PRODUCER RETURN ON INVESTMENTS IN SORGHUM RESEARCH AND PROMOTION: AN UPDATED ANALYSIS FROM 2008 TO 2021

Research Report to the
United Sorghum Checkoff Program (USCP) Board

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Report to the United Sorghum Checkoff Board by the Agribusiness, Food, and Consumer Economics Research Center (AFCERC), Department of Agricultural Economics, Texas A&M University, College Station, Texas

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The Agribusiness, Food, and Consumer Economics Research Center (AFCERC) provides analyses, strategic planning, and forecasts of the market conditions impacting domestic and global agricultural, agribusiness, and food industries. Our high-quality, objective, and timely research supports strategic decision-making at all levels of the supply chain from producers to processors, wholesalers, retailers, and consumers. An enhanced emphasis on consumer economics adds depth to our research on the behavioral and social aspects of health, nutrition, and food safety. Through research efforts, outreach programs, and industry collaboration, AFCERC has become a leading source of knowledge on how food reaches consumers efficiently and contributes to safe and healthy lives. AFCERC is a research and outreach service of Texas A&M AgriLife Research and Texas A&M AgriLife Extension and resides within the Department of Agricultural Economics at Texas A&M University.

ABSTRACT

This report is the third evaluation of the effectiveness of the sorghum checkoff program as required by the Sorghum Promotion, Research, and Information Order. The first study was completed in August 2013, and the second study was completed in November 2017. This report updates the two previous evaluations over the period 2008 to 2021 and addresses two basic questions to sorghum growers: (1) what have been the effects of sorghum checkoff investments on sorghum production, use, and prices paid to growers? and (2) what have been the benefits or returns to producers from their investments in the checkoff program associated with feed use, food and industrial use, and exports? For every checkoff dollar invested in crop improvement over the period 2008 to 2021, the net return on investment was $28.70 when modeling sorghum production as the product between harvested acreage and yield, and $35.01 when modeling sorghum production directly. The net return on investment attributed to renewables, sustainability, and market development associated with sorghum food and industrial use over this period was $4.99. The net return on investment attributed to programmatic activities associated with sorghum exports over this period was $7.46. On the other hand, no statistically significant impact was evident between checkoff dollars associated with renewables, sustainability, and market development and sorghum feed use. As well, a strengths, weaknesses, opportunities, and threats (SWOT) analysis was conducted, and recommendations for management of the sorghum checkoff program were made.

ACKNOWLEDGEMENTS

The research reported was conducted under contract with the United Sorghum Checkoff Program Board (USCP). The programmatic expenditures associated with sorghum promotion used in this study were collected with the assistance of USCP Executive Director Norma Ritz Johnson and Kurt Shultz, Senior Director of Global Strategies, USGC. Recognition is due to Loren Burns, AFCERC Program Manager, and Macie McCollum, AFCERC Student Worker, for their help in preparing this report. The conclusions reached and any views expressed in this report are those of the authors and do not necessarily represent those of USCP or Texas A&M University.

INTROSPECTIVE SUMMARY

This report is the third evaluation of the effectiveness of the sorghum checkoff program as required by the Sorghum Promotion, Research, and Information Order. The first study was completed in August 2013, and the second study was completed in November 2017. This evaluation, like the two previous evaluations, is intended to provide actionable information for sorghum checkoff program stakeholders as to the effectiveness of the checkoff program regarding its various promotional activities.

This evaluation entitled "Producer Return on Investments in Sorghum Research and Promotion: An Updated Analysis from 2008 to 2021" was conducted by Dr. Oral Capps, Jr., Executive Professor, Regents Professor, and Co-Director of AFCERC and by Dr. Mark Welch, Professor and Extension Economist at Texas A&M University.

The full report will be available from Norma Ritz Johnson, Executive Director of the United Sorghum Checkoff Program (USCP). Excerpts include:

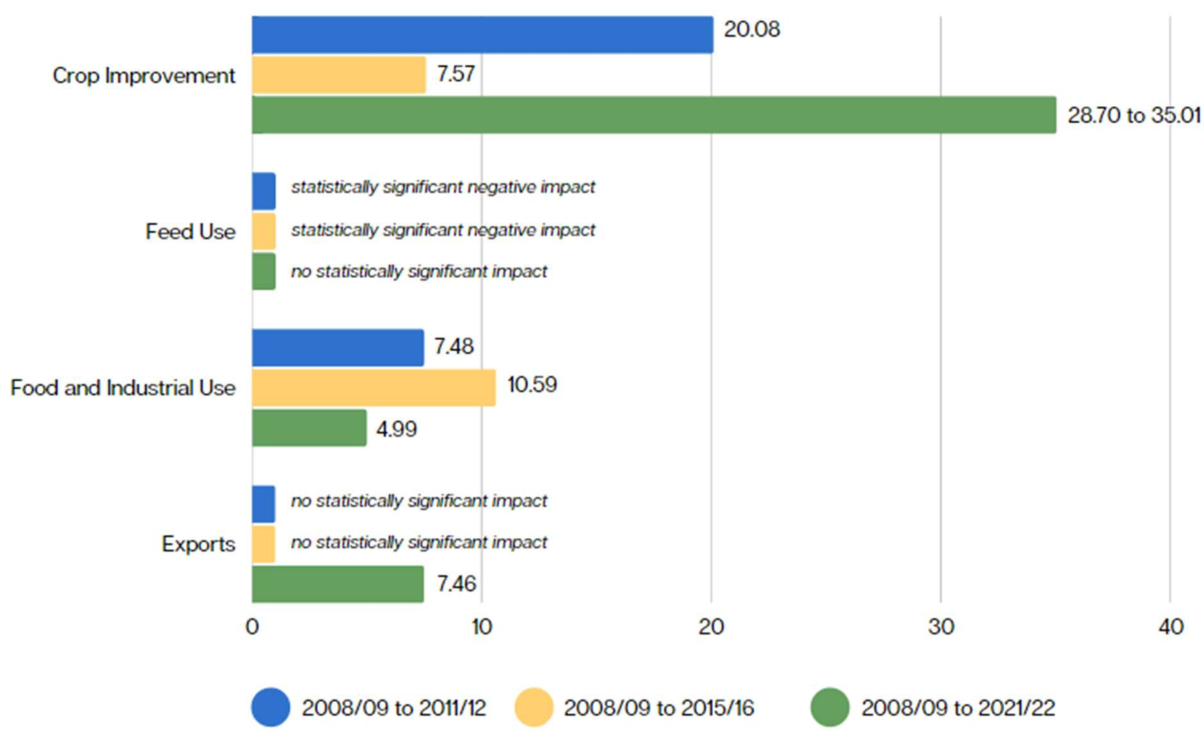
- USCP was established in 2008 with the objective of investing producer dollars to increase profitability in the sorghum industry.
- Sorghum checkoff investments in crop improvement activities boosted sorghum planted acreage in each year by 2.6% on average and harvested acreage by about 2.3% on average since the beginning of the program. These impacts were greater than those reported in the second evaluation wherein USCP investments in crop improvement activities boosted sorghum planted acreage year by 1.0% on average and harvested acreage by about 0.9% on average. Based on the first evaluation, despite the gains in planted and harvested acreage attributed to USCP, the gains were not statistically different from zero.
- Sorghum checkoff crop improvement activities enhanced yields by 0.39%, tantamount to a 0.26 increase in bushels per acre. That said, this increase was not significantly different from zero. This result is not surprising given the short amount of time that the checkoff program has been in operation (13 years) and the long period of time that often is required for research to register impacts on yields. The increase in yields experienced in recent years was found to be due mainly to weather and other technological innovations, such as adoption of minimum and no-tillage practices. This finding concerning the impact of crop improvement activities on yields aligns with the findings from the previous two evaluations.
- As a result of crop improvement activities of the USCP, sorghum production rose 2.68% to 3.35% between 2008 and 2021, a total increase in sorghum production of 133.3 million bushels to 166.8 million bushels over that period. This impact was much larger than those gleaned from the second evaluation wherein the efforts of USCP led to increases of sorghum production of 0.25%. However, this impact was smaller than that gleaned from the first evaluation wherein the efforts of USCP led to increases of production of 3.2% to 4.6%.
- Funds committed to crop improvement activities led to a higher sorghum farm price each year by an annual average on the order of 1 to 2 cents per bushel. From the second evaluation, funds committed to crop improvement activities led to a higher sorghum farm price each year by an annual average on the order of 2 to 3 cents per bushel. From the first evaluation, the impact on

sorghum farm prices attributed to funds committed to crop improvement activities was not statistically different from zero.

- Given the estimated production and price impacts of the sorghum checkoff investments in crop improvement activities, the farm value of U.S. sorghum production was higher by $620.0 million to $751.6 million (3.06% to 3.71%) over the period of 2008 to 2021. This impact on the farm value of U.S. sorghum production was much larger than those gleaned from the previous two evaluations.
- For every sorghum checkoff dollar invested in crop improvement, the net return to stakeholders was in the range of 29 to 1 to 35 to 1. That is for every checkoff dollar invested in crop improvement, the return to producers (net of the checkoff expenditures) was $28.70 to $35.01. Based on the second evaluation, for every sorghum checkoff dollar invested in crop improvement, the net return to stakeholders was about 7.6 to 1. That is for every checkoff dollar invested in crop improvement, the return to producers (net of the checkoff expenditures) was $7.57. Based on the first evaluation, efforts made by USCP in committing funds to crop improvement activities were positive in enhancing overall farm revenue. The net return to stakeholders was 20.1 to 1. That is for every checkoff dollar invested in crop improvement, the return to producers (net of the checkoff expenditures) was $20.08.
- No statistically significant impact or return to stakeholders was evident from sorghum checkoff investments in promoting sorghum feed use. This finding is on par with the previous two checkoff evaluations.
- In contrast, sorghum checkoff investments increased food and industrial use of sorghum by an average of about 2.4 million bushels each year for a total of 31.4 million bushels of additional sales of sorghum over the period of 2008 to 2021. This finding was lower than the finding from the first evaluation wherein sorghum checkoff investments increased food and industrial use by 4.1 million bushels on average each year as well as the finding from the second evaluation wherein sorghum checkoff investments increased food and industrial use by 6.0 million bushels on average each year.
- For every sorghum checkoff dollar invested to promote food and industrial uses of sorghum, the net return to stakeholders was estimated to be nearly 5 to 1. That is, the investment of $21.5 million in sorghum checkoff funds to promote sorghum use for food and industrial purposes enhanced the farm value of sorghum sales by about $128.8 million, a net benefit-cost ratio or return-on-investment of 4.99 to 1. This net return on investment associated with food and industrial uses of sorghum was lower than the 7.5 to 1 return from the first evaluation and the 10.6 to 1 net return from the second evaluation.
- The USCP provides funds to promote sorghum exports directly to the U.S. Grains Council (USGC). Those funds in turn are used in conjunction with Foreign Agriculture Service (FAS) dollars in the Foreign Market Development (FMD) program, the Market Access Program (MAP), and the Agricultural Trade Program (ATP). In other words, the USGC leverages USCP dollars with FAS dollars.
- The Sorghum Checkoff and the U.S. Grains Council work together to build demand for U.S. sorghum around the globe; however, this partnership is not the only international effort for U.S. sorghum promotion. The Sorghum Checkoff has partnerships with state organizations, state departments of agriculture, the Southern United States Trade Association and Food Export Midwest to pursue opportunities by creating programs to develop markets and promote trade. A

joint venture with multiple organizations bolsters the Sorghum Checkoff's footprint and international efforts allowing the pursuit of projects not possible within their standalone budget. Additional programming brings together prospective sorghum buyers with producers and sellers in the United States, training that educates overseas companies on how to import U.S. grain as well as facilitation of rail and port facilities to increase economic and trade opportunities. The Sorghum Checkoff also partners with others to market U.S. sorghum overseas involving cost sharing of various expenses including trade shows, advertising, demonstrations, and trials.

- Unlike the previous two evaluations, sorghum export promotion expenditures (USCP and FAS) positively and *significantly* affected total sorghum exports. In the previous two evaluations the impact on investments to enhance sorghum exports were not significantly different from zero.
- The programmatic activities of the USCP and the FAS geared toward sorghum exports led to a rise of 1.72 million metric tons cumulatively over the 2008 to 2021 period. The investment of roughly $44.5 million over the period 2008 to 2021 resulted in a gain of $376.7 million. The return on investment or the net benefit-cost ratio was calculated to be 7.46 to 1.
- A graphical summary of the return-on-investment or benefit-cost ratios across the three respective evaluations is provided:



Caution must be exercised in making comparisons of various evaluations across years. The economic phrase/condition, *ceteris paribus*, meaning all other factors invariant, does not hold. Data for the underlying endogenous and exogenous variables which come from various government sources have been revised and updated, and now six additional years of data are available not only pertaining to these variables but also pertaining to the data associated with the programmatic expenditures of the United Sorghum Checkoff Program.

- Given that checkoff expenditures often require time for those investments in various markets to register statistically significant effects and that the USCP only has been in existence since 2008, this report notes **continued** *"movement in the right direction"* in achieving the goal of enhancing profitability in the sorghum industry.
- The study results suggest several recommendations for the management of the sorghum checkoff program:

(1) *Increased funding for crop improvement activities which have successfully boosted acreage, sorghum production, and the farm value of production.*

Although yields have yet to show a statistically significant response to research investments, the response time of yields to research often is slow. Maintaining domestic and international competitiveness through research aimed at increasing sorghum yields is likely to be a critically important and strategic choice for the investment of sorghum checkoff funds.

(2) *A reallocation of promotion funds from feed demand to the demand for sorghum in food and industrial uses.*

Promoting the use of sorghum in the production of ethanol, gluten-free products, pet foods, aquaculture, and renewable chemicals rather than for feed used is likely to provide maximum opportunities for enhancing producer profitability. If funds are invested in feed demand promotion, priority investments may include research to enhance the quality of sorghum as a feed grain to better compete with corn. Additionally, investments may include the promotion of non-genetically modified (non-GMO) sorghum for livestock feeding.

(3) *Increase USCP funding and/or leveraging of FAS dollars associated with export promotion*

Given the statistically significant effect of export promotion on sorghum exports, efforts should center attention on increasing USCP funding and/or leveraging of FAS dollars for export promotion. Given the size of export markets and the need to maintain or enhance the competitiveness of U.S. sorghum in international markets, investment and/or re-engineering of export promotion programs is critical to the future viability and profitability of the U.S. sorghum industry. Any funds allocated to export promotion would likely be most successful in enhancing producer profitability if focused on three priorities: (1) maintaining market share and export volume in China; (2) recapturing market share and volume in Japan and in Mexico; and (3) gaining market share in sub-Saharan Africa, particularly Sudan.

(4) *Maintain quality records on funds committed to various activities over time to support effective evaluation of the sorghum checkoff program.*

A substantial amount of time in this project was devoted to obtaining accurate data on expenditures committed to various activities, namely crop improvement, market development, renewables, sustainability, and exports. A complete record management system and database of checkoff expenditures made over time and across production, research, and promotional activities would greatly facilitate efforts to effectively evaluate the performance of the sorghum checkoff program going forward.

(5) *Devise a system for collecting and warehousing data in state level checkoff expenditures.*

This program evaluation did not include sorghum checkoff expenditures made by state programs because those data were not available. Efforts to retrieve those data were largely unsuccessful. As well, this evaluation did not include FAS expenditures for sorghum promotion prior to 2000, again because those data were not available. Consequently, the results of this study may not reflect the full impact of the checkoff funds spent to promote the profitability of the sorghum industry.

EXECUTIVE SUMMARY

This study is the third evaluation of the impacts and returns to checkoff investments made by the United Sorghum Checkoff Program (USCP) as required by the Sorghum Promotion, Research, and Information Order under authority of the 1996 Farm Bill (FAIR Act).

Specific missions of USCP are to increase yields through investment in research programs and to increase the demand for sorghum through a set of marketing, promotion, and education programs, thereby providing U.S. producers with expanding markets for their commodity. An increase in demand may occur through an expansion of the use of sorghum in the domestic market in the ethanol industry, as a livestock feed or as a feedstock for advanced biofuels, through the development of new uses for sorghum, and/or by expanding sorghum exports. The overarching goal of all USCP activities is to maximize return on grower investment.

USCP was established in 2008 with the objective of investing producer dollars to increase profitability for the sorghum industry. The overall objective of this evaluation of USCP programs, like the two previous evaluations, is to provide the sorghum industry with meaningful and reliable measurements of the impacts of sorghum checkoff activities on the sorghum industry over time. Thus, this report intends to assist USCP in the management of its programs while meeting legislative requirements and maintaining established academic standards for such evaluations. To accomplish this overall objective, we undertake the following activities:

(1) Provide a qualitative analysis of the U.S. sorghum industry, including a strengths, weaknesses, opportunities, and threats (SWOT) analysis of the sorghum industry, as background to the subsequent quantitative analysis of the effectiveness of sorghum checkoff programs.

(2) Determine the impacts of USCP sorghum-oriented programs implemented since 2008, as related to promotion, research, and information, on the industry.

(3) Evaluate the effectiveness of the "Crop Improvement Program" in relation to changes in yields, planted and harvested acreage, and hence production as well as in relation to changes in profitability through improved management practices.

(4) Evaluate the effectiveness of the "Market Development, Renewables, and Sustainability Program" in relation to the demand for sorghum in export markets and in relation to the demand for sorghum in domestic markets associated with uses in the food industry, in the livestock industry, and in other industries.

The initial evaluation completed in August 2013 and the second evaluation was completed in November 2017. Like the two previous evaluations, this third updated evaluation uses statistical procedures to measure the effects of the programmatic activities of USCP for domestic and export markets for sorghum as well as for the sorghum production. This analysis provides the basis for determining if the programmatic activities of the USCP Board have led to increases in sorghum industry profits as well as for calculating the benefit-cost ratio (BCR) metrics to stakeholders related to sorghum checkoff investments. These return-on-investment metrics can be useful in helping to improve the efficiency and effectiveness of the investments in marketing activities and to provide needed feedback to stakeholders.

In essence, this report answers the most relevant questions to sorghum growers: (1) what have been the effects of sorghum checkoff investments on sorghum production, use, and prices paid to growers? and (2) what have been the benefits or returns to producers from their investments in the checkoff program? The key findings of this study follow and are organized into four groups: (1) expenditures of the United Sorghum Checkoff Program, (2) qualitative background analysis of the sorghum industry, (3) quantitative analysis of the sorghum checkoff program, and (4) recommendations.

USCP Expenditures

- Total revenues associated with the USCP ranged from $6.6 million to $11.8 million, while total expenses ranged from $6.2 million to $13.0 million. On average, total expenses accounted for roughly 94 percent of total revenues over the period 2008 to 2021.
- Compared to the farm value of sorghum, on the order of $1.13 billion to $2.06 billion from 2008 to 2021, the amount of funds collected from the checkoff is extremely small. The ratio of revenue from assessments to farm value of production, often referred to as the investment-intensity ratio, averaged only 0.54%, ranging from 0.45 percent to 0.60 percent over the 2008 to 2021 period. In other words, the amount of funds collected by USCP has been on the order of one-half of one percent to three-fifths of one percent.
- The share of research expenses to total expenses was in the interval from 18 percent to 50 percent, averaging slightly more than 28 percent. Funds allocated to market development activities ranged from $0.7 million to $4.4 million. The share of market development expenses to total expenses varied from 10 percent to 41 percent, averaging slightly more than 27 percent. Funds allocated to information, communication, and education ranged from $0 million to $2.0 million. The share of information, communication, and education expenses to total expenses was on the order of 0 percent to 15 percent, averaging slightly less than 8 percent.
- Expenses for administration purposes and for USDA oversight and fees ranged from 5 percent to 15 percent, averaging close to 10 percent. USCP sends funds back to states that have submitted paperwork to be qualified organizations. These states use funds for research, market development, and education in conjunction with USCP to benefit U.S. producers. Funds allocated to this passback reserve varied from $1.2 million to $2.5 million. Passback reserve accounted for 19 percent to 35 percent of total expenses, averaging slightly more than 24 percent.

Background Analysis of the U.S. Sorghum Industry

- From 1960 to 2021, a notable decline in acres planted of sorghum, acres harvested of sorghum, and sorghum production was evident. Over the same period, sorghum yields rose modestly. Average yields prior to the checkoff program were 57.6 bushels per acre but average yields during the checkoff program were 67.9 bushels per acre.
- Until 2000, the dominant demand or end use component of sorghum historically has been feed use, followed by exports, food and industry use, and seed use in that order. But over the past 20 years, exports have become the major end use component of U.S. produced sorghum. Industry use is defined as any use of sorghum not related to seed use, feed use, food use, or exports. Currently, food and industry use of sorghum is 9 million bushes, sorghum exports are 310 million bushels, feed and residual use is 115 million bushels, and seed use is 0.86 million bushels.

Consequently, exports and feed and residual use currently account for slightly less than 98 percent of the total disappearance of sorghum.

- On average, sorghum feed use dropped from 457 million bushels between 1975 and 1997, to 234 million bushels between 1998 to 2002, to 158 million bushels between 2003 and 2007, and to 115 million bushels during the mandatory checkoff period. Seed use followed the same pattern, a monotonic decline over the respective four periods on average as with feed and residual use.

- However, sorghum food and industry use rose dramatically 16.7 million bushels on average between 1975 and 1997, 35.2 million bushels on average from 1998 to 2002, 44.1 million bushels on average from 2003 to 2007, and 74.0 million bushels on average between 2008 to 2021. That said, however, since 2019, sorghum food and industrial use has declined markedly to 9 million bushels.

- From 1975 to 2006, sorghum exports ranged from 4.4 million metric tons to 8.3 million metric tons. Then China jumped heavily into global sorghum markets beginning in 2014 driving U.S. exports to slightly more than 6 million metric tons on average over the past eight years. Chinese restrictions on genetically modified (GM) corn imports, a slow corn import approval process, and high corn support prices to Chinese farmers sent the Chinese livestock industry to sorghum, allowing feeders to get around the Chinese GM restrictions and "a variety of trade barriers" on corn. Within a relatively short amount of time, China quickly went from not importing any sorghum at all to being the world's largest sorghum importer.

- The principal U.S. sorghum export competitors are Argentina and Australia. The United States, Argentina, and Australia historically have accounted for 90% to 98% of world sorghum exports. Argentina is the main competitive threat to U.S. sorghum exports.

- An extensive Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis of the U.S. sorghum industry revealed three major areas of strategic importance, including:

  (1) Productivity Issues

    - Yield increases are necessary to keep up with increasing demand given land area constraints to make grain sorghum returns more competitive with alternative crops.
    - Varieties with characteristics such as drought tolerance as well as disease and pest resistance are increasingly important in the face of climate change. Biotech or genetically modified grain sorghum strains may play a role in this effort. But product introduction is dependent upon consumer acceptance
    - Management tools, decision aids, economic thresholds for management decisions are important to support growers in their ability to increase profitability from grain sorghum production.

  (2) Product Development Needs

    - Investment is needed in new uses or processes for grain sorghum in all major uses categories: feed, food, fuel, and industrial. Grain sorghum has the characteristics to make a noteworthy contribution in enhancing respective uses.
    - Advances in grain sorghum product development have the potential to close the price differential between grain sorghum and corn, adding to crop profitability.

(3) Trade

- Exports are the number one use of U.S. grain sorghum currently.
- Argentina and Australia are noteworthy competitors to the United States concerning sorghum exports.
- Product development and trait enhancement can increase the global demand for grain sorghum.
- Trade agreements and trade policies that support market access and the elimination of trade barriers are particularly important for grain sorghum.

This SWOT analysis is very similar to that from the second evaluation. Efforts based on the SWOT analysis from the second evaluation has paid dividends to the sorghum industry as illustrated by the positive and statistically significant impacts of the checkoff program on sorghum production, sorghum prices, farm value of sorghum production, food and industrial use, and sorghum exports. Continued efforts in this regard therefore are warranted.

Quantitative Evaluation of the Sorghum Checkoff Program

- Sorghum checkoff investments in crop improvement activities boosted sorghum planted acreage in each year by 2.6% on average and harvested acreage by about 2.3% since the beginning of the program. These impacts are greater than those reported in the second evaluation wherein USCP investments in crop improvement activities boosted sorghum planted acreage year by 1.0% on average and harvested acreage by about 0.9%. Based on the first evaluation, despite the gains in planted and harvested acreage attributed to USCP, the gains were not statistically different from zero. The incremental increase in planted and harvested acreage likely is linked in part to research and education efforts associated with sugarcane aphid (SCA).

- Sorghum checkoff crop improvement activities enhanced yields by 0.39%, tantamount to a 0.26 increase in bushels per acre. This increase was not significantly different from zero. The increase in yields experienced in recent years was mainly to weather and other technological innovations. This result is not surprising given the short amount of time that the checkoff program has been in operation (13 years) and the long period of time that often is required for research to register impacts on yields. The increase in yields experienced in recent years was found to be due mainly to weather and other technological innovations, such as adoption of minimum and no-tillage practices. This finding concerning the impact of crop improvement activities on yields aligns with the findings from the previous two evaluations.

- As a result of crop improvement activities of the USCP, sorghum production rose 2.68% to 3.35% between 2008 and 2021, a total increase in sorghum production of 133.3 million bushels to 166.8 million bushels over that period. This impact was much larger than those gleaned from the second evaluation wherein the efforts of USCP led to increases of sorghum production of 0.25%. That said, this impact was smaller than those gleaned from the first evaluation wherein the efforts of USCP led to increases of production of 3.2% to 4.6%.

- Funds committed to crop improvement activities led to a higher sorghum farm price each year by an annual average on the order of 1 to 2 cents per bushel. From the second evaluation, funds committed to crop improvement activities led to a higher sorghum farm price each year by an annual average on the order of 2 to 3 cents per bushel. From the first evaluation, funds committed to crop improvement activities, the impact on sorghum farm prices was not statistically different from zero.

- Given the estimated production and price impacts of the sorghum checkoff investments in crop improvement activities, the farm value of U.S. sorghum production was higher by $620.0 million to $751.6 million (3.06% to 3.71%) over the period of 2008 to 2021. This impact on the farm value of U.S. sorghum production was much larger than those gleaned from the previous two evaluations.

- For every sorghum checkoff dollar invested in crop improvement, the net return to stakeholders was in the range of 29 to 1 to 35 to 1. That is for every checkoff dollar invested in crop improvement, the return to producers (net of the checkoff expenditures) was $28.70 to $35.01. Based on the second evaluation, for every sorghum checkoff dollar invested in crop improvement, the net return to stakeholders was about 8.6 to 1. That is for every checkoff dollar invested in crop improvement, the return to producers (net of the checkoff expenditures) was $8.57. Based on the first evaluation, efforts made by USCP in committing funds to crop improvement activities were positive in enhancing overall farm revenue. The net return to stakeholders was 20.1 to 1. That is for every checkoff dollar invested in crop improvement, the return to producers (net of the checkoff expenditures) was $20.08.

- No statistically significant impact or return to stakeholders was evident from sorghum checkoff investments in promoting sorghum feed use. This finding is on par with the previous two checkoff evaluations.

- In contrast, sorghum checkoff investments increased food and industrial use of sorghum by an average of about 2.4 million bushels each year for a total of 31.4 million bushels of additional sales of sorghum over the period of 2008 to 2021. This finding was lower than the finding from the first evaluation wherein sorghum checkoff investments increased food and industrial use by 4.1 million bushels on average each year as well as the finding from the second evaluation wherein sorghum checkoff investments increased food and industrial use by 6.0 million bushels on average each year.

