assefa and Staggenborg 2010). This research has also shown how a risk-assessment model created by Widmar and Gloy (2014) could be used to calculate risk at subnational and local scales, and could be used by stakeholders to determine whether or not sorghum could (or should) be part of their agricultural production portfolio.

The future of sorghum has also evolved. Sorghum is a nongenetically modified organism (GMO-free) grain, as well as gluten-free, leading to a recent increase in the direct consumption of sorghum, especially in the developed world, as a food. Approximately one third of the U.S. grain sorghum crop is used for biofuel production (Sorghum Checkoff 2015) as sorghum and corn, on a per-bushel basis, produce the same amount of ethanol. Sorghum DDGS, a by-product of the ethanol industry, tend to be lower in fat and higher in protein than corn-based equivalents, which prove beneficial for some in the livestock (both beef and dairy) industry. What might be the most important aspect with respect to future sorghum production is its tolerance for drought and its ability to thrive in low-moisture conditions, as water levels in the Ogallala/High Plains aquifer—found below much of the region where most of the U.S. sorghum crop is grown—continue to decline (Kromm and White 1992; Hornbeck and Keskin 2014). Further research is needed to compare precipitation and temperature trends in regions where both sorghum and corn are grown to help determine how future climate change could affect agricultural production and to help determine whether or not farmers should make sorghum a more dominant crop on the region's agricultural landscape.

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