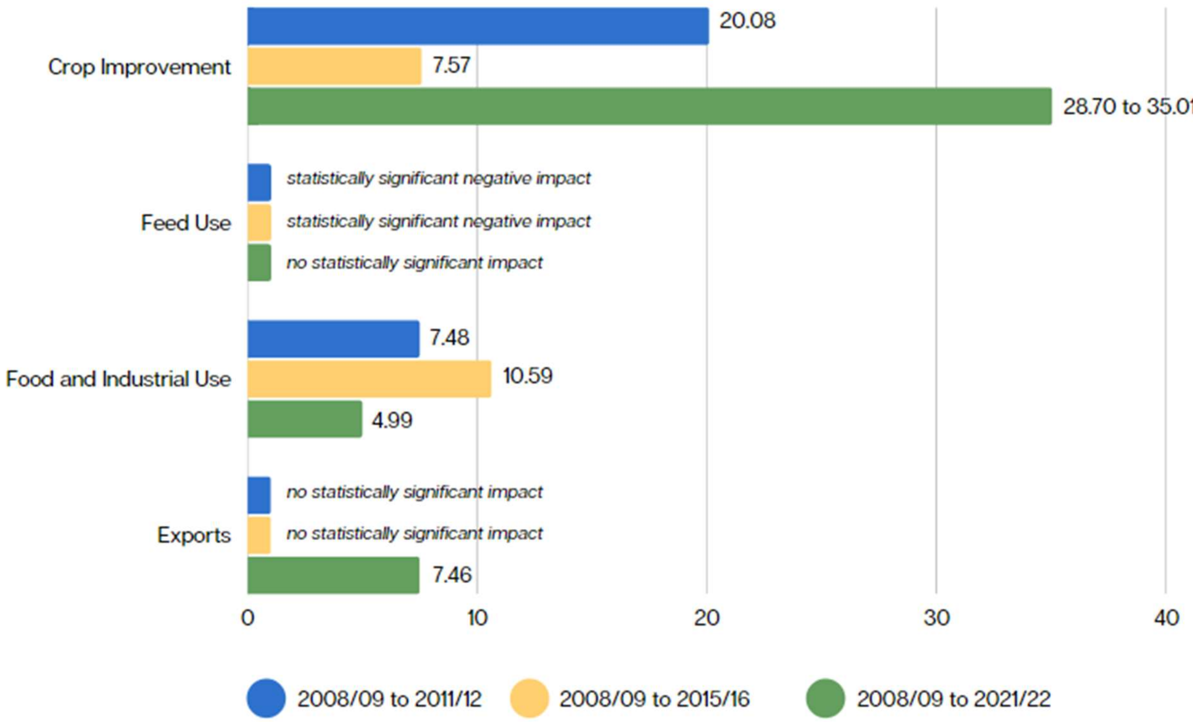
- For every sorghum checkoff dollar invested to promote food and industrial uses of sorghum, the net return to stakeholders was estimated to be nearly 5 to 1. That is, the investment of $21.5 million in sorghum checkoff funds to promote sorghum use for food and industrial purposes enhanced the farm value of sorghum sales by about $128.8 million, a net benefit-cost ratio or return-on-investment of 4.99 to 1. This net return on investment associated with food and industrial uses of sorghum was lower than the 7.5 to 1 return from the first evaluation and the 10.6 to 1 net return from the second evaluation.

- The USCP provides funds to promote sorghum exports directly to the U.S. Grains Council (USGC). Those funds in turn are used in conjunction with Foreign Agriculture Service (FAS) dollars in the Foreign Market Development (FMD) program, the Market Access Program (MAP), and the Agricultural Trade Program (ATP). In other words, the USGC leverages USCP dollars with FAS dollars.

- Unlike the previous two evaluations, sorghum export promotion expenditures (USCP and FAS) positively and significantly affected total sorghum exports. In the previous two evaluations the impact on investments to enhance sorghum exports were not significantly different from zero.

- The programmatic activities of the USCP and the FAS geared toward sorghum exports led to a rise of 1.72 million metric tons cumulatively over the 2008 to 2021 period. The investment of roughly $44.5 million over this period resulted in a gain of $376.7 million. The return on investment or the net benefit-cost ratio was calculated to be 7.46 to 1.

- A graphical summary of the return-on-investment or benefit-cost ratios across the three respective evaluations is provided:



Caution must be exercised in making comparisons of various evaluations across years. The economic phrase/condition, *ceteris paribus*, meaning all other factors invariant, does not hold. Data for the underlying endogenous and exogenous variables which come from various government sources have been revised and updated, and now six additional years of data are available not only pertaining to these variables but also pertaining to the data associated with the programmatic expenditures of the United Sorghum Checkoff Program.

- Given that checkoff expenditures often require time for those investments in various markets to register statistically significant effects and that the USCP only has been in existence since 2008, this report notes continued *"movement in the right direction"* in achieving the goal of enhancing profitability in the sorghum industry.

Recommendations

- The study results suggest several recommendations for the management of the sorghum checkoff program:

  (1) *Increased funding for crop improvement activities which have successfully boosted acreage, sorghum production, and the farm value of production.*

  Although yields have yet to show a statistically significant response to research investments, the response time of yields to research is often slow. Maintaining domestic and international competitiveness through research aimed at increasing sorghum yields is likely to be a critically important and strategic choice for the investment of sorghum checkoff funds.

  (2) *A reallocation of promotion funds from feed demand to the demand for sorghum in food and industrial uses.*

  Promoting the use of sorghum in the production of ethanol, gluten-free products, pet foods, aquaculture, and renewable chemicals rather than for feed used is likely to provide maximum opportunities for enhancing producer profitability. If funds are invested in feed demand promotion, priority investments may include research to enhance the quality of sorghum as a feed grain to better compete with corn. Additionally, investments may include the promotion of non-genetically modified (non-GMO) sorghum for livestock feeding.

  (3) *Increase USCP funding and/or leveraging of FAS dollars associated with export promotion*

  Given the statistically significant effect of export promotion on sorghum exports, efforts should center attention on increasing USCP funding and/or leveraging of FAS dollars for export promotion. Given the size of export markets and the need to maintain or enhance the competitiveness of U.S. sorghum in international markets, investment and/or re-engineering of export promotion programs, is critical to the future viability and profitability of the U.S. sorghum industry. Any funds allocated to export promotion would likely be most successful in enhancing producer profitability if focused on three priorities: (1) maintaining market share and export volume in China; (2) recapturing market share and volume in Japan and in Mexico; and (3) gaining market share in sub-Saharan Africa, particularly Sudan.

  (4) *Maintain quality records on funds committed to various activities over time to support effective evaluation of the sorghum checkoff program.*

  A substantial amount of time in this project was devoted to obtaining accurate data on expenditures committed to various activities, namely crop improvement, market development, renewables, sustainability, and exports. A complete record management system and database of checkoff expenditures made over time and across production research and promotional activities would greatly facilitate efforts to effectively evaluate the performance of the sorghum checkoff program going forward.

  (5) *Devise a system for collecting and warehousing data in state level checkoff expenditures.*

  This program evaluation did not include sorghum checkoff expenditures made by state programs because those data were not available. Efforts to retrieve those data were largely unsuccessful. As well, this evaluation did not include FAS expenditures for sorghum promotion prior to 2000, again because those data were not available. Consequently, the results of this study may not reflect the full impact of the checkoff funds spent to promote the profitability of the sorghum industry.

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PRODUCER RETURN ON INVESTMENTS IN SORGHUM RESEARCH AND PROMOTION: AN UPDATED ANALYSIS FROM 2008 TO 2021

INTRODUCTION

The Sorghum Promotion, Research, and Information Order, commonly known as the United Sorghum Checkoff Program (USCP), was established in 2008 under the Commodity Promotion, Research, and Information Act of 1996. The goal of the USCP is to maintain and expand sorghum markets thereby enhancing the profitability of U.S. sorghum producers. USCP programs are designed to advance sorghum into the ethanol market, develop foreign markets for sorghum, and, in general, enhance the sorghum industry. As required under the Federal Agricultural Improvement and Reform (FAIR) Act of 1996 (7 U.S.C. 7401), the 2008 Order establishing the USCP calls for the Board to "authorize and fund an independent evaluation of the effectiveness of the Order and other programs conducted by the Board pursuant to the Act." An evaluation is to be done "not less often than every five years." The initial required study was published in 2013 (Capps, Williams, and Málaga, 2013). The second required study was published in 2017 (Capps, Williams, and Welch, 2017) This report is the third mandated five-year evaluation of the effectiveness of the sorghum checkoff program and covers the period 2008 to 2021.

USCP conducts market research and development projects, promotion, and related activities under the supervision of the Agricultural Marketing Service (AMS). Specific missions of USCP are to increase yields through investment in research programs and to increase the demand for sorghum through a set of marketing and promotion programs, thereby providing U.S. producers with expanding markets for their commodity. The rightward shift in demand may occur through expansion of sorghum in the ethanol industry, the use of sorghum as a feedstock for advanced biofuels, the development of new uses for sorghum, and expansion of sorghum in international markets. The overriding goal of all USCP activities is to maximize return on grower investment.

The overall objective of this evaluation of USCP programs is to provide the sorghum industry with meaningful and reliable measurements of the impacts of sorghum checkoff activities on the sorghum industry over time. In so doing, this report provides updated measures of program impact and return-on-investment (ROI) measures for the sorghum checkoff program. Specifically, the report undertakes five specific tasks: (1) an analysis of the strengths, weaknesses, opportunities, and threats (SWOT) facing the sorghum industry; (2) measurements of the impacts of USCP sorghum-oriented programs implemented since the inception of USCP in 2008 related to promotion and research; (3) an evaluation of the effectiveness of the "Crop Improvement Program" in boosting yields and production; (4) an evaluation of the effectiveness of the "Renewables, Sustainability and Market Development Programs" in enhancing the demand for sorghum in export markets and in domestic markets associated with uses in the food industry, livestock industry, other industries; and (5) an assessment of the availability and adequacy of data currently in place to support the required evaluation of the impacts of USCP activities over time with regard to establishing key tracking mechanisms that can be analyzed, documented, reviewed and communicated concerning the effectiveness of the checkoff program.

The accomplishment of these tasks requires the measurement, via the use of statistical procedures, of the effects of the programmatic activities of USCP relating to domestic and export markets for U.S. sorghum as well as to sorghum production. These analyses provide the basis for determining if the programmatic activities of the USCP Board have expanded the domestic and export demand for sorghum and for calculating benefit-cost ratio (BCR) metrics related to stakeholder investments in sorghum market development, promotion, and research programs.

In essence, the "metrics" part of program evaluation is an after-the-fact assessment of whether the checkoff program has been "doing things right," that is, whether the program has effectively met its goals after the funds have been committed and expended. This evaluation provides checkoff program managers the critically needed information to: (1) improve the efficiency and effectiveness of the program; (2) design and adjust the program's long-run strategic plan; (3) serve the information needs of contributors, industry, and other stakeholders; and (4) disseminate the information and program impact analysis required by the legislation establishing the program.

SCOPE AND ORGANIZATION

The scope of the project covers data from several periods. Data concerning acres planted, acres harvested, yields and production of sorghum range from 1960 to 2021. Data concerning end uses of sorghum range from 1975 to 2021. Funds committed by USCP cover the period 2008 to 2021. The frequency of data is annual, that is, on a year-by-year basis.

The organization this report is as follows. Initially, we discuss data indigenous to the evaluation of checkoff programs. Next, we provide details associated with the programmatic activities of USCP as well as details on the funds committed (expenditures) made by USCP. Then, we center attention on trends associated with acres planted, acres harvested, yield and production of sorghum. Further, we focus on trends dealing with end uses of sorghum, namely seed use; food and industry use; feed and residual use; and exports. In addition, we develop the specifications of econometric models for planted acres and yields to determine the impact of the checkoff program on sorghum production. In addition, we develop the specification of the econometric model to determine the impact of the checkoff program on sorghum production directly. Hence, we provide indirect and direct ways of ascertaining the impact of the checkoff program on sorghum production. In similar fashion, we also develop econometric models for food and industrial use of sorghum, feed and residual use of sorghum, and sorghum exports to assess the effectiveness of the checkoff program on key end uses of this commodity. Subsequently, we provide a SWOT analysis of the activities associated with the USCP. Finally, to end the report, we provide concluding remarks and recommendations to the sorghum board based on this updated analysis.

DATA INDIGENOUS TO EVALUATION OF CHECKOFF PROGRAMS

Evaluations of programmatic activities associated with any checkoff program face several challenges, the most important of which is the extensive set of data covering an extended period that is required for such analyses. Because the impacts of checkoff programs can be spread over a long period of time, data gathering is required before a quantitative evaluation of the impact of the overall program can be attempted. Other types of evaluation of program impacts, including the effects of research expenditures in increasing sorghum yields, the effects of market development and sustainability in expanding export markets, domestic use of sorghum for feed in various livestock industries, domestic use of sorghum as additives in selected food industries and domestic use of sorghum in ethanol production are data intensive. In general, three sets of data must be collected on a continuing basis from the outset of a checkoff program: (1) benchmark data, (2) market factor data, and (3) checkoff program expenditure data.

Benchmark Data: Data for production, sales, inventories, trade, prices, and related information over time are needed to provide benchmarks against which the checkoff program performance can be measured. The impact of the program on exports or domestic uses, for example, would be impossible to measure without detailed data over a sufficiently long period of time.

Market Factor Data: A second but related set of data that must be consistently collected over time relates to various factors which influence markets associated with the checkoff commodity, such as weather, competing commodity prices, supply, and demand, government domestic and trade policies, etc. In measuring the impact of the checkoff program, the specific effects of the program must be isolated from those of all other factors that can influence the market. Without data on these other factors, controlling for their impacts on the market and then isolating the specific effects of the checkoff program is not possible.

Checkoff Program Expenditure Data: The third set of data that must be systematically and consistently collected over time includes the types, levels, and other details of checkoff program expenditures. These data correspond to the type and level of expenditures approved and made by the checkoff organization over time. Without these data, no assessment of program performance is possible. There are various forms and formats for archiving these important data. However, the data are maintained, it is critical that the projects, activities, and related expenditures be related directly to the strategic plan. Because the strategic plan usually identifies more than one program objective, expenditures made to achieve the separate objectives of the program over time must be able to be identified and separated. In this way, the effectiveness of the program in achieving multiple objectives can be assessed using the relevant program expenditure data. The expenditure data should include funds expended both by USCP and any state sorghum organizations or third-party groups (such as the USGC) as well, particularly if the national checkoff funds are shared in any way with such groups. In addition, collection of historical data is necessary for voluntary programs that were in place prior to the establishment of the mandatory checkoff program in 2008.

Revenues and Expenses Associated with the Sorghum Checkoff Program

The Sorghum Promotion, Research, and Information Program, commonly known as the Sorghum Checkoff Program, was established in 2008 under the Commodity Promotion, Research, and Information Act of 1996. The Act authorizes generic promotion, research, and information activities aimed at advancing the demand for agricultural commodities to benefit U.S. producers. Under the auspices of the Agricultural Marketing Service (AMS), the Sorghum Promotion, Research, and Information Order became effective on May 7, 2008. The collection of assessments began on July 1, 2008. USCP is funded by an assessment of 0.6 percent of the net market value of grain sorghum and 0.35 percent of the net market value of sorghum forage, silage, hay, and billets.

All producers must pay the assessment. Imports of sorghum products also are assessed, but imports are very limited presently. The Secretary of Agriculture is authorized, under the Act, to collect assessments. The Order provides that between 15 and 25 percent of the total assessments collected annually be returned to qualified state programs for promotion and research activities. Currently, nine state-level checkoff programs exist for sorghum. The source of this information is the USCP website, http://www.sorghumcheckoff.com. Prior to the establishment of the mandatory USCP, voluntary tax collections occurred in several states from 1977 to 2008. For example, the Kansas commission collected a half cent a bushel tax on sorghum sold.

The set of sorghum checkoff program revenues and expenditures over the period 2008 to 2021 is exhibited in Table 1. The revenue from assessments and investments ranged from roughly $6.6 million to $11.8 million. Total expenses ranged from $6.2 million to $13.0 million. On average, total expenses accounted for roughly 94 percent of total revenues over the period 2008 to 2021.

Funds allocated to research activities varied from $1.1 million to $4.4 million; the share of research expenses to total expenses was in the interval from18 percent to 50 percent, averaging slightly more than 28 percent. Funds allocated to market development activities ranged from $0.7 million to $4.4 million. The share of market development expenses to total expenses varied from 10 percent to 41 percent, averaging slightly more than 27 percent. Funds allocated to information, communication, and education ranged from $0 million to $2.0 million. The share of information, communication, and education expenses to total expenses was on the order of 0 percent to 15 percent, averaging slightly less than 8 percent. Expenses for administration purposes and for USDA oversight and fees ranged from 5 percent to 15 percent, averaging close to 10 percent. USCP sends funds back to states that have submitted paperwork to be qualified organizations. These states use funds for research, market development, and education in conjunction with USCP to benefit U.S. producers. Funds allocated to this passback reserve varied from $1.2 million to $2.5 million. Passback reserve accounted for 19 percent to 35 percent of total expenses, averaging slightly more than 24 percent.

Certified producer organizations and qualified state organizations include (USDA, 2021):

- Arkansas Corn and Grain Sorghum Board (http://www.corn-sorghum.com/)
- Colorado Sorghum Producers Association (http://www.cosorghum.com)
- Kansas Farm Bureau (https://kfb.org)
- Kansas Grain Sorghum Commission (http://www.ksgrainsorghum.org/)
- Kansas Grain Sorghum Producers Association (http://ksgrains.com/)
- Louisiana Cotton and Grain Association (http://www.lacottonandgrain.com)
- National Black Growers Council (https://nationalblackgrowerscouncil.com)
- National Sorghum Producers (http://www.sorghumgrowers.com/)
- Nebraska Farm Bureau (http://nefb.org/)
- Nebraska Grain Sorghum Association (http://sorghum.state.ne.us/)
- Nebraska Grain Sorghum Board (https://nebraskasorghum.org)
- New Mexico Sorghum Producers Association (http://nmsorghum.com)
- Oklahoma Sorghum Commission (http://oksorghum.com/)
- Oklahoma Sorghum Producers Association (http://oksorghum.com/)
- South Dakota Corn Growers Association (http://sdcorn.org/)
- South Dakota Farm Bureau (https://www.sdfbf.org)
- South Dakota Farmers Union (http://sdfu.org/)
- Texas Farm Bureau (http://texasfarmbureau.org/)
- Texas Grain Sorghum Association (http://texassorghum.org/)
- Texas Grain Sorghum Board (http://texassorghum.org)
- U.S. Grains Council (http://www.grains.org/

Table 1. Sorghum Checkoff Program Revenues and Expenses, 2008/2009 to 2020/2021

	2008/2009	2009/2010	2010/2011	2011/2012	2012/2013	2013/2014	2014/2015
Revenues							
Revenues from Assessments	$7,470,074	$6,582,472	$8,801,109	$6,995,053	$7,872,929	$9,202,775	$9,243,543
Revenues from Investments	$14,404	$27,261	$24,029	$36,372	$41,767	$60,783	$93,027
Total Revenues[1]	$7,448,213	$6,604,438	$8,764,830	$7,167,847	$8,096,736	$9,274,290	$9,369,315
Expenses							
Research	$1,726,321	$1,358,274	$1,409,065	$1,588,428	$3,938,790	$3,520,415	$2,661,125[4]
Market Development	$680,718	$955,147	$1,137,621	$1,117,897	$1,275,243	$1,728,912	$4,250,621[5]
Information, Communication, & Education	$1,102,641	$927,631	$599,234	$936,888	$634,201	$411,332	$525,000[6]
Passback Reserve[2]	$1,281,613	$1,490,010	$2,325,327	$2,014,346	$1,627,393	$2,039,099	$2,043,434
Administration	$643,224	$469,556	$522,308	$477,532	$520,147	$566,606	$685,762
USDA Oversight and Fees	$237,295	$150,000	$222,833	$133,650	$16,896	$126,778	$92,657
Total Expenses[3]	$6,618,819	$6,158,866	$6,666,388	$6,268,541	$8,012,670	$8,393,142	$10,418,095

	2015/2016	2016/2017	2017/2018	2018/2019	2019/2020	2020/2021
Revenues						
Revenues from Assessments	$11,386,443	6,828,574.71	6,306,432.30	5,445,731.40	6,478,841.32	9,103,272.00
Revenues from Investments	$122,913	126,461.38	179,603.17	230,777.00	134,327.57	(1,931.25)
Total Revenues[1]	$11,778,796	7,187,539.76	6,667,169.19	6,444,384.97	6,713,129.24	9,356,912.00
Expenses						
Research	$3,281,186[4]	4,433,896.51	4,433,896.51	1,127,467.18	831,575.89	735,900.94
Market Development	$4,398,627[5]	2,249,160.96	2,249,160.96	2,892,320.99	1,545,381.50	1,659,861.16
Information, Communication, & Education	$2,000,000[7]	-	-	-	94,833.90	243,832.10
Passback Reserve[2]	$2,457,241	1,548,010.35	1,548,010.35	1,430,964.97	1,245,904.82	1,492,101.35
Administration	$720,957	587,512.85	587,512.85	607,928.80	509,562.41	518,970.12
USDA Oversight and Fees	$120,818	100,180.83	100,180.83	149,472.74	142,171.93	176,297.15
Total Expenses[3]	$12,978,829	8,918,761.50	6,208,154.68	4,369,430.45	4,826,962.82	10,307,024.86

[1]Accounts for refunds on double assessments; [2]USCP sends funds back to states that have submitted paperwork to be qualified organizations. These states use funds for research, market development, and education in conjunction with USCP to benefit producers; [3]Exclusive of mandatory reserve, referendum reserve, and refund reserve categories; [4]Research is defined to be crop improvement; [5]Market development is defined to be high value markets and renewables; [6]Information, communication, and education is defined to be regional development; [7]7Information, communication, and education is defined to be the collaborative sorghum investment program

Source: http://sorghumcheckoff.com, various Annual Reports of the United Sorghum Checkoff Program

Table 2. Intensity* of the USCP Program

Marketing Year	Farm Value Dollars	Total Revenues Dollars	Intensity %
2008/09	$1,641,963,000	$7,448,313	0.4536
2009/10	$1,202,331,000	$6,604,438	0.5493
2010/11	$1,616,773,000	$8,764,830	0.5421
2011/12	$1,259,635,000	$7,167,847	0.5690
2012/13	$1,606,237,000	$8,096,736	0.5041
2013/14	$1,716,927,000	$9,274,290	0.5402
2014/15	$1,721,330,000	$9,369,315	0.5443
2015/16	$2,064,638,000	$11,778,796	0.5705
2016/17	$1,352,438,000	$7,187,540	0.5315
2017/18	$1,168,526,000	$6,667,169	0.5706
2018/19	$1,180,847,000	$6,444,385	0.5457
2019/20	$1,125,759,000	$6,713,129	0.5963
2020/21	$1,767,844,000	$9,356,912	0.5293
Total	$19,425,248,000	$104,873,700	0.5399

*Intensity as defined as the ratio of total revenue to farm value expressed as a percent.

Bottom line, this checkoff program is modest in terms of size of expenditures (on the order of $6 million to $13 million) in comparison to other commodity groups. To illustrate, expenditures associated with the milk checkoff program are on the order of $400 million (Capps and Brown, 2022), with the cotton checkoff program, expenditures are on the order of $80 million (Williams *et al*, 2021), and expenditures associated with the soybean checkoff program are on the order of $100 million (Williams, Capps, and Bessler, 2009).

As exhibited in Table 2, compared to the farm value of sorghum, on the order of $1.13 billion to $2.06 billion from 2008 to 2021, the amount of funds collected from the checkoff is extremely small. The ratio of revenue from assessments to farm vale of production (often referred to as the investment-intensity ratio), is, on average, 0.54 percent, ranging from 0.45 percent to 0.60 percent over the existence of the checkoff program. In other words, the amount of funds collected by USCP has been on the order of one-half of one percent to three-fifths of one percent.

USCP funds research projects to improve yield, production, profitability, genetic improvement, and herbicide tolerance. In the livestock industry, USCP has developed educational material for dairies, cattle, feedlots, other livestock operations, and for feed manufacturers designed to increase awareness of the financial benefits associated with the use of sorghum. USCP marketing activities focus on the benefits of using sorghum as a feedstock. These benefits include improvements in efficiency due to less water requirements and other inputs compared to corn as well as the ability of sorghum to be produced on marginal land. Further, USCP supports educational efforts focusing on food and industrial uses. Food uses include gluten-free products and food additives that include high-antioxidant specialty sorghums. On the industrial side, checkoff dollars support research and education to make distillers dry grains (DDGs) more valuable by developing unique, renewable industrial products.

A notable segment of the U.S. sorghum crop has been used for biofuels production. Grain sorghum is a suitable crop for sustainable ethanol production. Grain sorghum produces the same amount of ethanol per bushel as comparable feed grains while using up to one-third less water in the plant growth process. From the standpoint of ethanol production, grain sorghum is equal to corn as an input. One bushel of grain sorghum or corn produces an equal amount of ethanol. With that in mind, ethanol producers can make grain sorghum part of successful feedstock procurement strategy, especially in areas where there is a ready supply of grain sorghum. Sweet sorghum, also drought-tolerant, grows very tall and the stalks contain a high volume of fermentable sugars. India and Asia are already using this crop to produce ethanol. Research is ongoing in the United States into infrastructure development needs to make sweet sorghum ethanol a mainstream reality. Forage and high tonnage biomass sorghums are under evaluation for their compositional makeup and production potential for use as a renewable feedstock for both the cellulosic and thermochemical process for conversion into biofuels. These annual feedstocks could become an important option for farmers looking to diversify their farming systems and to maintain rotation strategies on their farms.

USCP works in conjunction with the U.S. Grains Council (USGC) (2022) to explore and develop overseas markets for sorghum. Checkoff dollars support general activities of the Council as well as a full-time USGC employee whose primary responsibility is to expand sorghum markets. In general, the sorghum checkoff helps to facilitate marketing relationships globally that ultimately benefit domestic sorghum producers.

The Sorghum Checkoff and the U.S. Grains Council work together to build demand for U.S. sorghum around the globe; however, this partnership is not the only international effort for U.S. sorghum promotion. The Sorghum Checkoff has partnerships with state organizations, state departments of agriculture, the Southern United States Trade Association and Food Export Midwest to pursue opportunities by creating programs to develop markets and promote trade. A joint venture with multiple organizations bolsters the Sorghum Checkoff's footprint and international efforts allowing the pursuit of projects not possible within their standalone budget.

Additional programming brings together prospective sorghum buyers with producers and sellers in the United States, training that educates overseas companies on how to import U.S. grain as well as facilitation of rail and port facilities to increase economic and trade opportunities. The Sorghum Checkoff also partners with others to market U.S. sorghum overseas involving cost sharing of various expenses including trade shows, advertising, demonstrations, and trials.

Animal feeding is a key end use for U.S. sorghum production. Sorghum is utilized in the nutrition of dairy and beef cattle as well as swine and poultry. Importantly, besides the livestock industry, the pet food industry is utilizing sorghum in their products. This market is small in comparison to the livestock market at present.

The United Sorghum Checkoff Program is working to enhance the usability of sorghum in industries that reach beyond conventional markets. Traditionally, nearly one-third of the U.S. sorghum crop is used for renewable fuel production, Sorghum produces the same amount of ethanol per bushel as comparable feedstocks while using up to one-third less water. Domestically, checkoff-funded research opportunities are looking at sorghum's potential to fight cancer and to combat high cholesterol and obesity problems. Sorghum is high in antioxidants, and sorghum is gluten free. As such, sorghum is a versatile product for individuals diagnosed with Celiac disease which concerns intolerance to gluten found in products like wheat.

The pet food industry already uses sorghum because of its low glycemic index which helps it to control diabetes in companion animals. Sorghum is used in florals, birdseed, and deer feeders. Around the world, sorghum is already used for building materials like fencing, a plywood-like product and as a binder is wallboard. Within the aquaculture industry, interest in the use of sorghum has accelerated, particularly as a cost-effective protein source. The sorghum checkoff continues to fund projects which encourage new markets for this crop.

Finally, while there are currently no commercialized green chemical products made from sorghum on the market, research has demonstrated that sorghum has potential in meeting demand for environmentally friendly products. By funding research and market development projects, the sorghum checkoff hopes to increase sorghum's use in green chemicals and consequently the demand for U.S. sorghum.

As exhibited in Table 3, the commitment of funds made by USCP in crop improvement, sustainability, market development, renewables, and exports are provided. These data come directly from the Executive Director of USCP, Norma Ritz Johnson.

Funds committed to crop improvement over the checkoff period ranged from $0.69 million to $4.43 million; for market development, the range was $0.50 million to $2,86 million; for renewables/sustainability, the range was $0.14 million to $1.73 million, and for exports, the range was $0.23 million to $0.51 million. The total commitment of checkoff dollars for crop improvement, market development, exports and renewables/sustainability spanned from $1.94 million to $8.06 million over the period 2008 to 2021.

In addition, as exhibited in Table 3, the Foreign Agricultural Service (FAS) also provided funds for promotion of sorghum exports, separate from the contribution of the USCP. These funds are for the Market Access Program (MAP) and for Foreign Market Development (FMD). These contributions from FAS for sorghum exports varied from $2.03 million to $3.55 million over the period 2008 to 2021. The share of FAS funds for sorghum ranged from 16.24 percent to 24.55 percent over the period 2008 to 2021. Starting in 2019, FAS also received $20.8 million for the Agricultural Trade Program (ATP) to be spent from 2019 to 2024. Based on shares of FAS expenditures on sorghum, we estimated that for sorghum exports, the amount of ATP spending ranged from $563,128 to $656,299 over the period 2019 to 2021.

BACKGROUND ON SORGHUM PRODUCTION AND END USES

Sorghum, also known as milo, is a grain, forage, or sugar crop, among the most efficient crops in conversion of solar energy and use of water. A high-energy, drought tolerant crop, sorghum is produced largely in six states - Kansas, Texas, Nebraska, Oklahoma, Colorado, and South Dakota. Since 1960, 26 states have produced sorghum. By far, Kansas and Texas are the primary states for sorghum production. Sorghum is used as a livestock feed in the poultry, beef, and pork industries and as a feedstock in the production of ethanol. A notable amount of U.S. sorghum also is exported to international markets, principally Mexico, Japan, Sudan and more recently China. Because it is gluten-free, sorghum is a viable substitute for wheat in U.S. food products. Finally, sorghum also is used for building materials, fencing, floral arrangements, pet food, and brooms. Clearly, sorghum has a variety of uses including food for human consumption, feed grain for livestock, and industrial applications, particularly ethanol production and use of renewable chemicals (Stroade and Boland, 2003).

Table 3. USPC Programmatic Activities and Funds Actually Spent, 2008/09 to 2020/21

Marketing Year	Crop Improvement	Market Development Exclusive of Exports	Exports--USGC	Renewables/ Sustainability	Total Funds Actually Spent
2008/09	$1,373,806.49	$659,004.10	$306,000.00	$333,329.10	$2,672,139.69
2009/10	$810,534.00	$574,028.00	$228,000.00	$328,437.75	$1,940,999.75
2010/11	$887,740.33	$578,250.59	$400,000.00	$147,768.33	$2,013,759.26
2011/12	$1,130,698.46	$287,610.86	$381,000.00	$520,137.18	$2,319,446.50
2012/13	$2,749,081.53	$497,826.03	$356,000.00	$142,398.03	$3,745,305.60
2013/14	$1,415,520.58	$724,122.26	$390,000.00	$1,005,365.33	$3,535,008.18
2014/15	$1,463,134.80	$1,122,674.68	$390,000.00	$842,810.50	$3,818,619.98
2015/16	$689,427.16	$936,186.50	$656,500.00	$571,128.66	$2,853,242.33
2016/17	$4,433,896.51	$1,340,538.49	$306,000.00	634,865.96	$6,715,300.96
2017/18	$1,127,467.18	$1,546,823.01	$512,000.00	873,185.51	$4,059,475.70
2018/19	$831,575.89	$956,669.82	$306,000.00	552,487.68	$2,646,733.39
2019/20	$807,994.71	$1,003,616.13	$336,600.00	738,160.18	$2,886,371.02
2020/21	$3,153,625.94	$2,864,113.09	$306,000.00	$1,733,413.74	$8,057,152.77

Year	Total FAS Funding	Total Sorghum	Share FAS Sorghum (%)	ATP Funding	ATP Funding Sorghum
2008	$14,481,882	$2,869,290	19.8130	$0	$0
2009	$14,448,088	$3,546,605	24.5472	$0	$0
2010	$14,395,561	$3,002,468	20.8569	$0	$0
2011	$14,941,323	$3,476,113	23.2651	$0	$0
2012	$12,956,691	$2,921,542	22.5485	$0	$0
2013	$11,682,158	$2,722,699	23.3065	$0	$0
2014	$12,249,223	$2,762,516	22.5526	$0	$0
2015	$11,818,013	$2,746,626	23.2410	$0	$0
2016	$12,000,974	$2,469,044	20.5737	$0	$0
2017	$11,747,561	$2,362,296	20.1088	$0	$0
2018	$11,644,644	$2,101,140	18.0438	$0	$0
2019	$12,518,196	$2,033,464	16.2441	$3,466,667	$563,128
2020	$12,420,409	$2,275,352	18.3195	$3,466,667	$635,075
2021	$13,340,837	$2,525,647	18.9317	$3,466,667	$656,299

Note: FAS funds include FMP and MAP funds only; does not include contributions to exports to USGC from USCP; also, does not include Agricultural Trade Promotion (ATP) funds starting in 2019 in the amount of $20.8 million.

Source: United Sorghum Checkoff Program, Norma Ritz Johnson, Executive Director, and Kurt Shultz, Senior Director of Global Strategies, United States Grain Council.

Sorghum Production

Sorghum production is the product of the number of harvested acres and the yield per harvested acre. As such, we focus initially on sorghum acres planted and harvested as well as on yield. Then we center attention on sorghum production directly. The discussion covers the period 1960 to 2021. As presented in Figure 1, a downward trend in sorghum acres planted and harvested is evident. Currently, the number of acres planted of sorghum is 7,305,000, and the number of harvested acres is 6,490,000. On the other hand, as shown in Figure 2, sorghum yields have experienced a general upward trend, ranging from 40 bushels per acre to 78 bushels per acre. Currently, sorghum yield is 69 bushels per acre in the United States. As exhibited in Figure 3, sorghum production ranged from a low of 214 million bushels to a high of 1,120 million bushels. Currently sorghum production in the United States is nearly 448 million bushels.

U.S. sorghum acreage, yields, and production have differed substantially over the years. Figures 4 through 6 compare averages of acres planted, acres harvested, yields, and production during four time periods: (1) 1960 to 1997; (2) 1998 to 2002; (3) 2003 to 2007; and (4) 2008 to 2021. The first three periods occurred before the implementation of the sorghum checkoff, and the fourth period includes the years during which the checkoff has been in force.

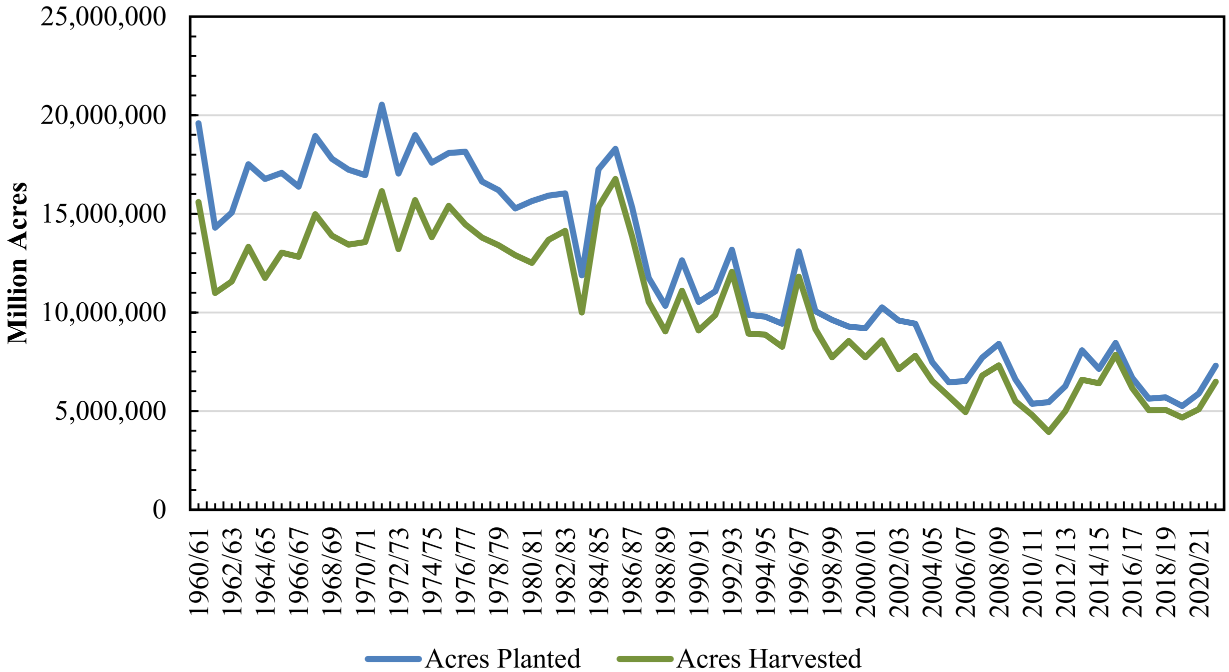
In the period prior to the implementation of the sorghum checkoff, U.S. the number of acres of sorghum planted and harvested dropped steadily averaging 15.2 million acres and 12.6 million acres, between 1960 and 1997, 9.6 million acres and 7.9 million acres, between 1998 to 2002, and 7.5 million acres and 6.4 million acres, between 2003 and 2007. Over the most recent period of 2008 to 2021 when the checkoff was in force, U.S. planted and harvested acreage continued to decline averaging 6.6 million acres and 5.7 million acres, respectively.

On the other hand, sorghum yield rose steadily, averaging 56.2 bu/acre during the period of 1960 to 1997, 61.7 bu/acre during the period of 1998 to 2002, and 64.0 bu/acre during the period of 2003 to 2007. During the checkoff years, yields continued to rise, averaging 67.9 bu/acre.

Despite the growth in yields, the sharper decline in acreage resulted in a steady decline in production averaging 703 million bushels between 1960 and 1997, 492 million bushels between 1998 and 2002, and 406 million bushels between 2003 and 2007. Production continued to decline in the checkoff years averaging 390 million bushels.

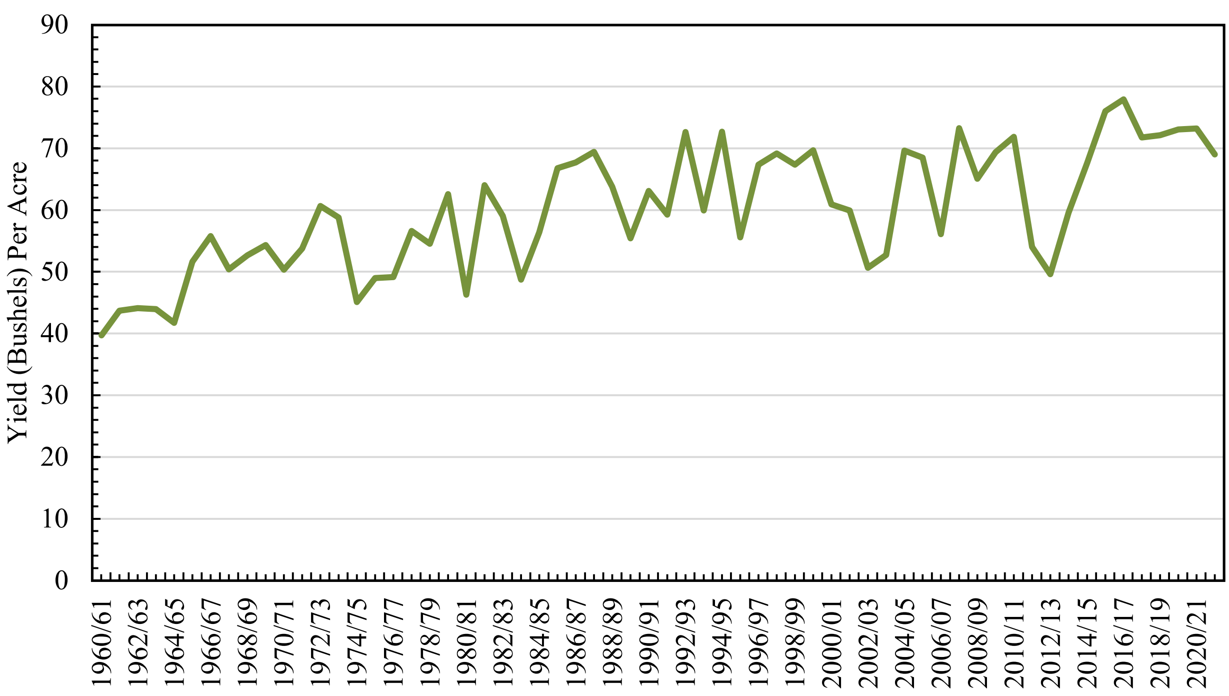
Regional sorghum planted and harvested acreage, yields, and production are presented in Figures 7a through 10e. Since 1960, six states have accounted for most of the sorghum production, planted acreage, and harvested acreage, namely Colorado, Kansas, Nebraska, Oklahoma, South Dakota, and Texas. Historically, Kansas and Texas have been the top two sorghum-producing states by far. Additionally, sorghum producing states generally are grouped into four regions: (1) Southwest (Texas, Arkansas, Louisiana, and Oklahoma); (2) Southeast (Alabama, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee, and Virginia); (3) Midwest (Iowa, Illinois, Indiana, Kansas, Missouri, Nebraska, and South Dakota); and (4) West (Arizona, California, Colorado, and New Mexico). Sporadically, sorghum production also has occurred in the Mid-Atlantic region (Delaware, Maryland, and Pennsylvania) since 1960. Because the Mid-Atlantic is almost negligible in terms of sorghum planted and harvested acreage, yields, and production, we do not provide any discussion of this region.

Figure 1. Sorghum Planted and Harvested Acres in the United States, 1960 to 2021



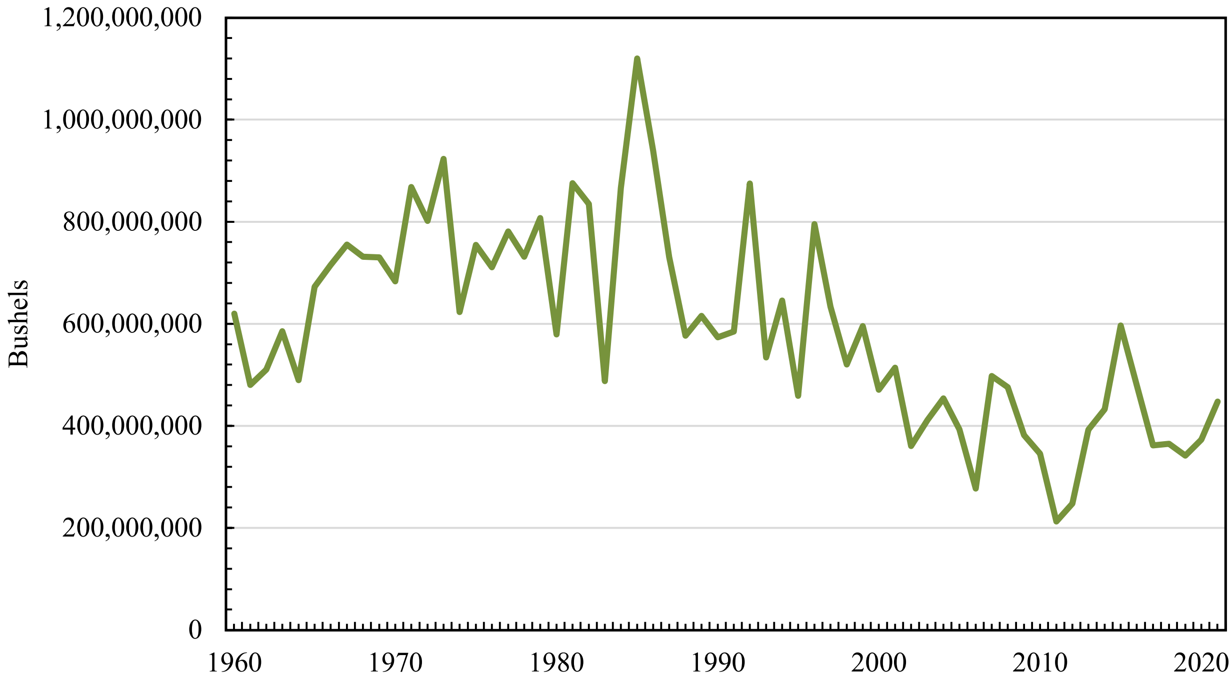
Source: National Agricultural Statistics Service (NASS), United States Department of Agriculture, USDA (2022).

Figure 2. Sorghum Yield in the United States, 1960 to 2021



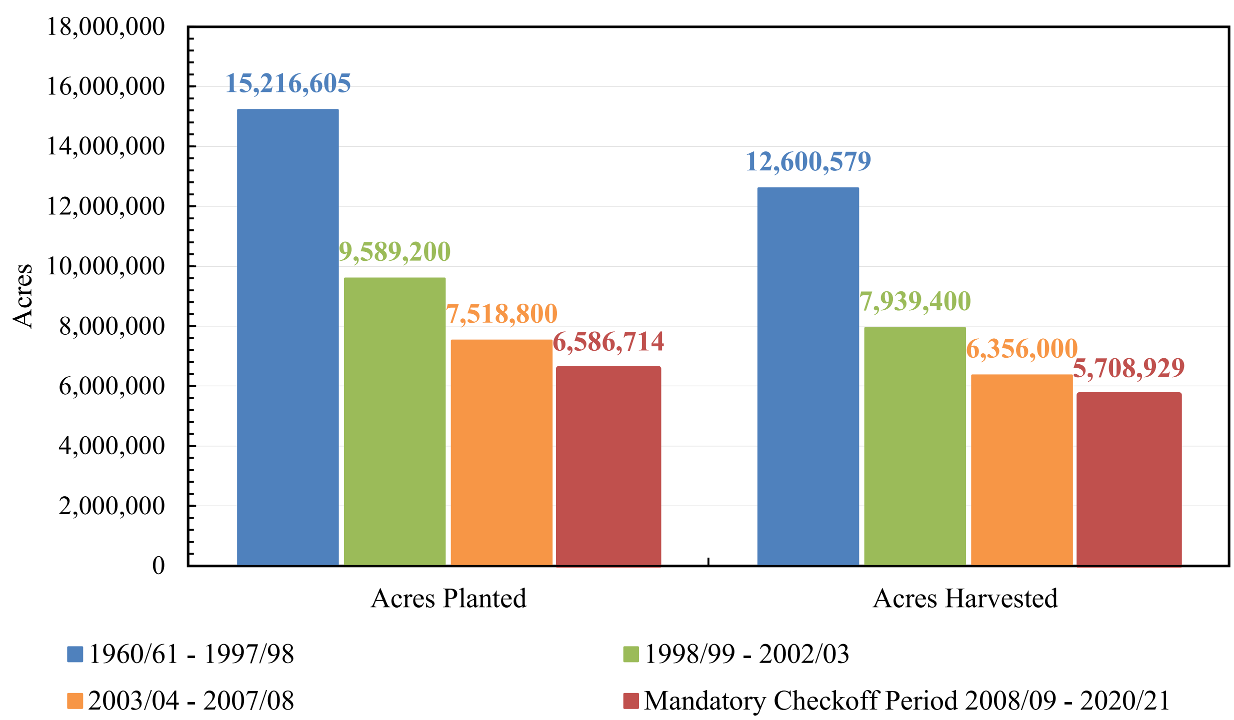
Source: National Agricultural Statistics Service (NASS), United States Department of Agriculture, USDA (2022).

Figure 3. Sorghum Production in the United States, 1960 to 2021, bushels



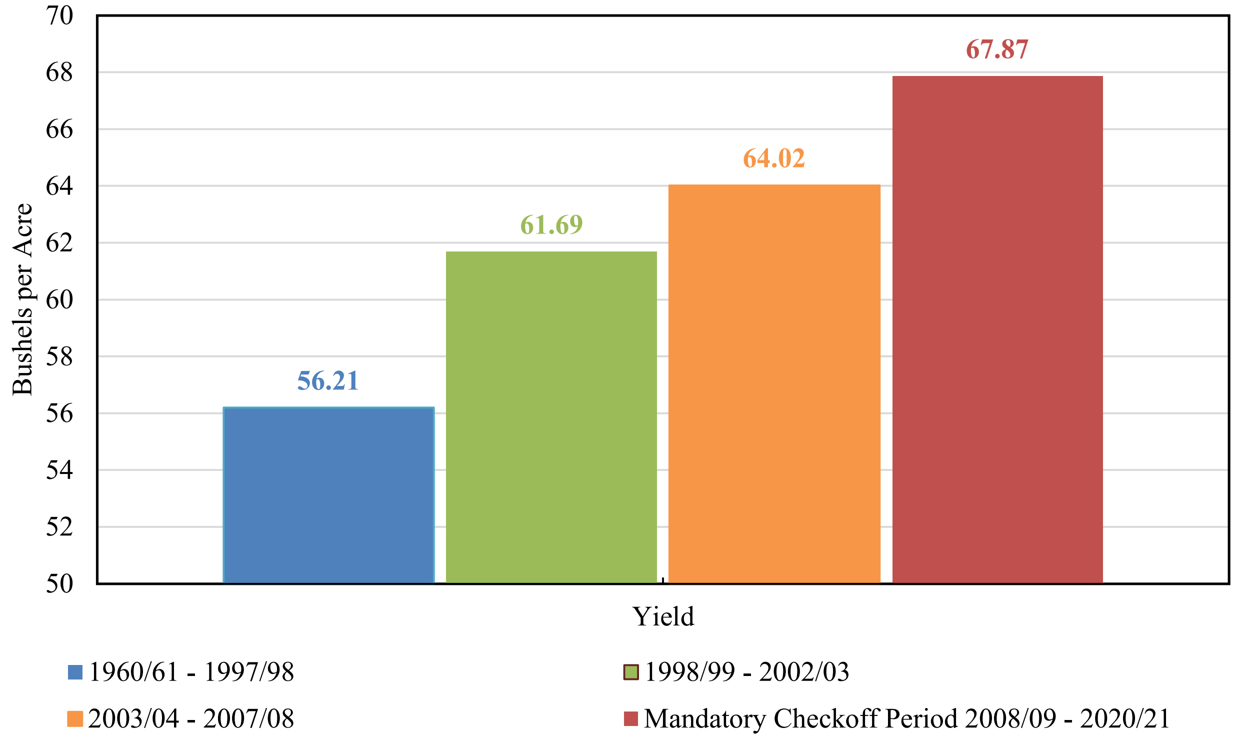
Source: National Agricultural Statistics Service (NASS), United States Department of Agriculture, USDA (2022).

Figure 4. Average Acres Planted and Acres Harvested of Sorghum by Selected Time Periods



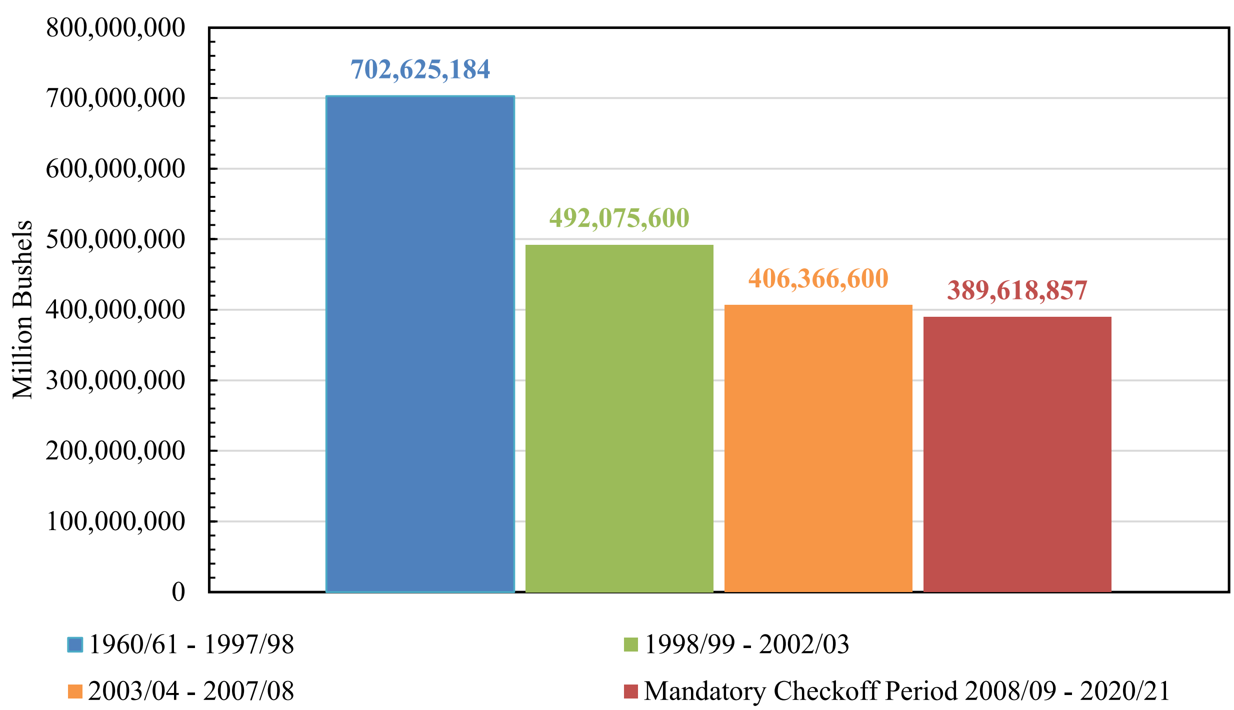
Source: National Agricultural Statistics Service (NASS), United States Department of Agriculture, USDA (2022).

Figure 5. Averages of U.S. Sorghum Yield by Selected Time Periods



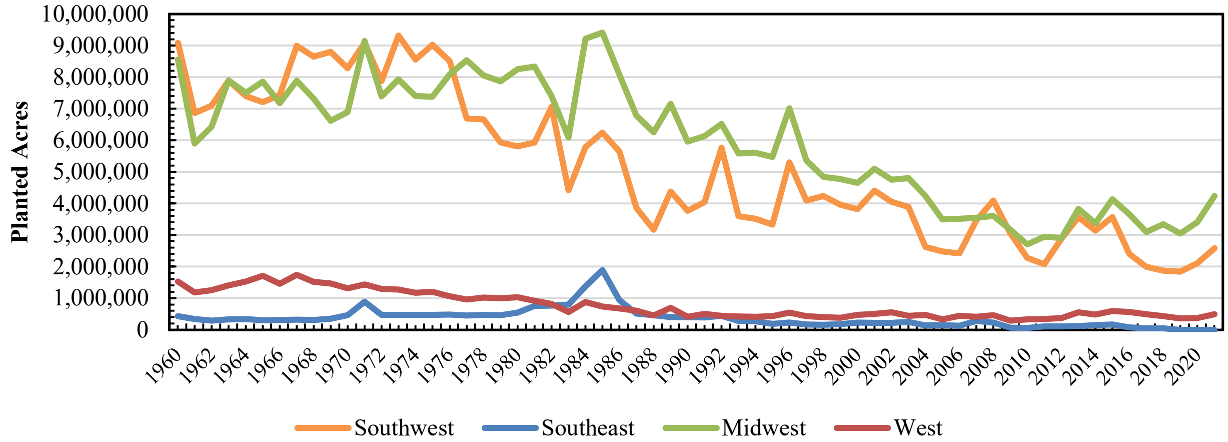
Source: National Agricultural Statistics Service (NASS), United States Department of Agriculture, USDA (2022).

Figure 6. Averages of U.S. Production of Sorghum by Selected Time Periods



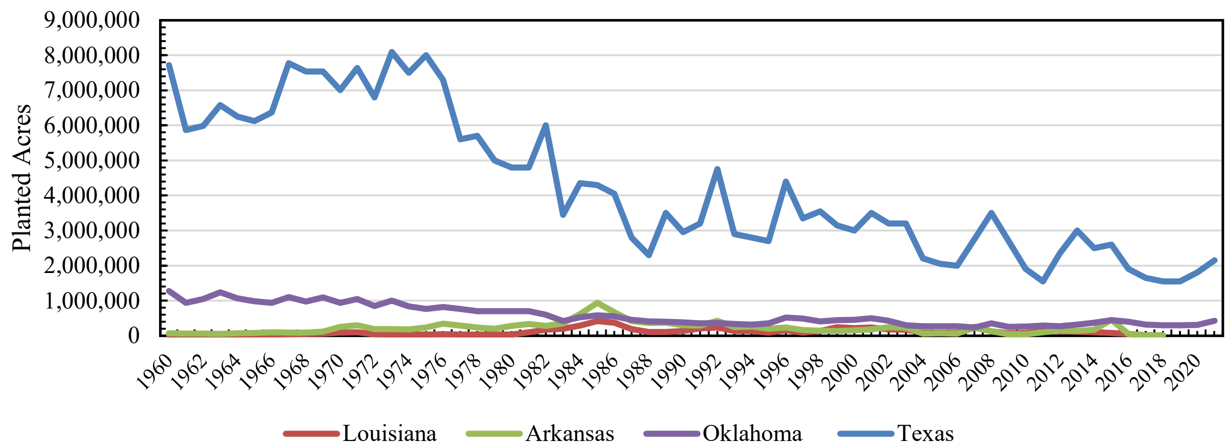
Source: National Agricultural Statistics Service (NASS), United States Department of Agriculture, USDA (2022).

Figure 7a. Number of Acres Planted by Region in the United States, 1960 to 2021



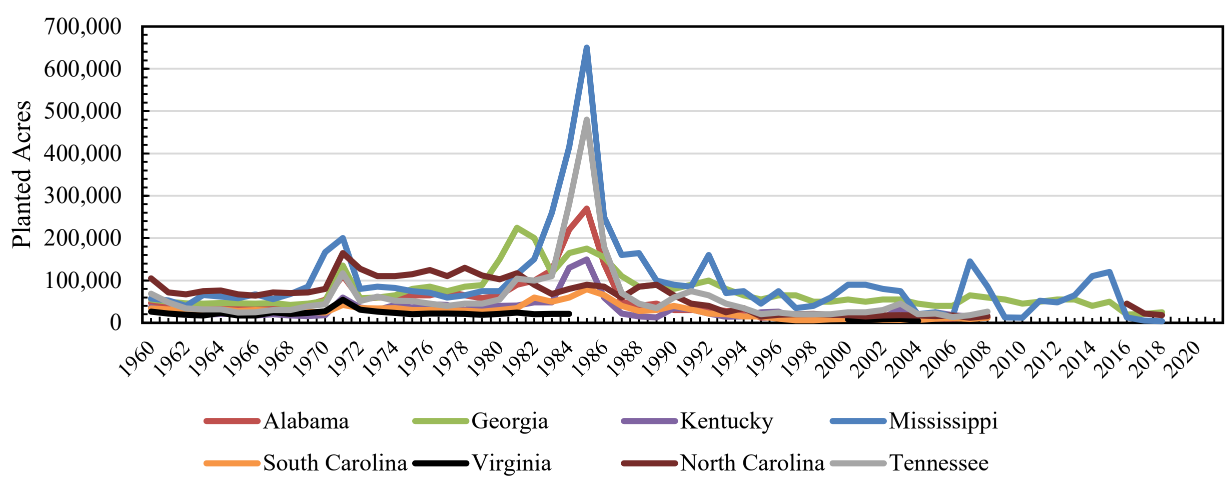
Source: National Agricultural Statistics Service (NASS), United States Department of Agriculture, USDA (2022).

Figure 7b. Planted Acres of Sorghum in the Southwest Region of the United States, 1960 to 2021



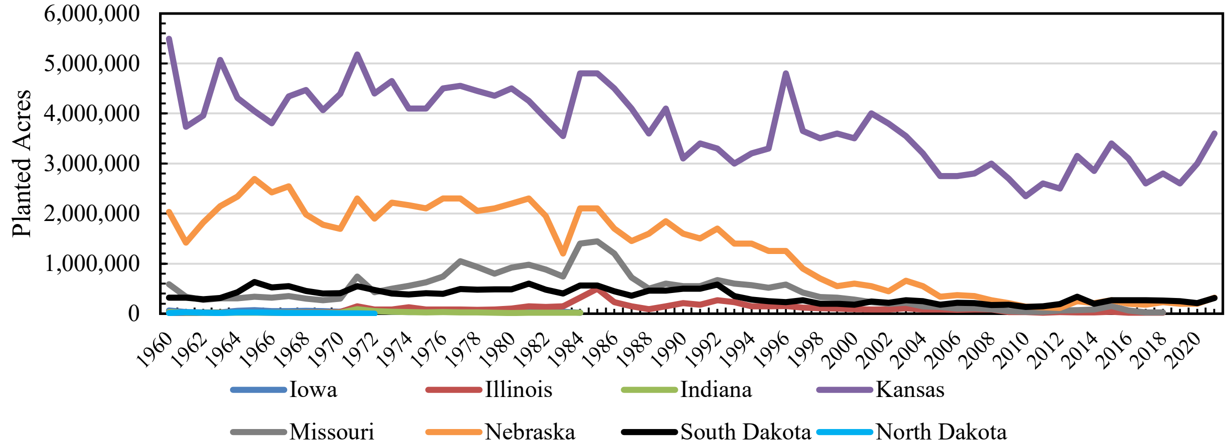
Source: National Agricultural Statistics Service (NASS), United States Department of Agriculture, USDA (2022).

Figure 7c. Planted Acres of Sorghum in the Southeast Region of the United States, 1960 to 2021



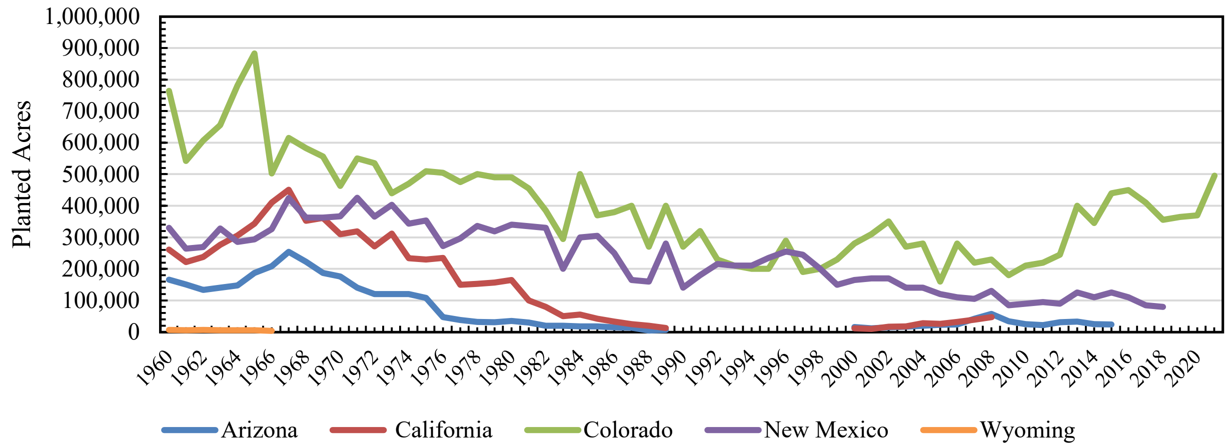
Source: National Agricultural Statistics Service (NASS), United States Department of Agriculture, USDA (2022).

Figure 7d. Planted Acres of Sorghum in the Midwest Region of the United States, 1960 to 2021



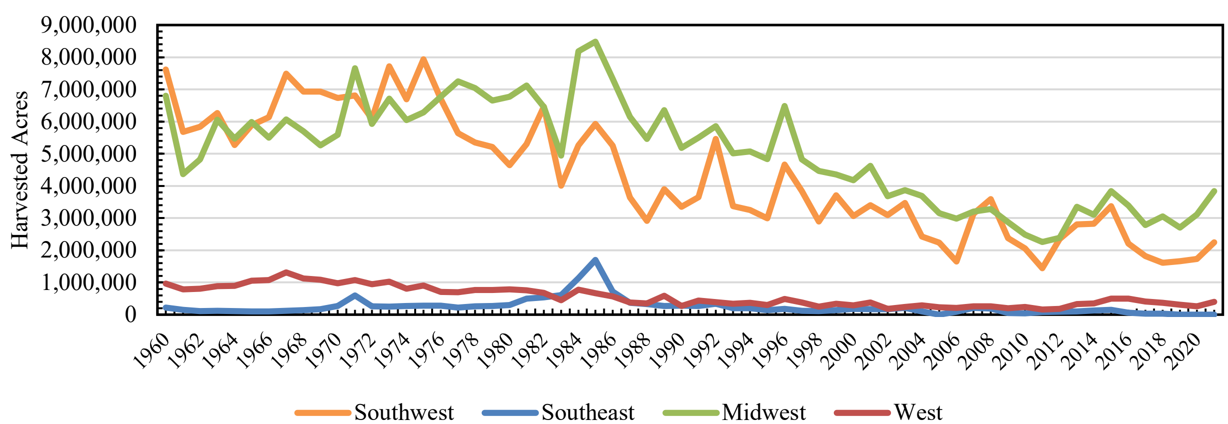
Source: National Agricultural Statistics Service (NASS), United States Department of Agriculture, USDA (2022).

Figure 7e. Planted Acres of Sorghum in the West Region of the United States, 1960 to 2021



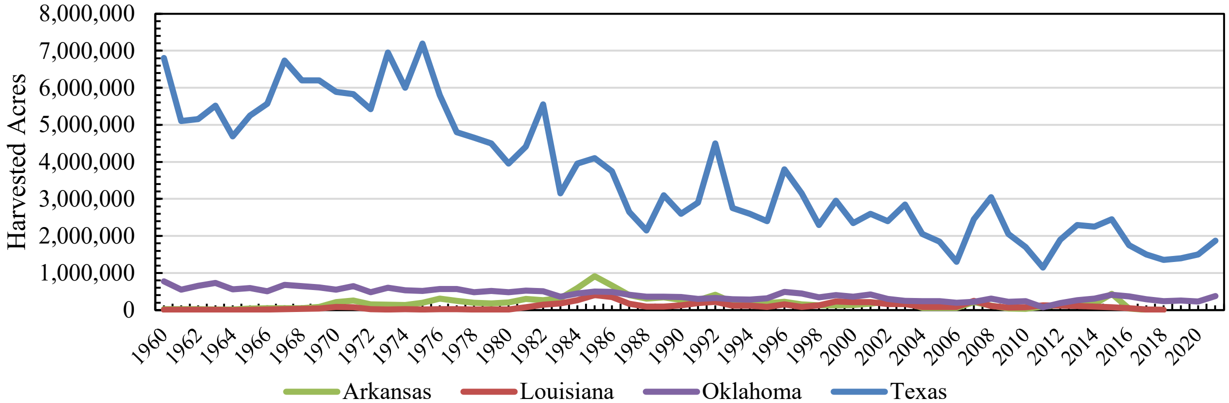
Source: National Agricultural Statistics Service (NASS), United States Department of Agriculture, USDA (2022).

Figure 8a. Number of Acres Harvested by Region in the United States, 1960 to 2021



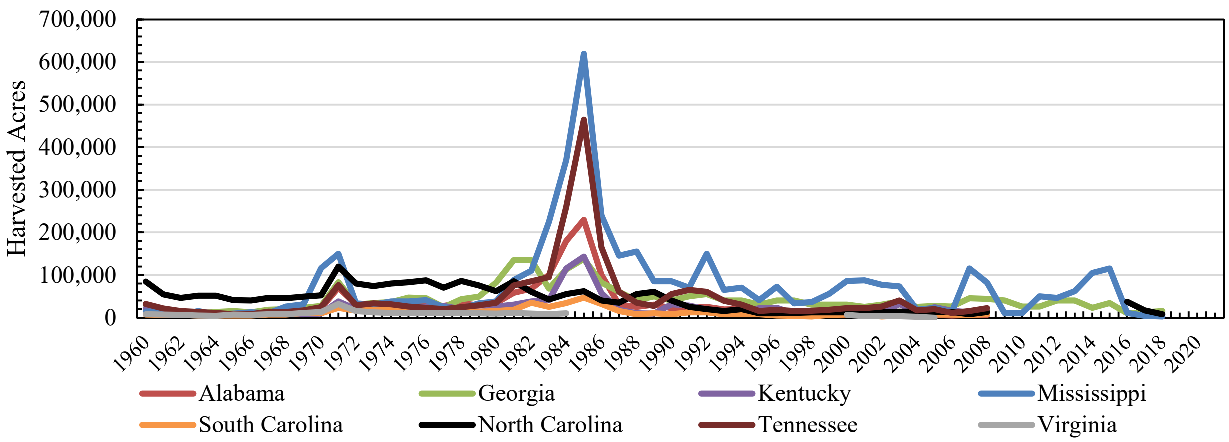
Source: National Agricultural Statistics Service (NASS), United States Department of Agriculture, USDA (2022).

Figure 8b. Harvested Acres of Sorghum in the Southwest Region of the United States, 1960 to 2021



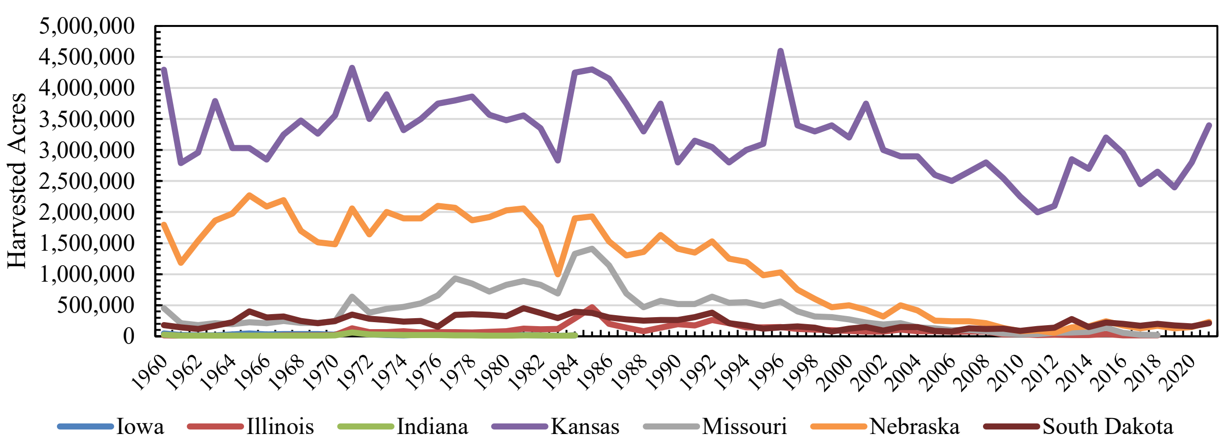
Source: National Agricultural Statistics Service (NASS), United States Department of Agriculture, USDA (2022).

Figure 8c. Harvested Acres of Sorghum in the Southeast Region of the United States, 1960 to 2021



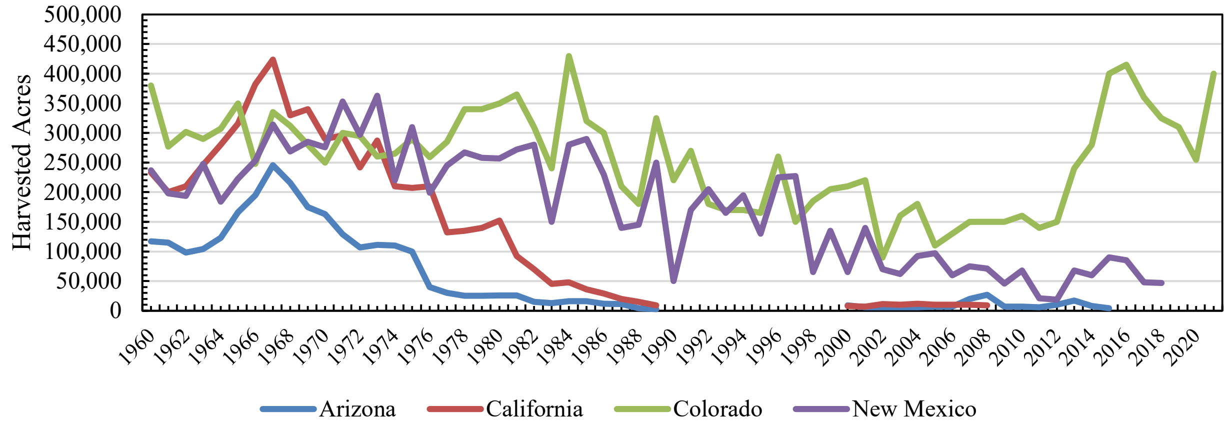
Source: National Agricultural Statistics Service (NASS), United States Department of Agriculture, USDA (2022).

Figure 8d. Harvested Acres of Sorghum in the Midwest Region of the United States, 1960 to 2021



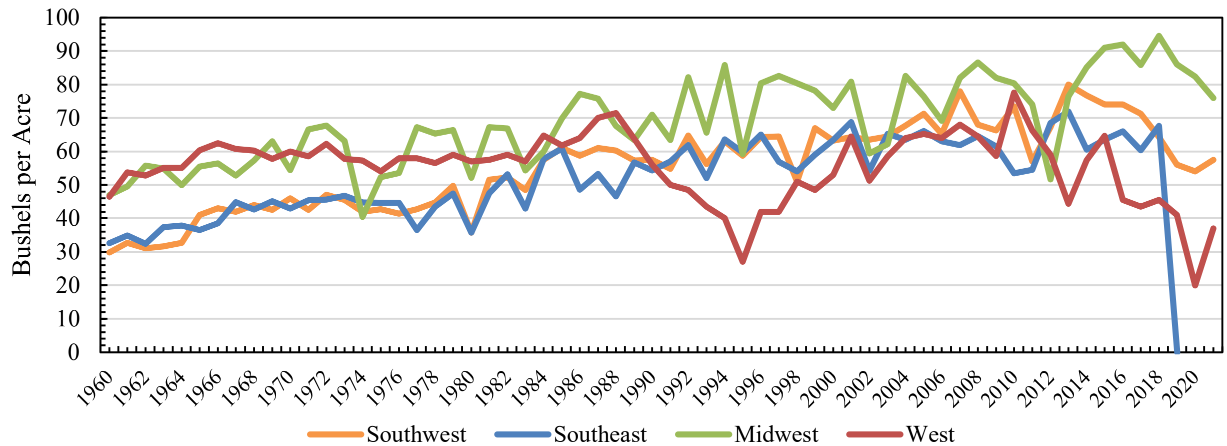
Source: National Agricultural Statistics Service (NASS), United States Department of Agriculture, USDA (2022).

Figure 8e. Harvested Acres of Sorghum in the West Region of the United States, 1960 to 2021



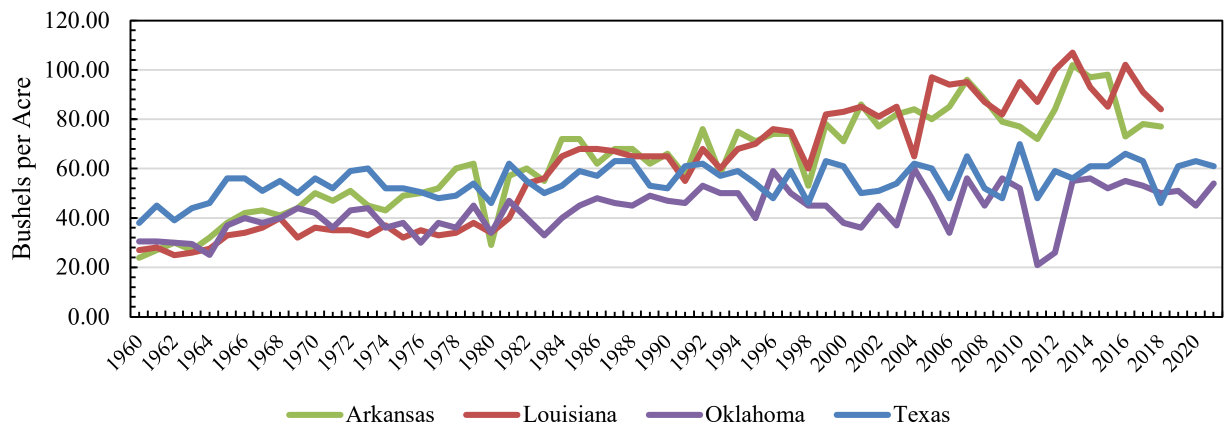
Source: National Agricultural Statistics Service (NASS), United States Department of Agriculture, USDA (2022).

Figure 9a. Sorghum Yield per Acre by Region in the United States, 1960 to 2021



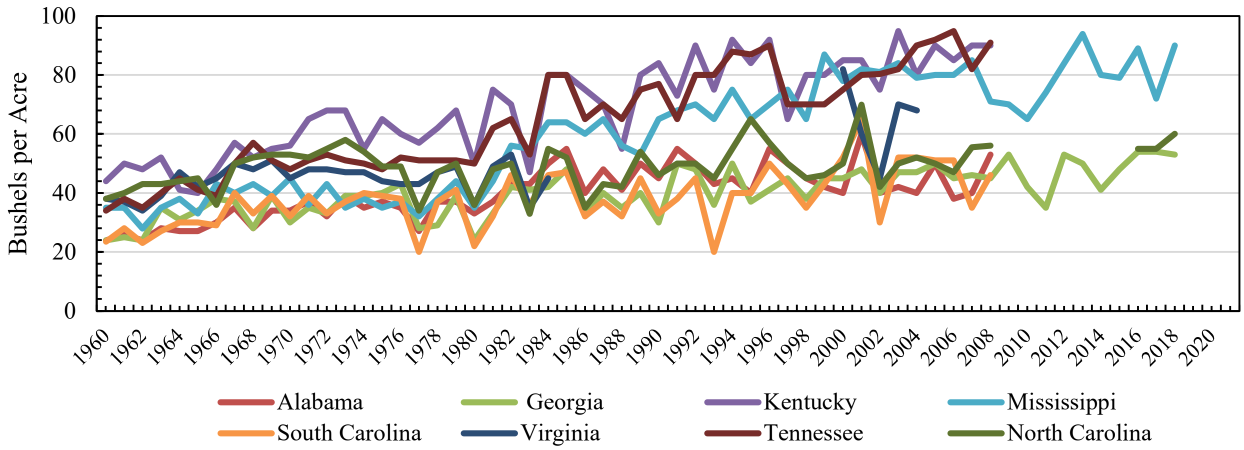
Source: National Agricultural Statistics Service (NASS), United States Department of Agriculture, USDA (2022).

Figure 9b. Sorghum Yields in the Southwest Region of the United States, 1960 to 2021, bushels per acre



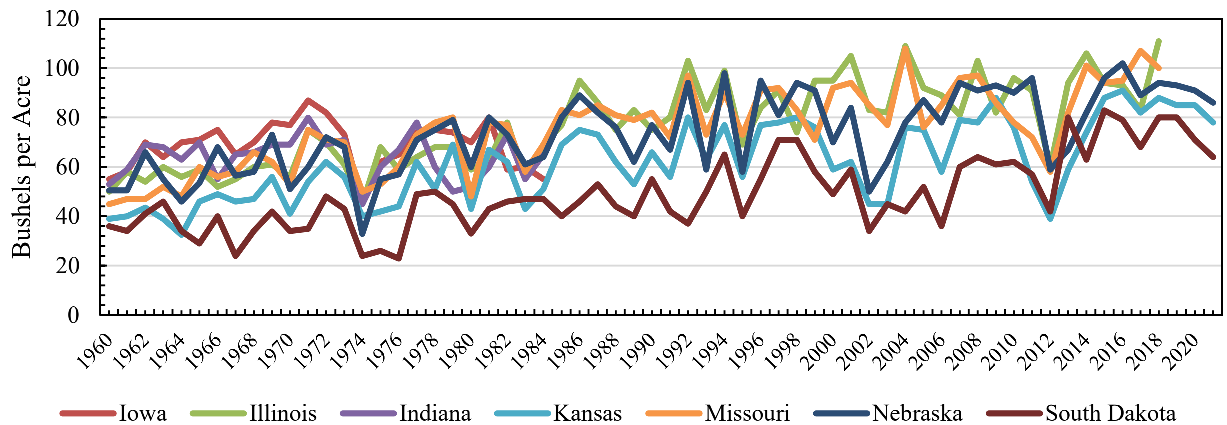
Source: National Agricultural Statistics Service (NASS), United States Department of Agriculture, USDA (2022).

Figure 9c. Sorghum Yields in the Southeast Region of the United States, 1960 to 2021, bushels per acre



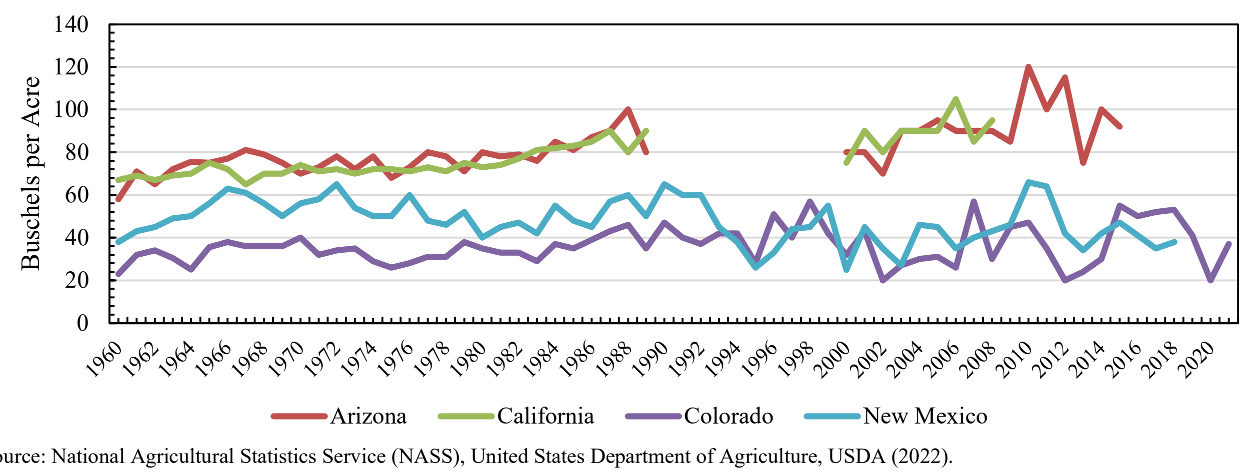
Source: National Agricultural Statistics Service (NASS), United States Department of Agriculture, USDA (2022).

Figure 9d. Sorghum Yields in the Midwest Region of the United States, 1960 to 2021, bushels per acre



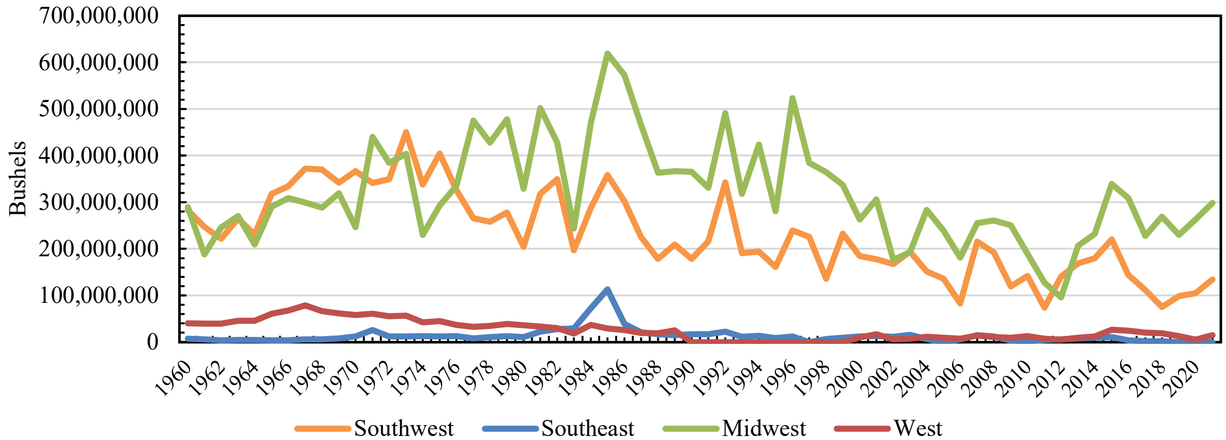
Source: National Agricultural Statistics Service (NASS), United States Department of Agriculture, USDA (2022).

Figure 9e. Sorghum Yields in the West Region of the United States, 1960 to 2021, bushels per acre



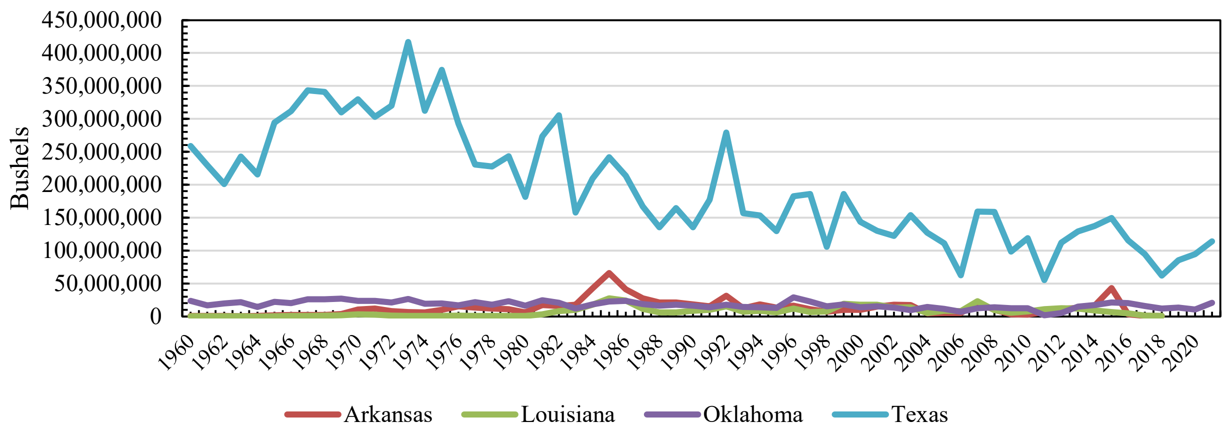
Source: National Agricultural Statistics Service (NASS), United States Department of Agriculture, USDA (2022).

Figure 10a. Sorghum Production by Region in the United States, 1960 to 2021, bushels



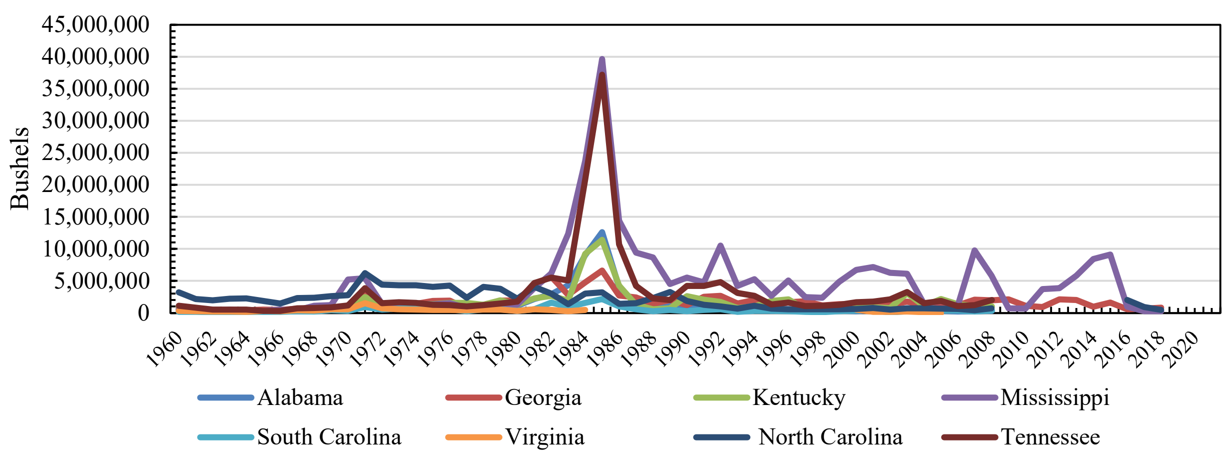
Source: National Agricultural Statistics Service (NASS), United States Department of Agriculture, USDA (2022).

Figure 10b. Sorghum Production in the Southwest Region of the United States, 1960 to 2021, bushels



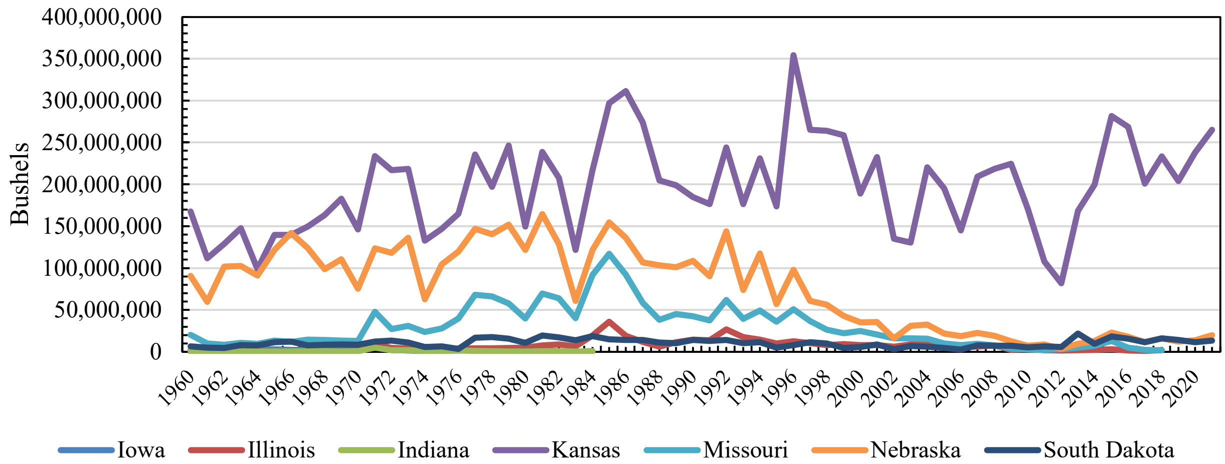
Source: National Agricultural Statistics Service (NASS), United States Department of Agriculture, USDA (2022).

Figure 10c. Sorghum Production in the Southeast Region of the United States, 1960 to 2021, bushels



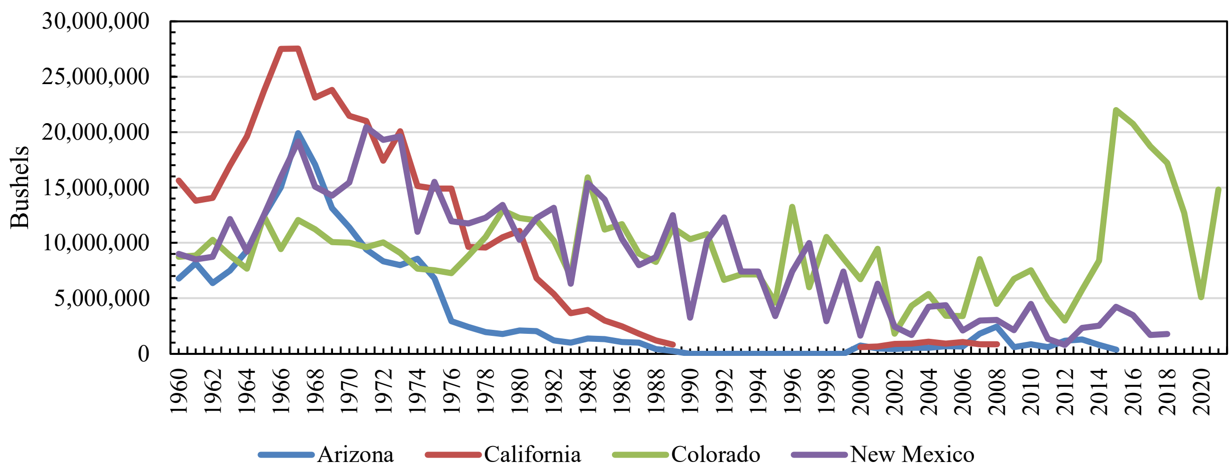
Source: National Agricultural Statistics Service (NASS), United States Department of Agriculture, USDA (2022).

Figure 10d. Sorghum Production in the Midwest Region of the United States, 1960 to 2021, bushels



Source: National Agricultural Statistics Service (NASS), United States Department of Agriculture, USDA (2022).

Figure 10e. Sorghum Production in the West Region of the United States, 1960 to 2021, bushels



Source: National Agricultural Statistics Service (NASS), United States Department of Agriculture, USDA (2022).

The following summarizes the salient information pertaining to acres planted, harvested acres, yields, and production in each region over the period of 1960 to 2021:

- *The Southwest Region*:
  - The number of acres planted and harvested in Texas generally have been on the decline from 1960 through 2020. The high for planted area was 8.1 million over that period and the low was roughly 1.5 million acres. The high for harvested area was 7.2 million acres and the low was roughly 1.2 million acres.
  - Acres planted and harvested in Oklahoma declined from 1960 to 1995; from 1996 to 2021, the decline in acres planted and harvested in Oklahoma has been less noticeable.

- Arkansas and Louisiana both consistently have planted and harvested less than 500,000 acres each year since 1960/61, with exceptions in the mid-1980s. Neither of these states reported any planted and harvested acreage since 2018.
- Increases in yields for all states in this region generally are evident.
- Yields in Louisiana and Arkansas were higher than yields in Texas and Oklahoma.
- Production in Texas varied greatly over the period, ranging from 55 million bushels to 417 million bushels.
- Generally, production levels in Texas generally have diminished since 1972.
- Texas continues to be the dominant state in sorghum production in this region.

- *The Southeast Region*
  - On average, Mississippi is the leading state in the Southeast in terms of planted and harvested acres, followed by Georgia
  - A notable spike was evident in this region except for Virginia in acres planted, acres harvested, and production for all states in the Southeast in 1984 and 1985.
  - On average, yields were highest in Kentucky, Tennessee, and Mississippi in the region, but lowest in South Carolina, Alabama, and Georgia.
  - Mississippi produced the most sorghum in this region, while Virginia produced the least sorghum in this region.

- *The Midwest Region*
  - Kansas had the highest planted and harvested acres in this region with an average of around 3.7 million planted acres and 3.2 million harvested acres.
  - On average, yields were highest in Illinois, Missouri, and Nebraska in this region, while yields were lowest in Kansas and South Dakota.
  - Kansas, by far, produced the most sorghum in this region followed by Nebraska and Missouri.
  - Production in Kansas ranged from 82 million bushels to 354 million bushels over the period.

- *The West Region*
  - Colorado accounted for the most planted and harvested acres in this region, followed by New Mexico.
  - On average, the number of planted acres was close to 400,000 for Colorado and close to 230,000 for New Mexico.
  - On average, the number of harvested acres was close to 260,000 for Colorado and close to 180,000 for New Mexico.
  - Yields were highest in California and Arizona in this region in years of production.
  - Sorghum production has been virtually nonexistent in California and Arizona since 1990.
  - Colorado and New Mexico were the primary sorghum-producing states in this region.
  - In recent years, sorghum production in Colorado has been on the rise.

Clearly, sorghum yields have varied greatly by state and by region. However, the states with the highest yields were not the top-producing states. Yields generally have increased in all regions since 1960. Clearly sorghum production historically has been highest in Texas and Kansas. The share of sorghum acres harvested accounted for by Texas ranged from 23% to 47% (Figure 11). The share of acres harvested accounted for by Kansas ranged from 22% to 55% (Figure 12). Currently, the Texas share was just under 30% and slightly more than 50% for Kansas. Consequently, those two states account for roughly 80% of the acres harvested of sorghum in at present. The share of sorghum production accounted for by Texas ranged from 17% to 50%, while Kansas accounted for about 20%

to 64% of production over the same period. Currently, the share of sorghum production accounted for by Texas was slightly more than 25% while the share accounted for by Kansas was about 59%. Hence, these two states accounted for nearly 85% of the U.S. production of sorghum. The Southeast region and the West region are minor players in the production of sorghum.

To provide some perspective, sorghum ranks second to corn in terms of acres planted, acres harvested, and production. Sorghum, barley, and oat yields have been quite similar, ranging from lows of about 30 bushels per acre to highs of near 78 bushels per acre. On average, from 1960 to 2021, yields of sorghum, barley, and oats were 59.9 bushels per acre, 54.9 bushels per acre, and 56.4 bushels per acre, respectively. In contrast, corn yields varied from a low of about 54.7 bushels per acre to a high of about 177.0 with an average of 118.2 bushels per acre of over this same period.

Sorghum End Uses and Prices

Until 2000, the dominant demand or end use component of sorghum historically was feed use, followed by exports, food and industry use, and seed use in that order (Figure 13). But over the past 20 years, exports have become the major end use component of U.S. produced sorghum. Industry use is defined as any use of sorghum not related to seed use, feed use, food use, or exports. Currently, food and industry use of sorghum is 9 million bushes, sorghum exports are 310 million bushels, feed and residual use is 115 million bushels, and seed use is 0.86 million bushels. Consequently, exports and feed and residual use currently account for slightly less than 98 percent of the total disappearance of sorghum.

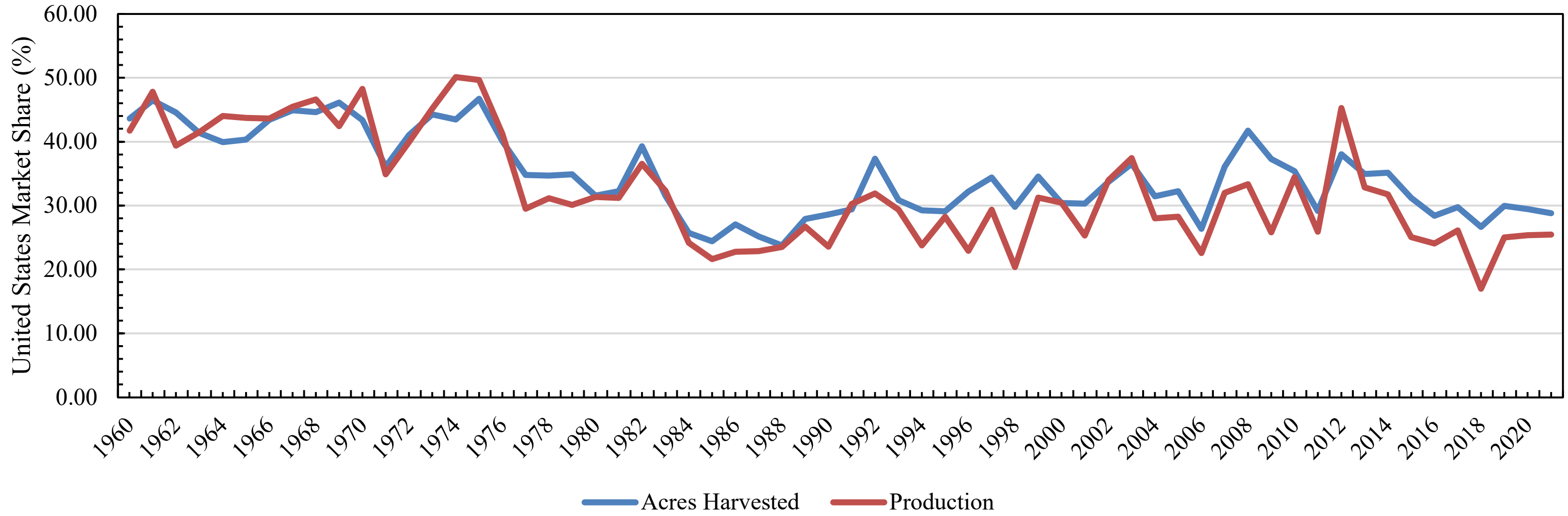
Historically much of the sorghum crop has been used as a component in livestock feed. Corn is the main substitute for sorghum in livestock feed. Figure 14 compares the average feed use, seed use, food and industry use, and exports during selected time periods. On average, sorghum feed use dropped from 457 million bushels between 1975 and 1997, to 234 million bushels between 1998 to 2002, to 158 million bushels between 2003 and 2007, and to 115 million bushels during the mandatory checkoff period. Seed use followed the same pattern, a monotonic decline over the respective four periods on average.

On average, sorghum exports over the period 1975 to 1997 were 241 million bushels and over the period 1998 to 2002 sorghum exports averaged 225 million bushels. From 2003 to 2007, sorghum exports averaged 178 million bushels. But since the inception of the USCP, sorghum exports on average were 199 million bushels.

However, sorghum food and industry use rose dramatically 16.7 million bushels on average between 1975 and 1997, 35.2 million bushels on average from 1998 to 2002, 44.1 million bushels on average from 2003 to 2007, 74.0 million bushels on average between 2008 to 202 That said, however, since 2019, sorghum food and industrial use has declined markedly to 9 million bushels.

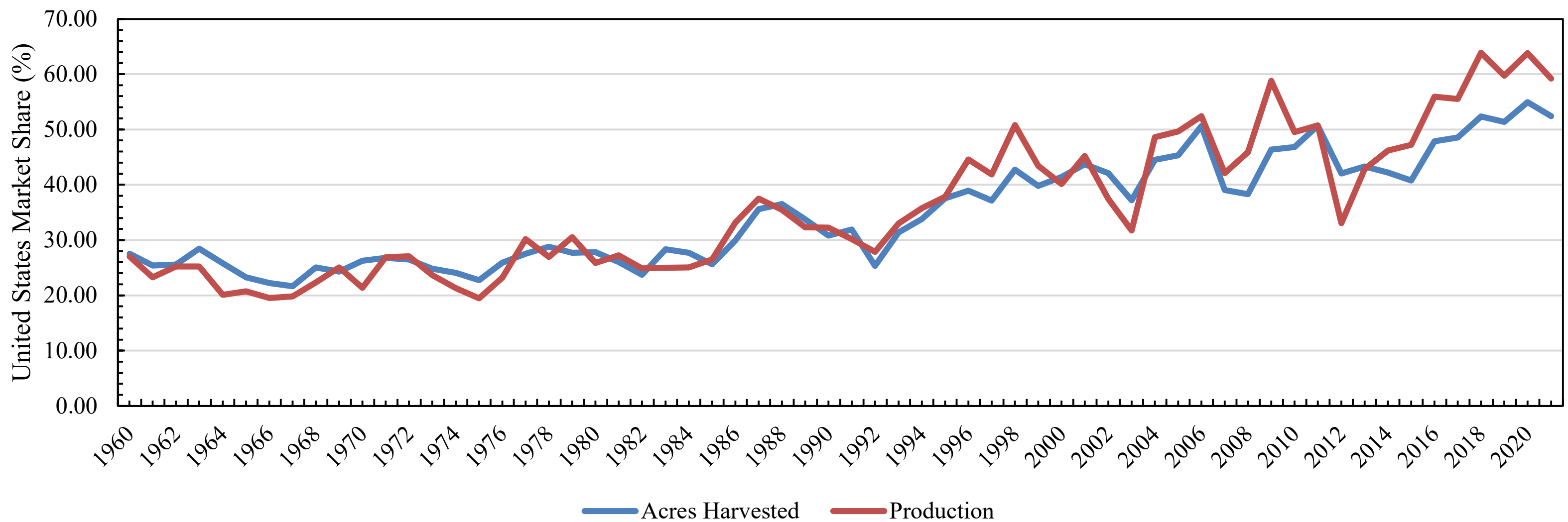
In general, U.S. domestic prices of feed grains move together as exhibited in Figure 15. In particular, the correlation of sorghum and corn farm prices was 0.99 between 1960 and 2021, almost a perfect linear association. Based on Granger causality tests (tests of precedence), sorghum farm prices and corn farm prices were contemporaneous. That is, neither of these farm prices was a leading indicator of the other. Remaining correlations of prices of feed grains were at least 0.91. Nominal farm prices of barley, corn, oats, and sorghum averaged $2.64 per bushel, $2.62 per bushel, $1.71 per bushel, and $2.43 per bushel, respectively, over the same period.

Figure 11. Texas: Share of U.S. Acres Harvested and Production, 1960 to 2021



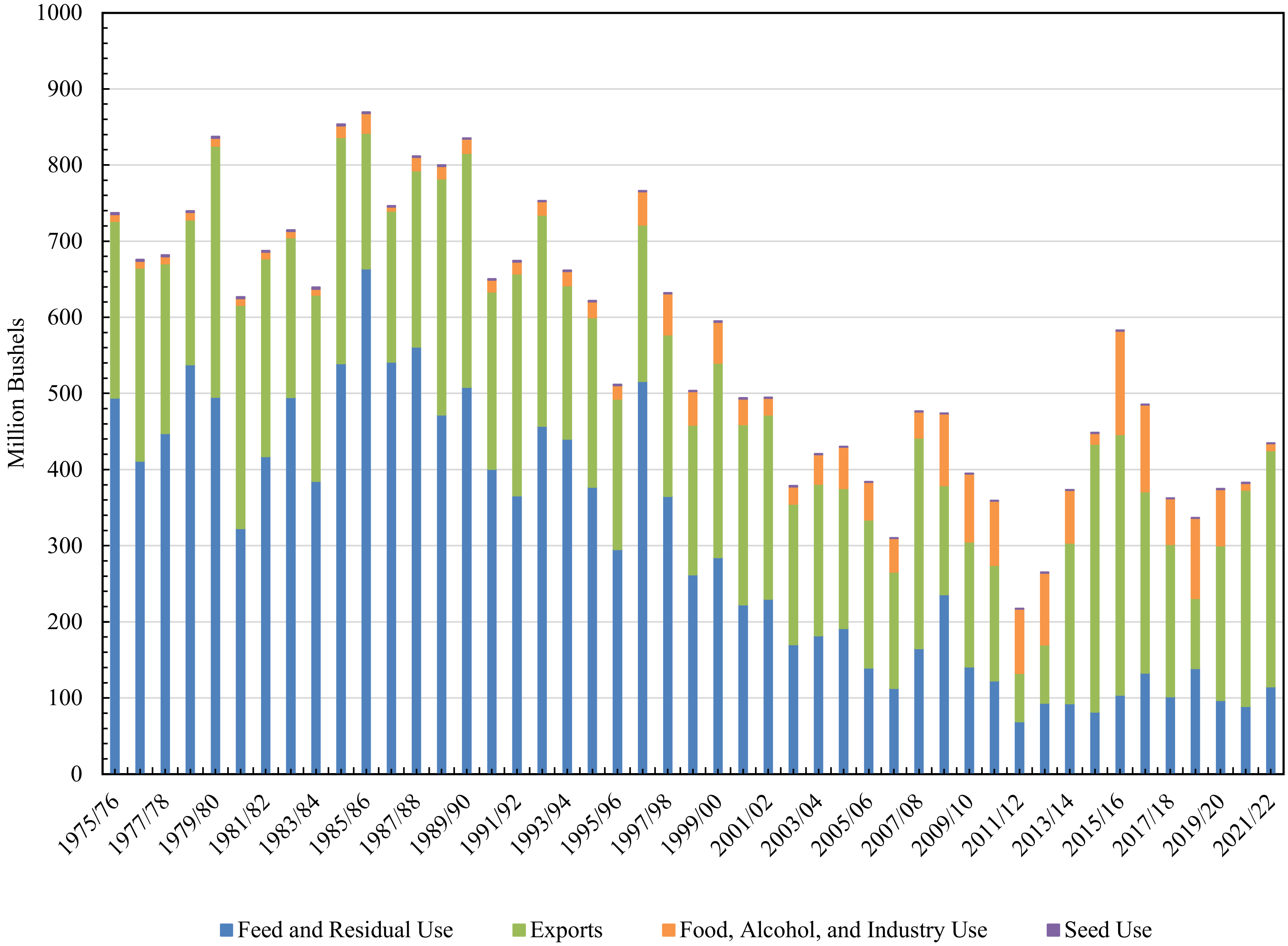
Source: National Agricultural Statistics Service (NASS), United States Department of Agriculture, USDA (2022) and calculations by the authors.

Figure 12. Kansas: Share of U.S. Acres Harvested and Total Production, 1960 to 2021



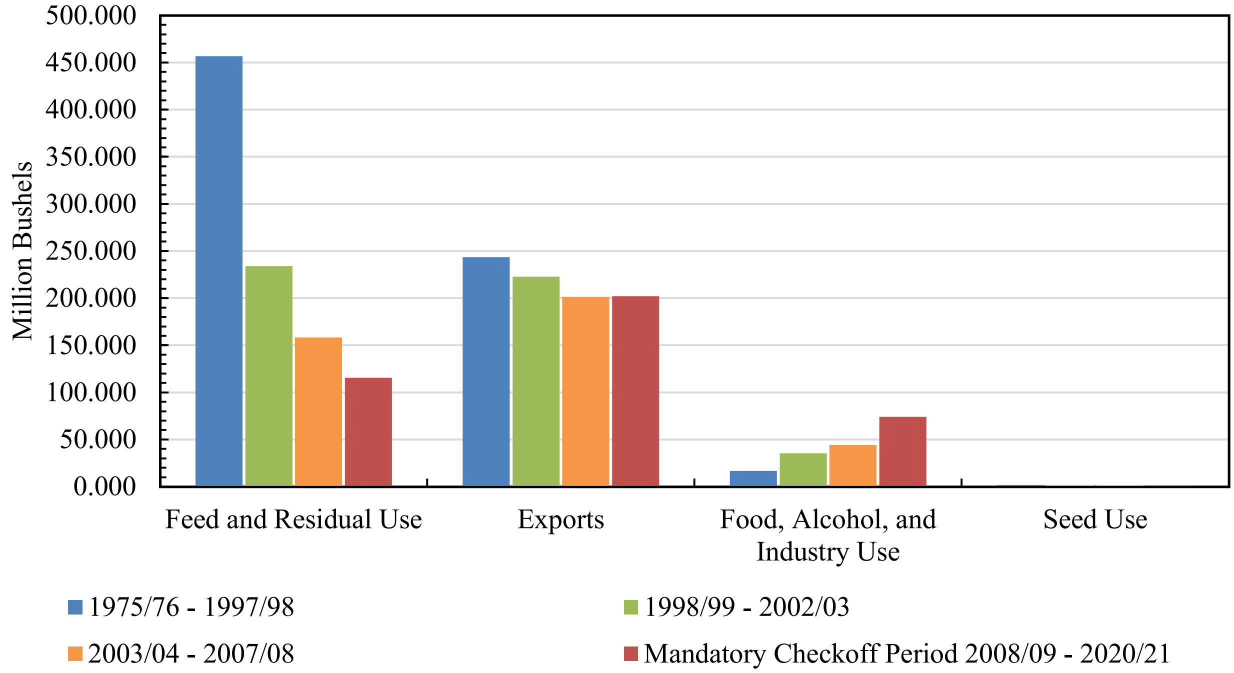
Source: National Agricultural Statistics Service (NASS), United States Department of Agriculture, USDA (2022) and calculations by the authors.

Figure 13. Sorghum End Uses by Type of Use (Feed, Food, Exports), 1975 to 2021



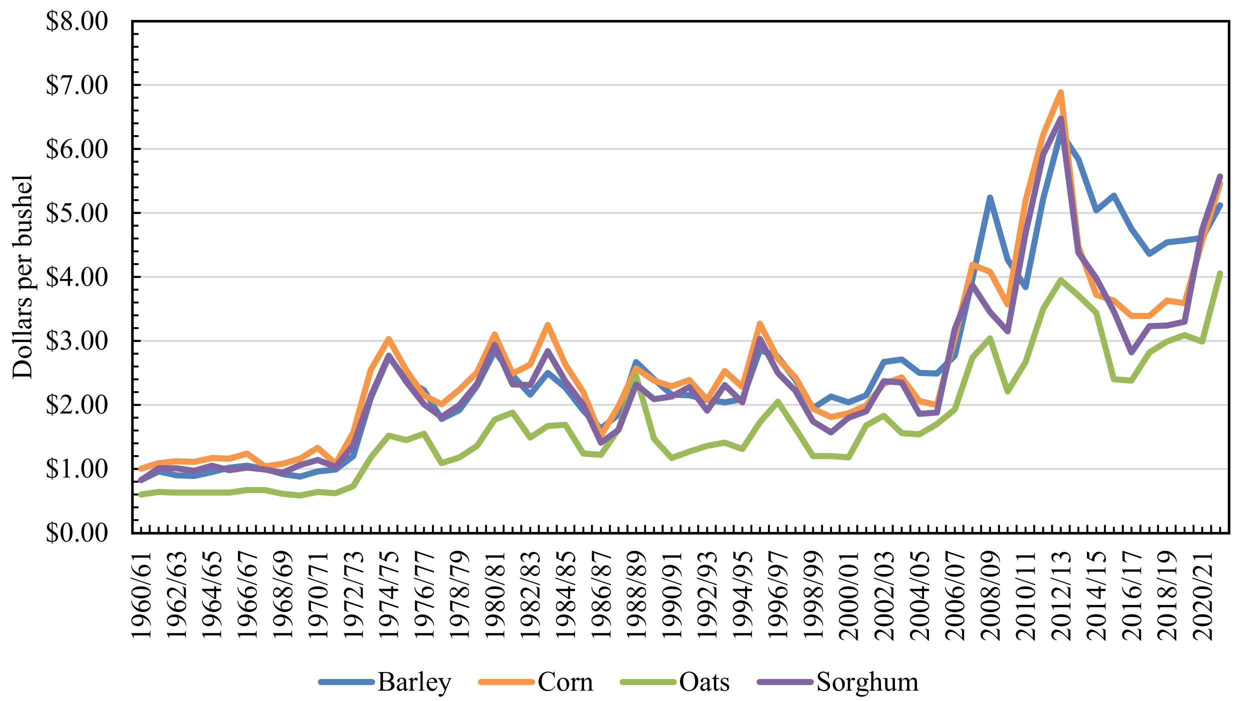
Source: National Agricultural Statistics Service (NASS), United States Department of Agriculture, USDA (2022) and calculations by the authors.

Figure 14. Sorghum Ends Uses, Average over Selected Time Periods



Source: National Agricultural Statistics Service (NASS), United States Department of Agriculture, USDA (2022) and calculations by the authors.

Figure 15. Farm Prices Received by Producers for Feed Grains in the United States, 1960 to 2021



Source: National Agricultural Statistics Service (NASS), United States Department of Agriculture, USDA (2022) and calculations by the authors.

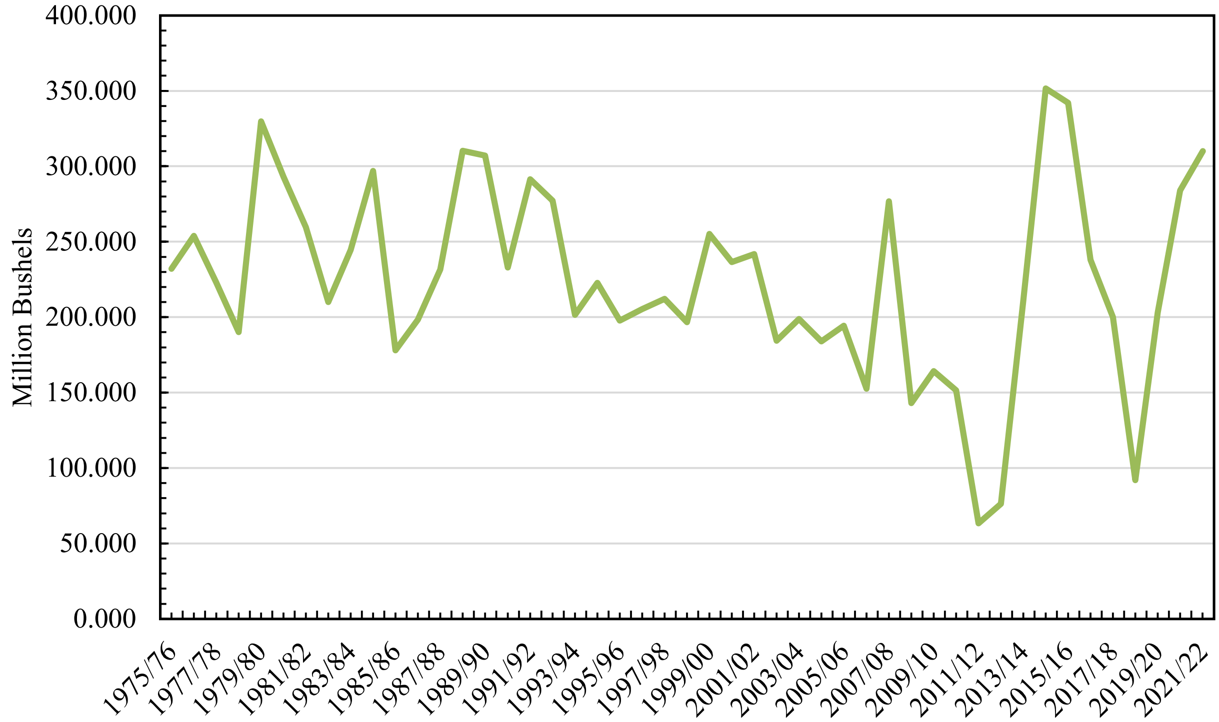
From 1975 to 2006, sorghum exports ranged from 4.4 million metric tons to 8.3 million metric tons (Figure 16). Then China jumped heavily into global sorghum markets beginning in 2014 driving U.S. exports to slightly more than 6 million metric tons on average over the past eight years. Chinese restrictions on genetically modified (GM) corn imports, a slow corn import approval process, and high corn support prices to Chinese farmers sent the Chinese livestock industry to sorghum, allowing feeders to get around the Chinese GM restrictions and "a variety of trade barriers" on corn (Tran et al., 2015). Within a couple years, China quickly went from not importing any sorghum at all to being the world's largest sorghum importer.

Historically, Mexico and Japan were the top destinations for U.S. sorghum exports but have now been surpassed by China (Figure 17). On average, over the period of 1975 to 2021, Mexico, Japan, and China accounted for roughly 75% of U.S. exports (Mexico 38%, Japan 24%, and China 13%). Given the NAFTA connection and its proximity to the United States, Mexico is almost a captive market for U.S. sorghum exports. As well, Mexico historically has been a major market for U.S. sorghum in part because its feeding industry is accustomed to sorghum and its corn imports have been limited by policies of the Mexican government (Hoffman et al, 2007). Japan had been the top market for U.S. sorghum exports until 1981. The entrance of rival exporters to the Japanese market, primarily Australia and Argentina, may make the re-establishment of Japan as a major U.S. export market difficult (Bryant Christie, Inc., 2013). The rest of the world (ROW) markets for U.S. sorghum include the European Union (the Netherlands and Spain), Israel, Saudi Arabia, Venezuela, and Sub-Saharan Africa (particularly Sudan). The European Union (EU) has been an erratic market for U.S. sorghum. For example, the EU took 25% of U.S. sorghum exports in 2006/07 and 60% in the next year while importing almost nothing in other years (Kustudija, 2012). The share of sorghum exports to Israel was on the order of 12% from 1975 to 1979 but has been nonexistent since 2012. Venezuela was a major export market for U.S. sorghum in the 1980s, but since 1990, the share of sorghum exports to Venezuela has been virtually zero. Sudan has been a key export market for sorghum since 2005, with export shares ranging from 1% to 11%. Notable shipments to Saudi Arabia occurred only in 2008/09 (Bryant Christie, Inc., 2013). These countries may have future potential but are facing infrastructural issues and policy issues which lead to difficulties for the expansion of imports of U.S. sorghum (Bryant Christie, Inc., 2013).

The principal rivals to the United States in terms of sorghum exports are Argentina and Australia (Figure 18). These three countries have historically accounted for over 90% and as much as 98% of world market exports of sorghum. The United States has been the primary sorghum supplier globally. On average, over the period 1975 to 2021, the level of U.S. exports of sorghum was 5.6 million metric tons, while the level of sorghum exports from Argentina and Australia was 1.6 million metric tons and 0.6 million metric tons, respectively. Argentina presents the largest competitive threat to U.S. sorghum exports with relatively low production costs. Argentina dominates the South American sorghum markets and competes with the U.S. in Asian markets (notably Japan) and in the European Union (EU) (Bryant Christie, Inc., 2013).

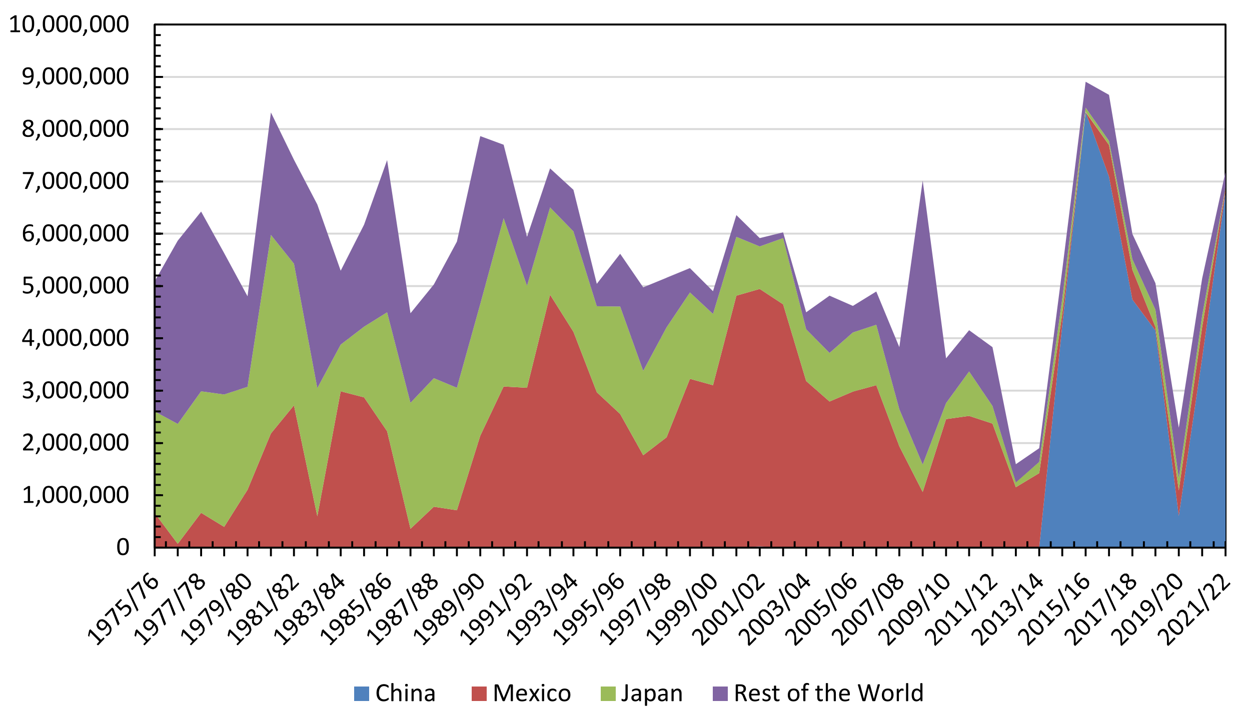
On average, over the period 1975 to 2021, export prices (export unit values) of sorghum from the United States, Argentina, and Australia, were \$145.66, \$119.49, and \$172.22 per metric ton, respectively (Figure 19). Export prices of sorghum from Australia historically have been highest followed by those of the United States. Correlations among sorghum export prices from the United States, Argentina, and Australia were 0.89 (Australia and Argentina), 0.90 (United States and Australia), and 0.96 (United States and Argentina). As such, prices from the major exporting countries of sorghum move together.

Figure 16. U.S. Exports of Sorghum to All Countries, 1975 to 2021



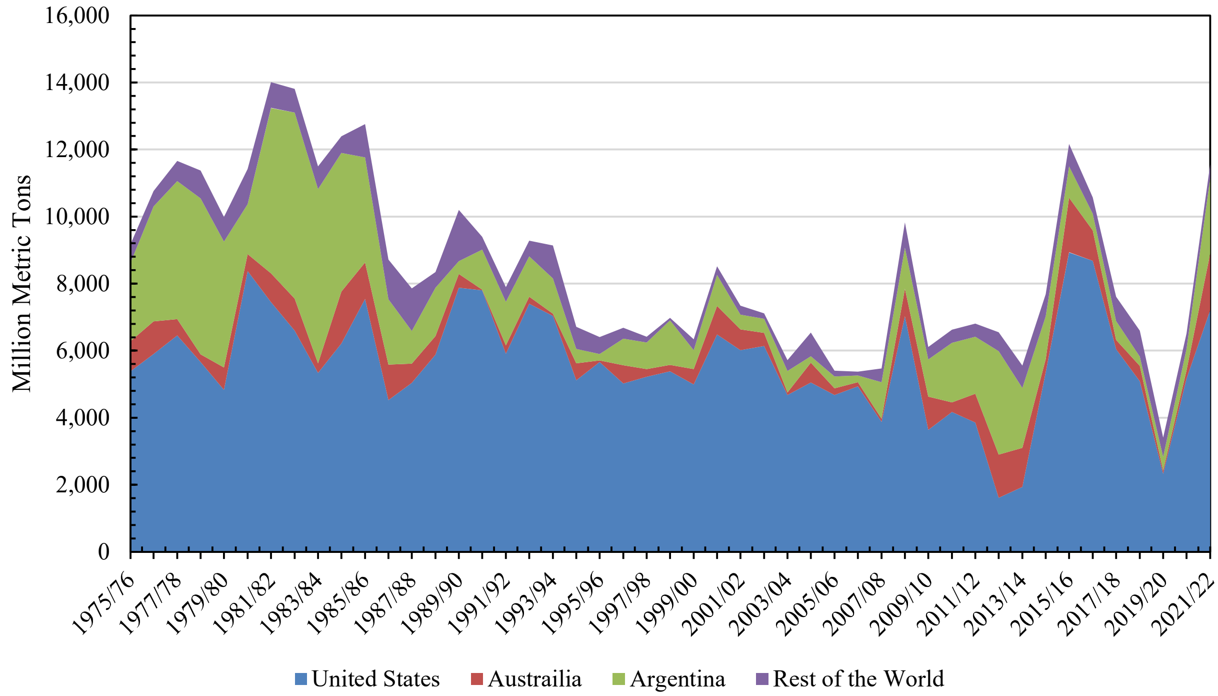
Source: Foreign Agricultural Service (FAS) and calculations by the authors.

Figure 17. U.S. Sorghum Exports by Country, 1975 to 2021



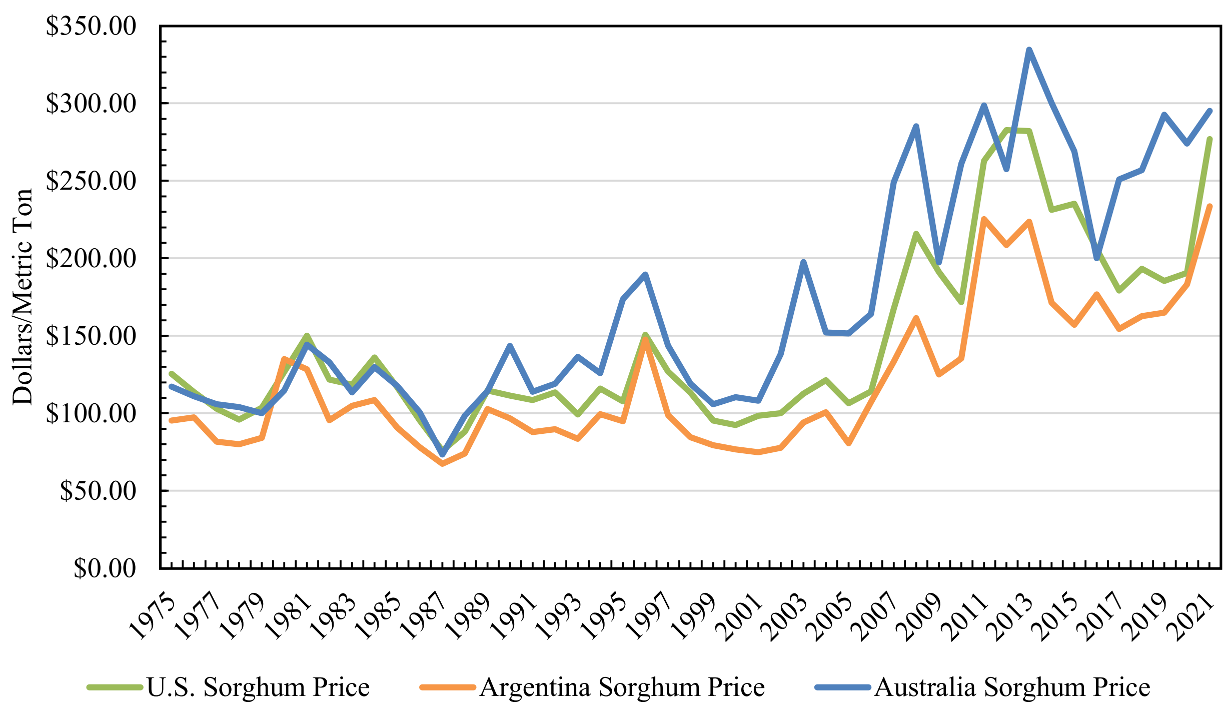
Source: Foreign Agricultural Service (FAS).

Figure 18. World Sorghum Exports by Major Exporter, 1975 to 2021



Source: Foreign Agricultural Service (FAS).

Figure 19. Sorghum Export Prices for the United States, Argentina, and Australia, 1975 to 2021



Source: Global Agricultural Trade System (GATS), Foreign Agricultural Service (FAS).

STRENGTHS, WEAKNESSES, OPPORTUNITIES, AND THREATS (SWOT) FACING THE U.S. SORGHUM INDUSTRY

Considering the background information on the U.S. sorghum industry allows for a Strengths, Weaknesses, Threats, and Opportunities (SWOT) analysis of the industry. This analysis provides not only actionable intelligence on the sorghum industry but also critical information and context for analyzing the effects of the sorghum checkoff program. The strengths, weaknesses, opportunities, and threats identified as potentially important for the U.S. sorghum industry are enumerated in Table 4.

Various factors impact U.S. and world grain sorghum production and consumption. As exhibited in Figure 20, world coarse grain consumption continues to increase (coarse grains include corn, sorghum, barley, oats, rye, millet, and mixed grains). Over the last twenty years, coarse grain consumption increased from 902 million metric tons to 1.494 billion metric tons, a rise of 60 percent (USDA, Foreign Agricultural Service (FAS), 2022).

In addition to the increase from a growing world population, per capita consumption of coarse grains continues to trend higher. The ability of grain sorghum to withstand heat and drought offers production advantages in the face of harsh growing environments or limited irrigation ability. As well, U.S. farm policy provides a safety net for grain sorghum producers in the form of price support, marketing loans, and cost-share crop insurance. The reference price for grain sorghum in the current farm bill is $3.95 per bushel compared to $3.70 per bushel for corn. Grain sorghum has a lower input cost per acre than corn due primarily to lower seed and fertilizer costs. Seed cost for sorghum ranges from $5.00 to $10.00 per acre; for corn, seed cost varies from $90.00 to $100.00 per acre. Though the pounds of nitrogen required per bushel of grain are similar for corn and sorghum, the yield goal of sorghum generally is lower meaning which translates to a lower expenditure for fertilizer per acre (Crop Profitability Analyzer, 2022). Per acre costs of sorghum compared to other coarse grains such as barley, oats, and millet typically are similar depending on production area and yield potential. As a non-GMO, gluten-free grain, sorghum is favored in markets sensitive to these issues, both domestically and abroad. Grain sorghum use in the United States the last several years has seen a surge in exports and has often traded at a premium price to corn.

The share of the coarse grain market for sorghum is on the decline. Yield growth for sorghum has lagged that of other crops. Consequently, grain sorghum is losing acres to corn and soybeans as varieties of these crops are being adapted to drier environments. Grain sorghum normally trades at a price discount to corn in most markets and its lower yields and lower prices do not offer the returns to investment compared to other crops.

Strengths

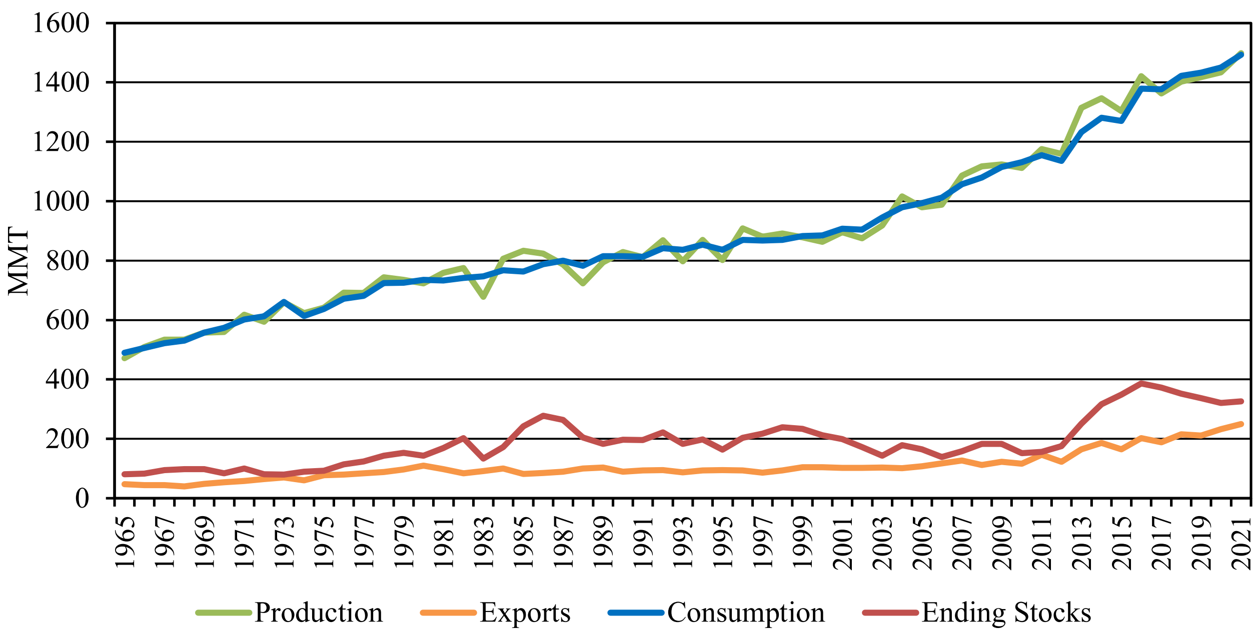
Demand

Growth in world population puts increased pressure on world agricultural productivity in the face of limited arable land and water resources. The world population surpassed 7 billion in 2013 and is expected to reach 8 billion by 2026 and 9 billion by 2050. While the population growth rate is slowing, world population continues to increase by about 70 million annually (USDA, Economic Research Service (ERS), (2022f). As presented in Figure 21, nations in Africa account for five of the top ten sorghum consuming countries in the world. UNICEF, the United Nations International

Table 4. Potential Strengths, Weaknesses, Opportunities, and Threats facing the U.S. Grain Sorghum Industry

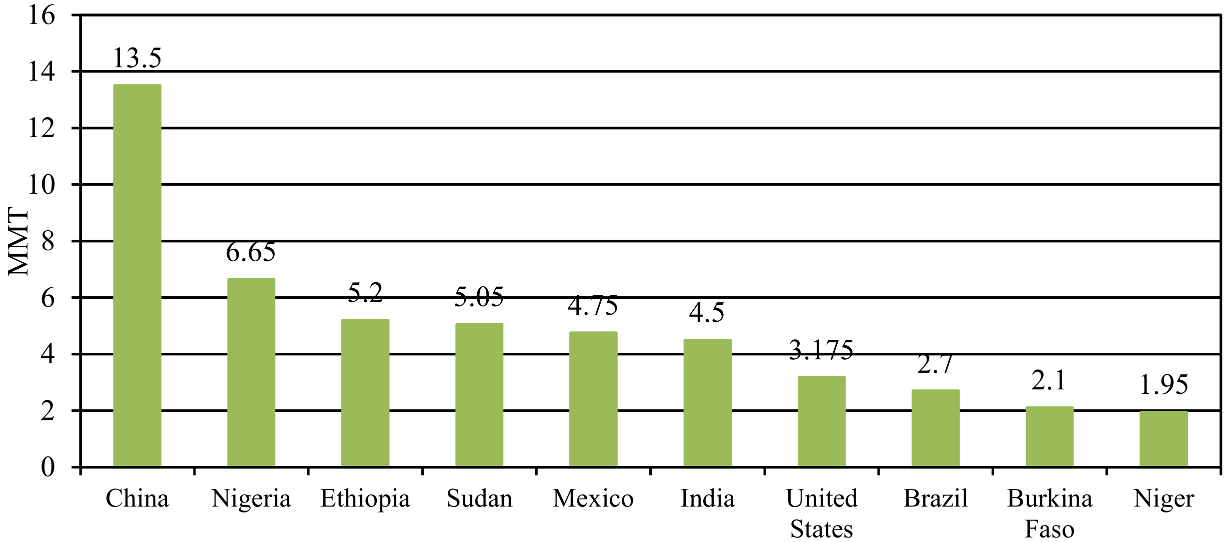
Strengths	Weaknesses
o Global coarse grain demand is increasing o GMO free/Gluten free o Value as a feed grain and feed stock for biofuel o Relatively low cost of production o Drought and heat resistance o Agronomic benefits o Farm policy safety net	o Grain sorghum's share of coarse grain use is in decline o Yield increases have fallen behind other field crops o Price discount relative to corn most times in most markets o Sugar Cane Aphid (SCA) o Feed processing inconsistency
Opportunities	**Threats**
o Enhance value as feed grain to gain market share in the feed industry o Increase value as a food grain in response to global food needs and consumer preferences o Increase use as a feed stock for biofuel o Trade arrangements and trade policies o Lower production costs, hence more competition for acres when capital availability is a constraint o Better crop adaptability to harsh environmental conditions, climate change	o Decline in planted and harvested acreage o Less investment in research and product development o Trade barriers and trade policies o Management practices o Climate change

Figure 20. World Coarse Grains Production, Exports, Consumption, and Ending Stocks, 1965/66 to 2021/22



Source: USDA, FAS, Office of the Chief Economist (OCE), World Agricultural Supply and Demand Estimates

Figure 21. Sorghum Domestic Consumption, 2021/22



Source: USDA, FAS, Production, Supply, and Distribution Database (PSD)

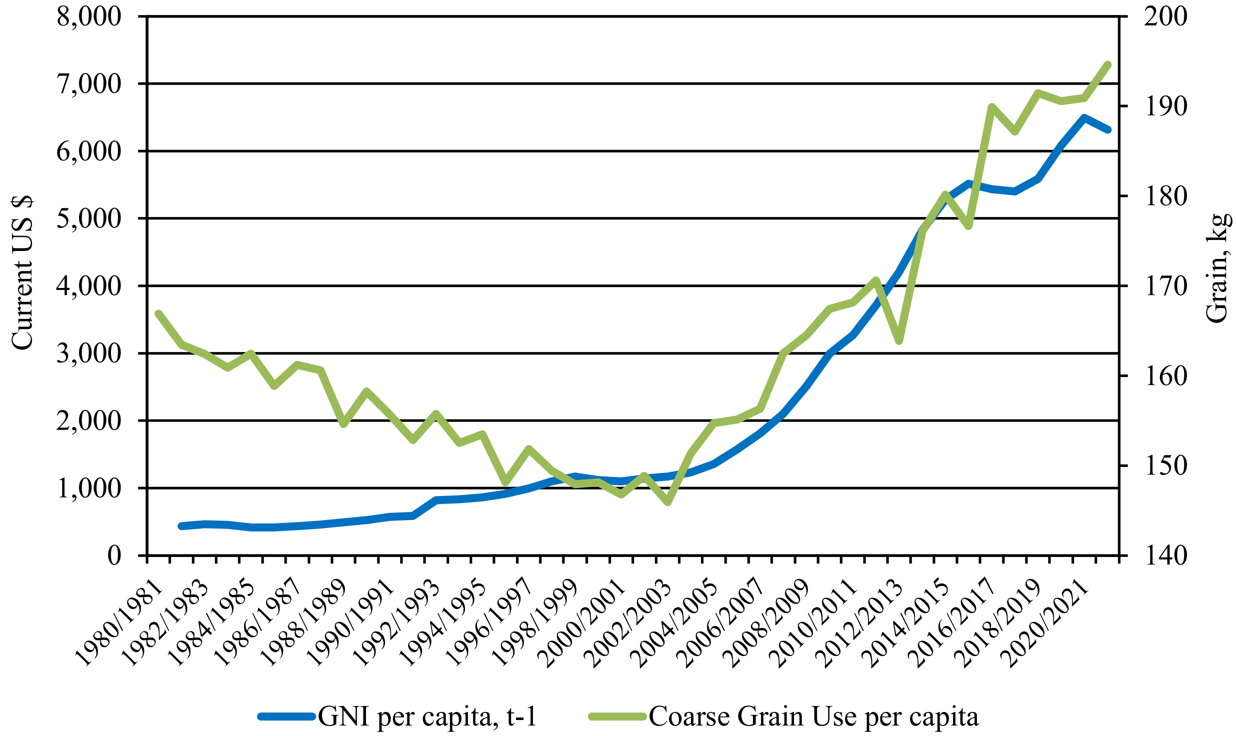
Children's Emergency Fund estimates that by 2050, the population of Africa will grow from about 1.2 billion today to 2.5 billion (UNICEF, 2017). Over that period, the population of Nigeria, one of the largest users of sorghum in the world, will increase from 186 million currently to 411 million.

In addition, the world is consuming more coarse grains per person. As exhibited in Figure 22, since 2003, world per capita coarse grain use has increased from 146 kilograms per person per year to 195 kg per person, a notable rise of 33 percent or put another way, a 1.8 percent per year over the last 19 years (USDA, FAS, 2022). This surge in world per capita coarse grain consumption coincides with global economic growth patterns (World Bank, 2021). The rise in economic growth has been driven by emerging and developing nations such as China, India, Brazil, Russia, Mexico, Indonesia, and other Southeast Asia nations. Growth in these countries, whose people strive for better living conditions and better diets, and which account for over 50% of the world population, is double the annual growth rate in advanced economies such as Australia, France, Germany, Japan, the United Kingdom, and the United States (International Monetary Fund (IMF), 2021). It is estimated that to feed a global population expected to reach 9 billion people in 2050, crop production will have to increase about 60 to 70 percent from current levels (Silva, 2018).

Non-GMO, Gluten-free

Since grain sorghum is a non-genetically modified crop and is gluten-free, it has natural appeal to consumers and markets with sensitivity to these issues. The market for food that excludes genetically-modified or genetically-engineered seeds is expanding, both in organic and conventionally grown cropping systems (Greene, Wechsler, Adalja, and Hanson, 2016). Additionally, it is estimated that 25 percent of Americans follow a gluten-free diet (Reed, 2020). Status as a non-GMO crop also can be an advantage in major export markets. That was evidenced by the surge in grain sorghum export demand to Europe in 2007. More recently, China has increased its imports of grain sorghum to record levels.

Figure 22. Emerging Economies Weighted Average Income, t-1, and World Per Capita Coarse Grain Consumption (Brazil, Russia, India, China, Mexico, Other Southeast Asia*)



*Other Southeast Asia refers to Indonesia, Vietnam, Philippines, Thailand, and Malaysia.
Source: World Bank, Gross National Income per capita; Grain Use USDA, FAS, PSD.

Use as Feed Grain and Biofuel feed stock near that of Corn

Processed grain sorghum as a livestock feed is at a slight disadvantage to corn but the difference is very small, depending on the form of processing. Studies of distillers' grain resulted in no significant differences between corn and grain sorghum (Brouk, 2012). The yield of ethanol and dried distillers' grains from a bushel of grain sorghum are on par with that of corn (Kansas Grain Sorghum, 2017). Sweet sorghum grown for biofuel production can produce high biomass yields with relatively low rates of nitrogen fertilizer (Stevens, 2014).

Relatively Low Cost of Production

The cost per acre to grow grain sorghum is less than that of corn due primarily to lower seed and fertilizer costs. Typically for yields in the Texas Panhandle in 2022, variable costs per acre for irrigated corn are $1,067 per acre compared to $560 per acre for irrigated grain sorghum (Crop Profitability Analyzer, 2022).

Drought and Heat Resistant

Grain sorghum often is grown in areas prone to water and heat stress. A study of corn and grain sorghum trials across Kansas and Nebraska found that in areas where corn yields are 100 bushels per acre or less, drought and temperature tolerance of grain sorghum provides a production advantage over corn (Staggenborg, Dhuyvetter, and Gordon, 2008).

Agronomic Benefits

The benefits of grain sorghum in rotation with other crops maintains soil productivity, improves soil moisture, and reduces the incidence of pests and disease, and helps with weed control and resistance management, especially for cotton (Lemon, 2009 and University of California Statewide Integrated Pest Management Program (UC IPM), 2013).

Farm Policy Safety Net

The Agricultural Improvement Act of 2018 (the 2018 Farm Bill) reauthorized the Price Loss Coverage (PLC) and Agricultural Risk Coverage (ARC) programs. PLC pays on base acres if the national marketing year average price falls below the reference price. The effective reference price for grain sorghum for 2022 is $3.95 per bushel; the effective reference price for corn is $3.70 per bushel.

The Risk Management Agency (RMA) has established the projected price for corn and grain sorghum for the 2022 crop year. For insurance products with a March 15 sales closing date, the projected price for corn is $5.90 per bushel, while the projected price for grain sorghum is $5.88 per bushel.

Weaknesses

Declining Share of Coarse Grain Consumption

As exhibited in Figure 23, global consumption of grain sorghum has not changed much since 1980 at around 60 million metric tons. As a share of world coarse grain consumption, sorghum has fallen from nine percent to below five percent.

Yield Gains for Grain Sorghum Less Than Competing Crops

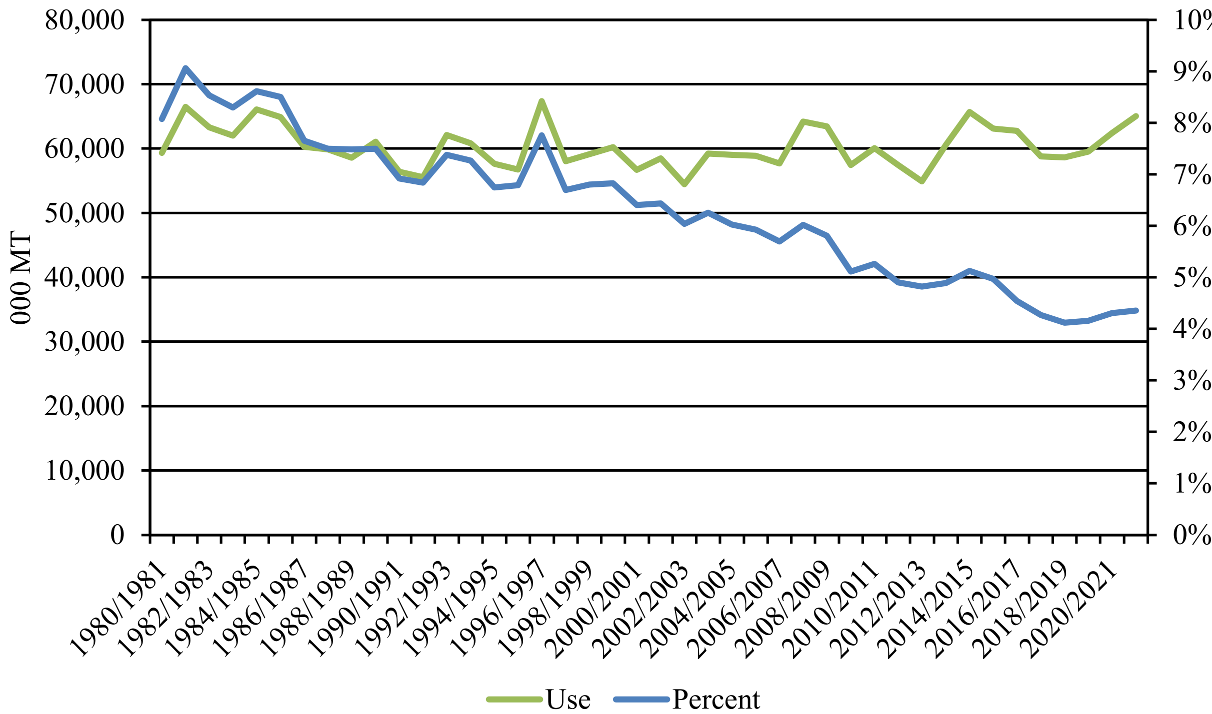
As shown in Figure 24, the gains in productivity for grain sorghum have lagged that of corn. Since the early 1980s, U.S. corn yields have increased about 70 percent, while grain sorghum yields are up only 20 to 30 percent.

In terms of water efficiency, grain sorghum yielded about seven bushels per acre inch of irrigation compared to eight bushels for corn. Given current commodity prices for 2022 in the Texas Panhandle, the gross return per inch of irrigation water was $48.40 for grain sorghum compared to $57.60 for corn (Trostle, 2022).

Price Discount Relative to Corn

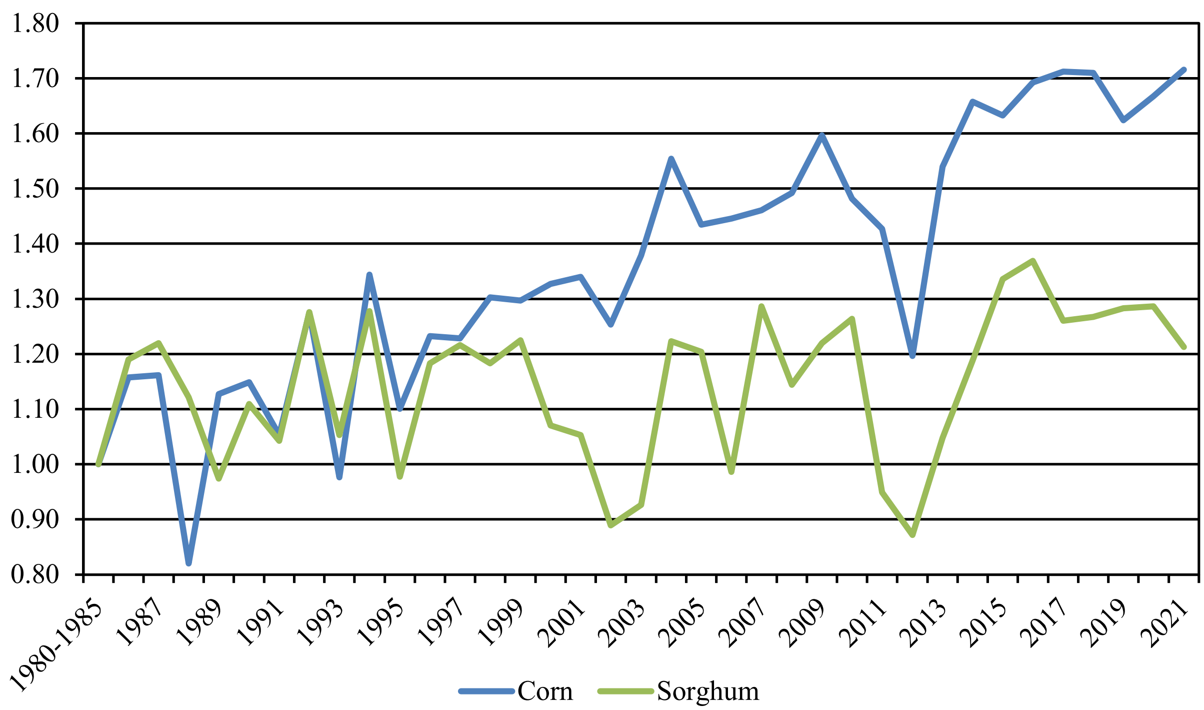
As depicted in Figure 25, historically, the national average price for grain sorghum is a $0.13 per bushel discount to corn. That said, in times of strong export demand, notably 2007, 2014-15, and 2020-2022, grain sorghum can trade at a premium to corn as shown in Figure 26.

Figure 23. World Grain Sorghum Consumption



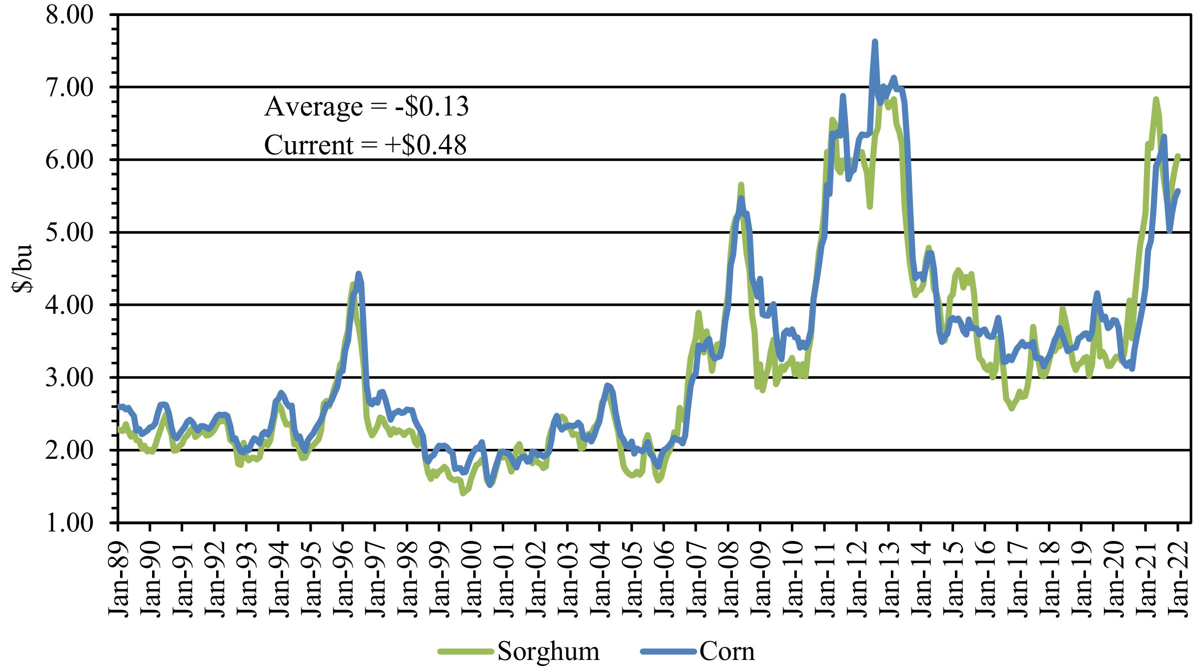
Source: USDA, FAS, Production, Supply, and Distribution Database (PSD)

Figure 24. Corn and Sorghum Yields as a Proportion of the Base Average from 1980 to 1985



Source: USDA, FAS, World Agricultural Supply and Demand Estimates (WASDE)

Figure 25. U.S. Average Prices Received by Farmers, Sorghum and Corn, January 1989 to January 2022



Source: USDA, National Agricultural Statistics Service (NASS)

Sugar Cane Aphid

Sugar cane aphids feed on the underside of sorghum leaves, can feed on the grain head after emergence, and produce large amounts of honeydew, which collects on the plant. Not only do sugar cane aphids reduce yields by sucking plant sap but also sticky honeydew can clog harvesting equipment and reduce separation of grain from the head (Knutson, Bowling, Brewer, Bynum, and Porter, 2016). Severe infestations can render a field un-harvestable. Control requires frequent infestation assessment and timely application of insecticide.

Feed Processing Consistency

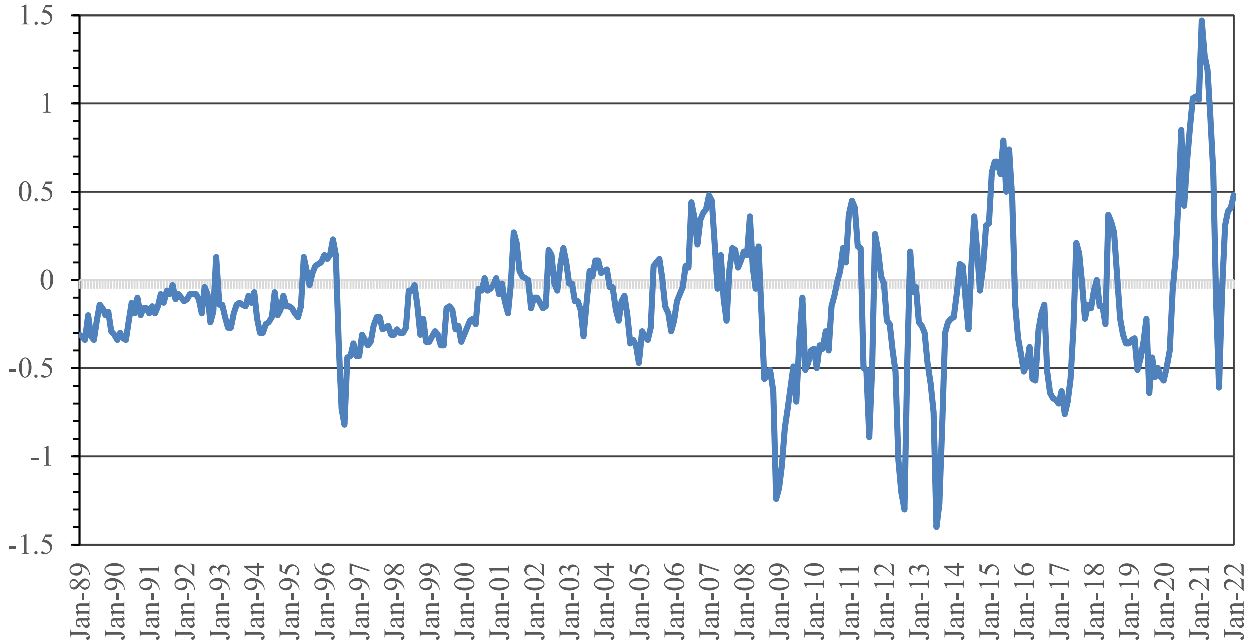
When processed, the value of grain sorghum in livestock rations is on par with corn (Richards and Hicks, 2007). However, the kernel characteristics of grain sorghum can raise processing costs and lower feed value. Variability in outcomes is due to overall small size, hardness, and inconsistent berry size which can result in slower processing or some kernels only minimally or semi-processed (McCollum, 2016).

Opportunities

Increased Feed Demand

The market for energy feed is increasing. In 2014 and more recently in 2020, China increased its imports of U.S. grain sorghum dramatically. As exhibited in Figure 27, the surge in imports coincided

Figure 26. U.S. Average Prices Received by Farmers, Sorghum Minus Corn, January 1989 to January 2022



Source: USDA, National Agricultural Statistics Service (NASS)

with a strong increase in the feed use category (USDA, Foreign Agricultural Service (FAS), Production, Supply, and Distribution Database (PSD), 2022). Research confirming and enhancing the value of grain sorghum as a feed grain has the potential to increase market share for sorghum.

Increased Food Demand

The growing demand for food globally and the increasing consumer preference for non-GMO, gluten-free products offer opportunities for sorghum to become a larger contributor to world food consumption.

Increased Fuel Demand

The Environmental Protection Agency (EPA) determined that ethanol made from grain sorghum qualifies as an advanced biofuel (EPA, 2018). Advanced biofuels are advantageous over conventional biofuels in that they result in less lifetime greenhouse gas production. This situation then could provide an opportunity for grain sorghum to capture a larger share of the ethanol market, both as a grain and as a forage-based environmentally beneficial biofuel feedstock.

Exports

Grain sorghum is favored as a feed and food grain in foreign markets where genetically modified organisms (GMO) is a concern and/or where trade barriers exist for other commodities. This situation includes China where grain sorghum does not face trade restrictions like corn. In addition, consumers in Europe and other nations prefer non-GMO products, especially where restrictions on GMO traits in food and feed grains are still in place. In periods of strong export demand, grain sorghum often has traded at a smaller discount to corn or more recently, earned a notable price premium.

Lower Production Costs

In situations of high input prices and increased financial risk, producers often struggle to obtain the credit they need to operate their farms and ranches. Grain sorghum has a low input cost per acre that can reduce borrowing needs and financial risk.

Better Suited to Harsh Growing Environmental Conditions

Grain sorghum's adaptability to hotter and drier growing conditions makes it a less risky enterprise choice in areas where these climactic conditions are more likely. The agricultural risk from global climate change comes from a hotter climate, altered precipitation amounts, altered precipitation intensity, and higher sea levels (McCarl, 2008). The regions at greatest risk are closer to the equator, specifically the Southern Regions of the United States (Fan, Fei, and McCarl, 2017).

The impacts of climate change on corn and grain sorghum are similar in that yields decline when precipitation declines and/or temperature increases. The differences being that with rising temperatures, corn yields become more variable and grain sorghum yields less variable, demonstrating sorghum's adaptability to warmer growing conditions (Chen, McCarl, and Schimmelpfennig, 2004).

Threats

Losing crop area

With a slower rate of yield increase and a price discount relative to corn, planted acres of grain sorghum are on the decline. As depicted in Figure 28, since 1996, when U.S. farm policy was reformed to allow more freedom in farmers' planting decisions, U.S. planted acres of corn are up 14 million (+18%), while planted acres of grain sorghum are down 6 million (-44%).

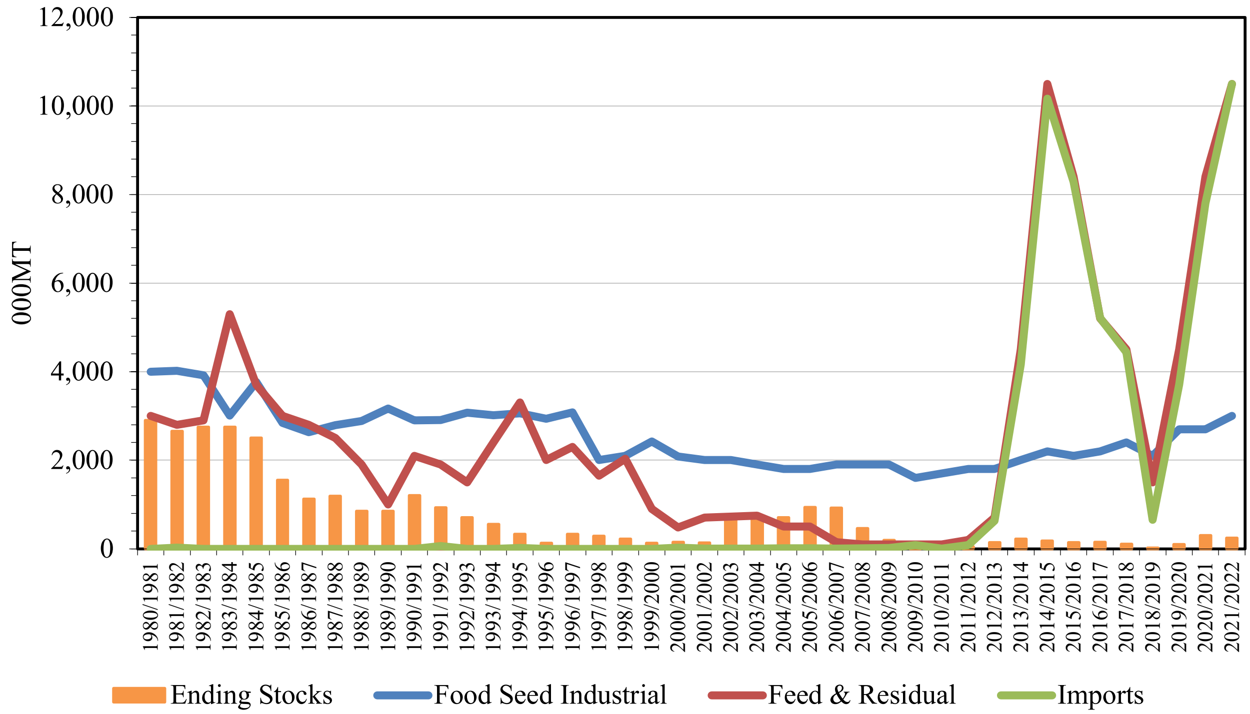
Lack of research investment

With relatively low acreage and low per acre revenue, grain sorghum generally receives less investment relative to other crops for variety development, disease and pest resistance, new pesticides, and other traits that increase productivity.

Trade

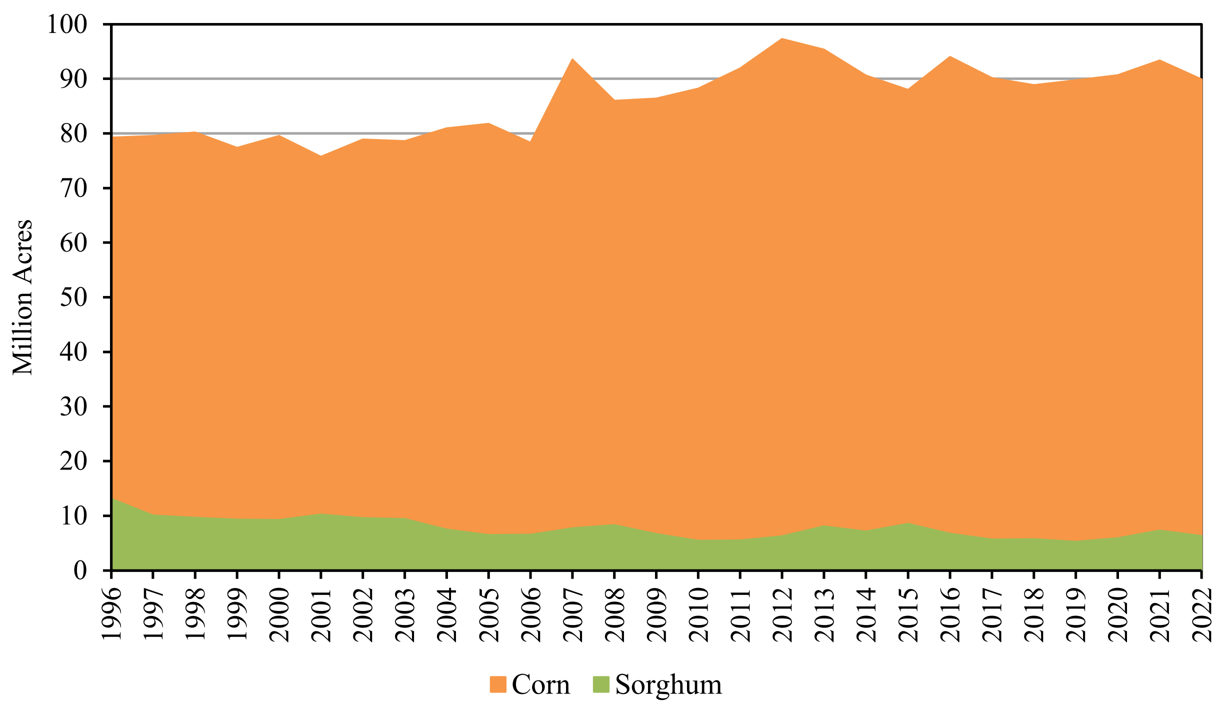
Exports constitute the major category for U.S. grain sorghum at present. As shown in Figure 29, the top sorghum importer in the world currently is China. Any issues that result in a breakdown of trade relations or the imposition of trade barriers would have a notable impact on the U.S. grain sorghum market. In addition, as exhibited in Figure 30, competition is evident among Argentina, Australia, and the United States concerning sorghum exports. Argentina and Australia then pose a distinct threat to the United States pertinent to sorghum exports.

Figure 27. China Sorghum, Uses and Imports



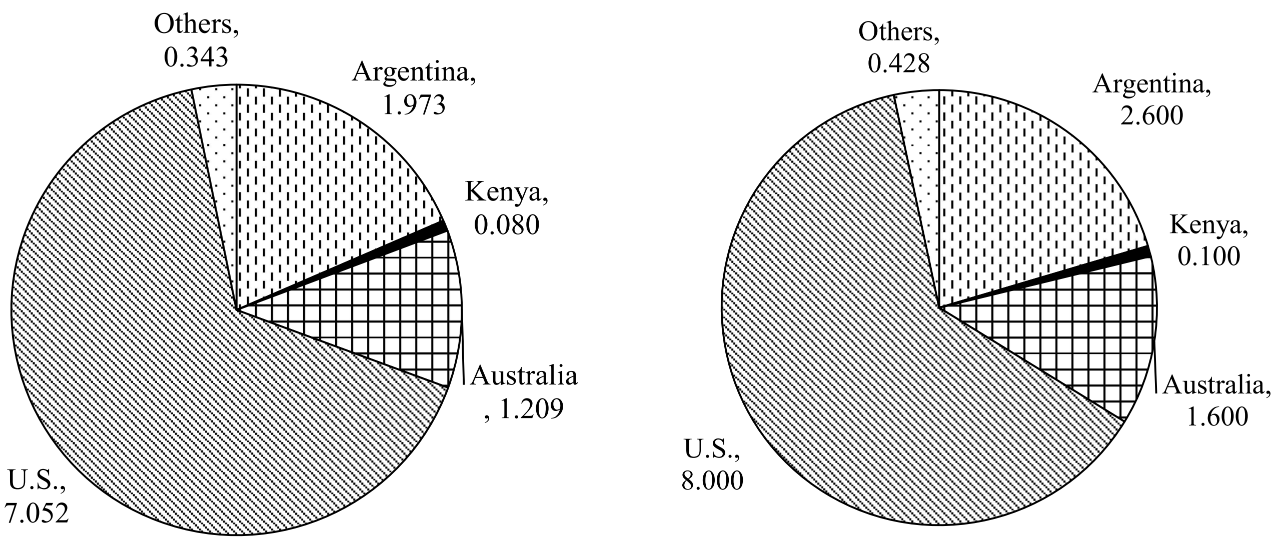
Source: USDA, FAS, Production, Supply, and Distribution Database (PSD), March 9, 2022.

Figure 28. U.S. Planted Acres of Corn and Grain Sorghum, 1996 – 2022



Source: USDA, National Agricultural Statistics Service (NASS)

Figure 29. Major Exporters of Sorghum, 2020/21 and 2021/22, million metric tons

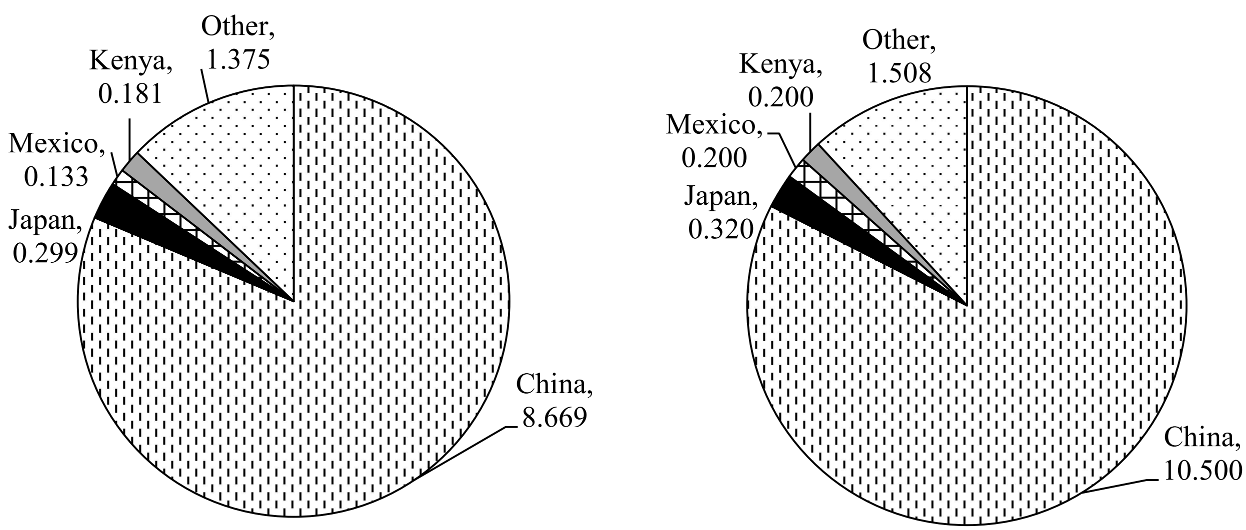


2021/21 (estimated) Total = 10.657

2021/22 (projected) Total = 12.728

Source: USDA, Office of the Chief Economist (OCE), World Agricultural Supply and Demand Estimates (WASDE)

Figure 30. Major Importers of Sorghum, 2020/21 and 2021/22, million metric tons



2021/21 (estimated) Total = 10.657

2021/22 (projected) Total = 12.728

Source: USDA, Office of the Chief Economist (OCE), World Agricultural Supply and Demand Estimates (WASDE)

Management Practices

Grain sorghum has a lower cost of production per acre than many other cropping alternatives, but the management required typically is higher. Being non-GMO, grain sorghum does not have built in resistance to many pests and weed control options and are either more limited or more costly. Diligence is required to make timely, efficient, and economically viable crop management decisions.

Climate Change

The impacts of climate change, while perhaps less detrimental to grain sorghum production than other crops, are still noteworthy such as potentially lower yields, increased water requirements, and increased pressure from weeds, pests, and fungi that thrive in warmer environments (EPA, 2017).

Summary and Conclusions

An overview of strengths, weaknesses, opportunities, and threats facing the U.S. grain sorghum industry reveals areas of strategic importance:

Supply

Productivity

- Yield increases are necessary to keep up with increasing demand given land area constraints as well as to make grain sorghum returns competitive with alternative crops.
- Varieties with characteristics such as drought tolerance and disease and pest resistance are increasingly important in the face of climate change. Biotech or genetically modified grain sorghum strains may play a role in this effort. But product introduction is dependent upon consumer acceptance.
- Management tools, decision aids, economic thresholds for management decisions are important to support growers in their ability to increase profitability from grain sorghum production.

Demand

Product development

- Investment is needed in new uses or processes for grain sorghum in all major consumption categories: feed, food, fuel. Grain sorghum has the characteristics to make a noteworthy contribution in enhancing these respective uses.
- Advances in grain sorghum product development have the potential to close the price differential between grain sorghum and corn, adding to crop profitability.

Trade

- Exports are the number one use of U.S. grain sorghum.
- Argentina and Australia are noteworthy competitors to the United States concerning sorghum exports.
- Product development and trait enhancement can increase the global demand for grain sorghum.

Trade agreements and trade policies that support market access and the elimination of trade barriers are particularly important for grain sorghum.

ANALYSIS OF THE IMPACTS AND RETURNS FROM USCP ACTIVITIES

In this section, two sets of analyses of the impacts of sorghum checkoff program expenditures (funds committed by USCP) are conducted: (1) analysis of the impact of sorghum checkoff expenditures for crop improvement (research) on sorghum acres planted, yields, and consequently production and (2) analysis of the impact of sorghum checkoff expenditures intended to boost the various uses (demand) for U.S. sorghum. The analyses include calculations of the returns to producers from the respective expenditures using benefit-cost analysis.

The first analysis is designed to determine whether USCP program expenditures since 2008 effectively led to increases in sorghum production, holding all other factors constant. The second set of analyses is designed to determine whether the sorghum checkoff program shifted out the demand for sorghum by enhancing any of the various uses of sorghum. If the answer to those questions is "yes," then the next question is whether any increase in sorghum production or increase in demand achieved through the checkoff program generated benefits to sorghum producers that have contributed to the program. Obviously, if the answer to the first questions is "no," then the answer to the second question is "no" as well. However, if the answer to the first questions is "yes," then answer to the second is not necessarily "yes" because any consequent increase in revenues to the contributors may or may not be sufficient to cover the cost of the various USCP programmatic activities.

To measure the returns to USCP program expenditures, the first step is to isolate the effects of those investments in domestic and international markets from those of other events that may have affected those markets. For this purpose, checkoff expenditures over the years must be incorporated into appropriate econometric models of domestic and international sorghum markets. These models then are simulated over the historical period under alternative assumptions regarding sorghum checkoff expenditure levels. The results are used subsequently to calculate benefit-cost ratios. We pioneered this cutting-edge evaluation procedure and have used this evaluation procedure in other checkoff program analyses including those for dairy, soybeans, pork, cotton, dairy, lamb, orange juice, and others.

The use of the structural or econometric models generates a baseline simulation of the various key endogenous or dependent variables (domestic sorghum production; domestic uses of sorghum; exports of sorghum to various foreign countries; and grower prices of sorghum). Because the programmatic expenditures made by USCP are set to their actual or historical values, the baseline simulation represents the *"With Expenditures" scenario.* Subsequently, these expenditures are set to zero and the simulation is conducted again to generate the *"Without Expenditures" scenario* results for the respective key variables in the structural models. These results then provide a measure of what the levels of production, prices, domestic uses, and exports would have been in the absence of the marketing activities of the USCP Board.

Differences in the solution values of the key variables in the *"Without Expenditures" scenario* (sometimes referred to as the "counterfactual" scenario) from their baseline solution values (the *"With Expenditures scenario"*) consequently are direct measures of the effects of the programmatic activities of the USCP board over time. Because no other exogenous or predetermined variables in the simulation model are allowed to change, this process effectively isolates the impacts of the checkoff program activities associated with the USCP board on production, domestic uses, exports, and prices of sorghum. Therefore, our study indeed presents econometric evaluations of the impacts of USCP market development and promotion, information, and research activities that ultimately lead to the calculations of the returns to producer investments associated with the programmatic activities of USCP.

All models are estimated using sorghum checkoff program expenditure data made available by the USCP. Those expenditures fall into three program areas: (1) research (crop improvement), (2) market development, renewables, and exports, and (3) sustainability (data collection, sampling, and partnerships that are producer driven). Data required for the analysis relating to sorghum markets, such as grower prices, production, yields, and planted and harvested acreage, are publicly available from the U.S. Department of Agriculture, National Agricultural Statistics Service (USDA, NASS). Sorghum export data are published by the Foreign Agricultural Service (FAS) of the U.S. Department of Agriculture and gathered by the U.S. Department of Commerce. Other data required for the analysis such as inflation, gross domestic incomes of foreign countries, FAS sorghum promotion expenditures (procured from USGC), and exchange rates are publicly available from various U.S. government agencies.

Impacts and Returns from USCP Crop Improvement Research Expenditures

Checkoff expenditures for agricultural research (crop improvement) are intended to shift out the supply of U.S. sorghum by increasing production efficiency (yield) and planted acreage and/or by reducing production costs. Typically, agricultural research expenditures that reduce production costs would be expected to lead to an expansion in acreage dedicated to sorghum production. On the other hand, agricultural research expenditures that increase production efficiency would be expected to increase production yields, that is, the output per acre in production. Since production is the product of harvested acreage and yield, successful agricultural research of either type would tend to increase output.

The effects of investments in research on the market supply of a commodity like sorghum, however, are often not immediate, measurable, or direct. Research investments may fund either basic, long-term types of research or more applied, short-term types of research. Because the lag between research activities, particularly basic research, and the commercialization of new technologies available for adoption by sorghum producers may be lengthy, the full market impacts and any benefits of checkoff-funded research to sorghum producers may not be felt for a long time following the research investment.

Also, research investments may not always result in measurable market impacts. For example, basic or applied research that provides knowledge about what does *not* work in increasing yields or reducing costs has value but is not measurable in terms of market impacts. At the same time, applied research often is related to or depends on previous investments in basic research. Consequently, investments in basic research may have only indirect market effects to the extent that the results of that research lead to more applied research to develop new technologies. An added complication is the difficulty of obtaining the necessary data over a sufficiently long enough time horizon to be able to statistically identify the relations between research and production. Thus, it may not be possible to quantify accurately the total effectiveness of sorghum checkoff research expenditures on the sorghum industry given that the program has been in existence since 2008. We address these issues in our analysis of checkoff expenditures on agricultural research.

Specification of the Supply Model

Major contributions to both the theory and measurement of the returns to producers from investments in agricultural research have been made by a variety of researchers (see, for example, Schultz, 1953; Griliches, 1958; Evenson, 1967; Peterson, 1967; Fox, 1985; Pardey and Craig, 1989; Chavas and Cox, 1992; and Williams, Shumway, and Love, 2002). Several commodities have been analyzed, including corn, cotton, poultry, rice, rapeseed, wheat, wool, and soybeans. The reality is that little research is available on the returns and supply effects of either public or private investments in sorghum research.

The economic relationships between sorghum checkoff-funded agricultural research expenditures and sorghum planted or harvested acreage and yield are measured using econometric analysis. Crop year data on planted acreage, harvested acreage and yield are available back to marketing years 1960/61. But data on USCP crop improvement activities are available only from 2008/09. We assume zero committed funds in crop improvement programs, prior to 2008/09, although we recognize that this assumption may not be tenable. Simply put, data on crop improvement activities prior to the establishment of USCP (state-funded activities) were not available.

Agricultural research expenditures, defined as expenditures on crop improvement, may affect planted acreage and yields and, therefore, production. The economic relationship between sorghum checkoff-funded agricultural crop improvement or research expenditures and sorghum planted and harvested acreage and yield is measured with the use of econometric analysis. We implement, where necessary, a polynomial distributed lag (PDL) formulation to account for the potential carryover effects of agricultural research expenditures on planted acreage and on yields. We specify planted acreage in the current period to be a function of several variables: (1) prices of sorghum and corn received by producers in the previous year; (2) a one-year lag of planted acreage; and (3) a PDL formulation of the funds committed to crop improvement activities by USCP (lag length of six years). Additionally, we capture factors affecting planted acres using trend variables and through the use of indicator variables representing qualitative events that occurred in 1967,1971,1984,1985, 1996, and 2008. Further, we estimate the relationship between acres harvested and acres planted. This relationship is important in establishing the impact of changes in harvested acreage attributed to USCP crop improvement activities. Harvested acres are specified to be a function of planted acres.

In the analysis of checkoff expenditure impacts on sorghum yield, yield in the current period is specified to be a function of: (1) weather effects, with the use of El Niño and La Niña proxy variables; (2) technological developments with the use of trend variables as proxies and indicator variables representing qualitative events that occurred in 1980, 1983, 1991, 1995, 2002, 2003, 2006, 2011, 2012, and 2013; and (3) a PDL formulation of crop improvement expenditures made by USCP (lag length of three years).

Weather effects are proxied through the occurrences of the El Niño/La Niña phenomena. El Niño and La Niña are two extreme phases of the El Niño/Southern Oscillation (ENSO) climate cycle. El Niño occurs when there is an irregular warming of subsurface temperatures from Peru to Ecuador to the Pacific. Over the period 1960 to 2021, major El Niño occurrences were recorded in 1963, 1964, 1965, 1966, 1968, 1969, 1972, 1973, 1982, 1983, 1986, 1987, 1988, 1991, 1992, 1994, 1995, 1997, 1998, 2002, 2003, 2009, 2010, 2015, and 2016. (NOAA, 2022). The effects of El Niño give rise to more rain across the southern part of the United States.

La Niña events were recorded in 1970, 1971, 1973, 1974, 1975, 1976, 1988, 1989, 1995, 1996, 1998, 1999, 2000, 2007, 2008, 2010, 2011, 2012, 2020, and 2021 (NOAA). 2022 La Niña leads to warmer conditions and less rain across the southern part of the United States. Consequently, for years in which La Niña occurred, owing to more drought conditions, yields are expected to be lower. For years in which El Niño occurred, yields are expected to be higher.

We use a natural logarithmic transformation of the variables in each equation which allows us to account for the diminishing returns to promotion expenditures as is commonly done in checkoff program evaluation studies. Various lag lengths are considered with the optimal lag lengths chosen based on statistical criteria, namely the Schwarz Information Criterion (SIC), the Akaike Information Criterion (AIC), and the Hannan-Quinn Criterion (HQC). These statistical criteria are also known as model selection criteria.

Separate single-equation models are specified for U.S. sorghum planted acreage, U.S. sorghum harvested acreage, and U.S. sorghum yield. The data for this analysis cover the marketing years 1960 through 2021. Agricultural research expenditures finance projects intended primarily to enhance sorghum yield and quality, improving sorghum's resistance to temperature extremes and to insects and diseases, advances in biotechnology, reduced dependence on pesticides, and profitable conservation tillage practices. Agricultural research expenditures that reduce production costs would be expected to give rise to expanding acreage dedicated to sorghum production.

We may summarize the econometric specifications of the supply model as follows:

(1) log (Planted Acreage of Sorghum$_t$) = f_1 (log ((sorghum farm price$_{t-1}$) / (corn farm price$_{t-1}$)), time^2, PDL of log (USCP_crop_improv)', log (Planted Acreage of Sorghum$_{t-1}$), D1967, D1971, D1984, D1985, D1996, D2008) + v_1

(2) Harvested Acres of Sorghum = f_2 (Planted Acreage of Sorghum) + v_2

(3) log (Sorghum Yield$_t$) = f_3 (LA_NINA$_t$, EL_NINO$_t$, time, time^2, PDL of log (USCP_crop_improv$_t$)', D1980, D1983, D1991, D1995, D2002, D2003, D2006, D2011, D2012, D2013) + v_3

(4) Sorghum Production = Harvested Acres of Sorghum * Sorghum Yield

where D1967, D1971, D1980, D1983, D1984, D1985, D1991, D1995, D1996, D2002, D2003, D2006, D2008, D2011, D2012, and D2013 are indicator variables, taking on the value of 1 for the year following the D prefix, and 0 otherwise, time is a time trend variable which takes on the values of 0,1, 2, etc. The indicator variables reflect structural changes as well as outliers or leverage points (Belsley, Kuh, and Welsch, 1980), while the time trend variables are a proxy for technological innovations and other factors affecting planted acreage and yield.

To close this system, we add a model specification for the farm price of sorghum:

(5) log (sorghum farm price) = f_4 (log (corn farm price$_t$), log (sorghum production$_t$), log (price of no. 2 sorghum at Kansas City$_t$), PDL of log (USCP_crop_improv), D1982, D1987, D1999, D2002, D2006, D2010, D2014, D2016, and D2018) + v_4

Corn prices are hypothesized to positively affect sorghum prices whereas sorghum production is hypothesized to be inversely related to sorghum prices. The price of no. 2 sorghum at Kansas City is hypothesized to be positively related to the farm price of sorghum. This relationship affects the price transmission process for farm prices to downstream prices in the marketing channel. D1982, D1987, D1999, D2002, D2006, D2010, D2014, D2016, and D2018 are indicator variables, taking on the value of 1 for the year following the D prefix, and 0 otherwise. This system of equations (1) through (5) can be used to captures the impacts of funds committed to USCP crop improvement activities on planted acres, harvested acres, yields, production, and farm prices.

Alternatively, we can model sorghum production directly, shown as equation (6).

(6) log (production_us) = f_5 (log (sorghum_farm_price$_{t-1}$)/(corn_farm price$_{t-1}$)), PDL of log (USCP_crop_improv), time, time^2, D1983, D1985, D2006, D2011, D2012) + v_5

With equations (4) and (6) in hand, we check on the robustness of the impacts of crop improvement on production.

Empirical Results for the Supply Model

As exhibited in Table 5, for planted acreage (equation (1) above), the R^2 measure of goodness-of-fit is 0.9595, which reflects that 96% of the variation in the number of acres planted is accounted for by the econometric model. The drivers of acres planted to sorghum in the United States are the ratio of the farm price of sorghum to the farm price of corn with a one-year lag, the number of acres planted in the previous year, qualitative factors that occurred in various years (1967, 1971, 1984, 1985, 1996, and 2008) and a nonlinear (squared) trend. The estimated coefficient of the square of the trend variable is negative and statistically different from zero. If the ratio of the farm price of sorghum to the farm price of corn in the previous year changes by one percent, then the number of acres planted of sorghum changes by 1.25% in the same direction. The significance of the number of acres of sorghum planted in the previous year is indicative of inertia on the part of growers. As well, the coefficient associated with the one-year lag of planted acres is technically the elasticity of adjustment. In this instance, roughly 75% of the adjustment to the “desired” level of planted acres is made after one year.

Of note, funds committed to crop improvement activities made by USCP are positively and related to acres planted to sorghum. The optimal lag length is six years. Hence this impact occurs not only contemporaneously but also over the previous six years. A one percent change in expenditures made to crop improvement activities today leads to a 0.0259% change in planted acres after a period of six years. The use of the logarithmic transformation captures diminishing marginal returns in planted acres attributed to USCP crop improvement expenditures.

As exhibited in Table 5, this sensitivity or elasticity of planted acreage to funds committed to crop improvement activities means that because of the checkoff program roughly an additional 1,998,993 acres of sorghum are planted as a direct result of those research investments over the period 2008 to 2021.

Table 5. Econometric Analysis of Planted Acres of Sorghum in the United States from 1960 to 2021

Dependent Variable: LOG(ACRES_PLANTED_US)
Method: Least Squares

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	12.67899	1.823771	6.952070	0.0000
LOG(SORGHUM_FARM_PRICE(-1)/CORN_FARM_PRICE(-1))	1.246320	0.252163	4.942520	0.0000
@TREND^2	-0.000364	5.37E-05	-6.771108	0.0000
LOG(ACRES_PLANTED_US(-1))	0.248921	0.108481	2.294602	0.0265
D1984	0.307054	0.096728	3.174421	0.0027
D1985	0.251680	0.095398	2.638205	0.0114
D1996	0.277637	0.094599	2.934880	0.0052
D1971	0.251769	0.095754	2.629330	0.0117
D1967	0.204451	0.098335	2.079127	0.0433
D2008	0.254515	0.098232	2.590949	0.0129
PDL01	0.002466	0.000494	4.989798	0.0000

R-squared	0.959497	Mean dependent var	16.19484
Adjusted R-squared	0.950497	S.D. dependent var	0.413683
S.E. of regression	0.092042	Akaike info criterion	-1.758984
Sum squared resid	0.381225	Schwarz criterion	-1.361147
Log likelihood	60.25156	Hannan-Quinn criter.	-1.604744
F-statistic	106.6039	Durbin-Watson stat	1.784408
Prob(F-statistic)	0.000000		

Lag Distribution of LOG(USCP_CROP_IMPROV_LOG)	i	Coefficient	Std. Error	t-Statistic
. * |	0	0.00216	0.00043	4.98980
. * |	1	0.00370	0.00074	4.98980
. * |	2	0.00462	0.00093	4.98980
. *|	3	0.00493	0.00099	4.98980
. * |	4	0.00462	0.00093	4.98980
. * |	5	0.00370	0.00074	4.98980
. * |	6	0.00216	0.00043	4.98980
	Sum of Lags	0.02589	0.00519	4.98980

Source: Calculations by the authors using EVIEWS 11.0.

For sorghum harvested acreage (equation (2) above), a one-unit change in number of acres planted leads to a 0.7742 unit change in the number of acres harvested (Table 6). Consequently, funds committed to crop improvement activities made by USCP generated additional harvested acreage between 105,532 to 169,553 acres each year. Put another way, because of the checkoff program, planted acreage rose 2.59 percent on average over the period 2008 to 2021 and harvested acreage rose 2.31 percent on average because of the research activities funded by the sorghum checkoff program (see Table 6).

Sorghum checkoff investments in crop improvement activities boosted sorghum planted acreage in each year by 2.6% on average and harvested acreage by about 2.3% since the beginning of the program. These impacts were greater than those reported in the second evaluation wherein USCP

Table 6. Relationship between Acres Harvested and Acres Planted of Sorghum, 1960 to 2021

Dependent Variable: ACRES_HARVESTED_US,
Method: Least Squares

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	724817.8	243583.7	2.975642	0.0042
ACRES_PLANTED_US	0.774202	0.018684	41.43630	0.0000

R-squared	0.966235	Mean dependent var	10164903
Adjusted R-squared	0.965672	S.D. dependent var	3663315.
S.E. of regression	678733.8	Akaike info criterion	29.72557
Sum squared resid	2.76E+13	Schwarz criterion	29.79419
Log likelihood	-919.4927	Hannan-Quinn criter.	29.75251
F-statistic	1716.967	Durbin-Watson stat	0.797864
Prob(F-statistic)	0.000000		

Source: Calculations by the authors using EVIEWS 11.0.

investments in crop improvement activities boosted sorghum planted acreage year by 1.0% on average and harvested acreage by about 0.9%. Based on the first evaluation, despite the gains in planted and harvested acreage attributed to USCP, the gains were not statistically different from zero.

For sorghum yield (equation (3) above), the goodness-of-fit measure (R^2) is 0.8508, meaning that roughly 85% of the variation in sorghum yields is explained by the model specification (Table 7). Key determinants of yield as hypothesized, are weather effects, trends (proxies for technological change), and qualitative events occurring in marketing years 1980, 1983, 1991, 1995, 2002, 2003, 2006, 2011, 2012, and 2013.The weather effects associated with La Niña reduced yields by 3.5%, while the weather effects associated with El-Niño led to increases in yields by slightly less than 7.2%.

Importantly, expenditures on crop improvement activities lead to increases in sorghum yields. The cumulative impact of a one percent increase in crop improvement activities today results in a 0.39% increase in sorghum years after a three-year period, tantamount to a 0.26 increase in bushels per acre. That said, this impact, however, is not significantly different from zero. This result is not surprising given the short amount of time that the checkoff program has been in operation (13 years) and the long period of time that is often required for research to register impacts on yields. The increase in yields experienced in recent years was found to be due mainly to weather and other technological innovations, such as adoption of minimum and no-tillage practices. This finding concerning the impact of crop improvement activities on yields aligns with the findings from the previous two evaluations. Again, a logarithmic transformation of dollar expenditures associated with crop improvement activities was used to reflect diminishing marginal returns.

Given that sorghum production is the product of harvested acreage and yield, the results suggest that the expenditures made on crop improvement activities by the USCP increase sorghum production by 2.68% on average over the period 2008 to 2021. That translates into 133.3 million additional bushels of sorghum production because of the sorghum checkoff program (see Table 8).

Table 7. Econometric Analysis of Sorghum Yields in the United States, 1960 to 2021

Dependent Variable: LOG(YIELD_US), Method: Least Squares

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	3.751624	0.041403	90.61275	0.0000
LA_NINA	-0.035631	0.022177	-1.606660	0.1154
EL_NINO	0.069056	0.021509	3.210601	0.0025
@TREND	0.018917	0.003357	5.634726	0.0000
@TREND^2	-0.000188	6.42E-05	-2.923149	0.0055
D2002	-0.359527	0.074283	-4.839994	0.0000
D2003	-0.321848	0.074723	-4.307193	0.0001
D2012	-0.341667	0.078703	-4.341197	0.0001
D1983	-0.269771	0.072563	-3.717728	0.0006
D2006	-0.198007	0.076051	-2.603596	0.0126
D1980	-0.219742	0.072472	-3.032079	0.0041
D2011	-0.246631	0.075278	-3.276270	0.0021
D1995	-0.199557	0.074573	-2.675999	0.0105
D2013	-0.193843	0.076222	-2.543143	0.0147
D1991	-0.144785	0.072841	-1.987677	0.0532
PDL01	0.000970	0.001207	0.803384	0.4262

R-squared	0.850769	Mean dependent var	4.095853
Adjusted R-squared	0.798712	S.D. dependent var	0.155410
S.E. of regression	0.069725	Akaike info criterion	-2.262479
Sum squared resid	0.209048	Schwarz criterion	-1.699079
Log likelihood	82.74314	Hannan-Quinn criter.	-2.042551
F-statistic	16.34298	Durbin-Watson stat	1.743916
Prob(F-statistic)	0.000000		

Lag Distribution of LOG(USCP_CROP_IMPROV_LOG)	i	Coefficient	Std. Error	t-Statistic
. * |	0	0.00078	0.00097	0.80338
. *|	1	0.00116	0.00145	0.80338
. *|	2	0.00116	0.00145	0.80338
. * |	3	0.00078	0.00097	0.80338
	Sum of Lags	0.00388	0.00483	0.80338

Source: Calculations by the authors using EVIEWS 11.0.

Table 8. Sorghum Checkoff-Funded Crop Improvement Research: Impacts and Benefit-Cost Ratio

Impact on Planted Acres and Harvested Acres

Year	Elasticity	Planted Acres	Incremental Planted Acres[1]	% Increase Planted Acres	Harvested Acres	Incremental Harvested Acres[2]	% Increase Harvested Acres
2008/09	0.02589	6,599,000	170,848	2.59	5,502,000	132,271	2.40
2009/10	0.02589	5,369,000	139,003	2.59	4,806,000	107,617	2.24
2010/11	0.02589	5,451,000	141,126	2.59	3,945,000	109,260	2.77
2011/12	0.02589	6,259,000	162,046	2.59	4,995,000	125,456	2.51
2012/13	0.02589	8,076,000	209,088	2.59	6,585,000	161,876	2.46
2013/14	0.02589	7,138,000	184,803	2.59	6,401,000	143,075	2.24
2014/15	0.02589	8,459,000	219,004	2.59	7,851,000	169,553	2.16
2015/16	0.02589	6,690,000	173,204	2.59	6,163,000	134,095	2.18
2016/17	0.02589	5,629,000	145,735	2.59	5,044,000	112,828	2.24
2017/18	0.02589	5,690,000	147,314	2.59	5,061,000	114,051	2.25
2018/19	0.02589	5,265,000	136,311	2.59	4,675,000	105,532	2.26
2019/20	0.02589	5,880,000	152,233	2.59	5,095,000	117,859	2.31
2020/21	0.02589	7,305,000	189,126	2.59	6,490,000	146,422	2.26
SUM or AVERAGE		77,211,000	1,998,993	2.59	67,111,000	1,547,624	2.31

Impact on Yields

Year	Elasticity	Yield (Bushels/Acre)	Incremental Yield[3] (Bushels/Acre)	% Increase Yield
2008/09	0.00388	69.36	0.27	0.39
2009/10	0.00388	71.88	0.28	0.39
2010/11	0.00388	53.99	0.21	0.39
2011/12	0.00388	49.60	0.19	0.39
2012/13	0.00388	59.58	0.23	0.39
2013/14	0.00388	67.58	0.26	0.39
2014/15	0.00388	76.01	0.29	0.39
2015/16	0.00388	77.93	0.30	0.39
2016/17	0.00388	71.74	0.28	0.39
2017/18	0.00388	72.12	0.28	0.39
2018/19	0.00388	73.04	0.28	0.39
2019/20	0.00388	73.20	0.28	0.39
2020/21	0.00388	69.00	0.27	0.39
OVERALL AVERAGE		68.08	0.26	0.39

[1]Incremental planted acres is the product of the estimated elasticity from Table 5 times the number of planted acres.
[2]Incremental harvested acres is the product of incremental planted acres times 0.774364 from Table 6.
[3]Incremental yield is the product of the estimated elasticity from Table 7 times the yield. Note, however, the estimated elasticity is not statistically different from zero.

Table 8. Sorghum Checkoff-Funded Crop Improvement Research: Impacts and Benefit-Cost Ratio (Continued)

Impact on Sorghum Farm Prices

Year	Elasticity	Actual Farm Price ($/Bushel)	Incremental Change in Farm Price[4] ($/Bushel)	Increase Farm Price (%)	Simulated Farm Price Without USCP ($/Bushel)
2008/09	0.00368	$3.15	$0.01	0.37	$3.14
2009/10	0.00368	$4.68	$0.02	0.37	$4.66
2010/11	0.00368	$5.91	$0.02	0.37	$5.89
2011/12	0.00368	$6.48	$0.02	0.37	$6.46
2012/13	0.00368	$4.38	$0.02	0.37	$4.36
2013/14	0.00368	$3.98	$0.01	0.37	$3.97
2014/15	0.00368	$3.46	$0.01	0.37	$3.45
2015/16	0.00368	$2.82	$0.01	0.37	$2.81
2016/17	0.00368	$3.23	$0.01	0.37	$3.22
2017/18	0.00368	$3.24	$0.01	0.37	$3.23
2018/19	0.00368	$3.30	$0.01	0.37	$3.29
2019/20	0.00368	$4.74	$0.02	0.37	$4.72
2020/21	0.00368	$5.57	$0.02	0.37	$5.55
SUM or AVERAGE		$4.23	$0.02	0.37	$4.21

[4]The incremental change in farm price is the product of the estimated elasticity from Table 9 times actual farm price.

Impact on Production as the Product of Harvested Acres and Yield

Year	Production With USCP in Place (Bushels)	Production Without USCP in Place (Bushels)	Incremental Production Due To USCP (Bushels)	Increase Production Due to USCP (%)
2008/09	381,618,720	370,999,323	10,619,397	2.78
2009/10	345,455,280	336,409,438	9,045,842	2.62
2010/11	212,990,550	206,288,069	6,702,481	3.15
2011/12	247,752,000	240,592,250	7,159,750	2.89
2012/13	392,334,300	381,204,888	11,129,412	2.84
2013/14	432,579,580	421,269,698	11,309,882	2.61
2014/15	596,754,510	581,601,387	15,153,123	2.54
2015/16	480,282,590	468,009,619	12,272,971	2.56
2016/17	361,856,560	352,389,669	9,466,891	2.62
2017/18	364,999,320	355,389,688	9,609,632	2.63
2018/19	341,462,000	332,458,968	9,003,032	2.64
2019/20	372,954,000	362,913,115	10,040,885	2.69
2020/21	447,810,000	436,008,574	11,801,426	2.64
SUM or AVERAGE	4,978,849,410	4,845,534,686	133,314,724	2.68

Table 8. Sorghum Checkoff-Funded Crop Improvement Research: Impacts and Benefit-Cost Ratio (Continued)

Impact on Sorghum Farm Revenue

Year	With USCP in Place Farm Revenue	Without USCP in Place Farm Revenue	Incremental Change in Farm Revenue	% Increase Farm Revenue	USCP Crop Research Expenditures	Benefit-Cost Ratio
2008/09	$1,202,098,968	$1,164,347,242	$37,751,726	3.14	$1,373,806	27.48
2009/10	$1,616,730,710	$1,568,602,390	$48,128,321	2.98	$810,534	59.38
2010/11	$1,258,774,151	$1,214,675,971	$44,098,179	3.50	$887,740	49.67
2011/12	$1,605,432,960	$1,553,300,524	$52,132,436	3.25	$1,130,698	46.11
2012/13	$1,718,424,234	$1,663,532,995	$54,891,239	3.19	$2,749,082	19.97
2013/14	$1,721,666,728	$1,670,483,313	$51,183,416	2.97	$1,415,521	36.16
2014/15	$2,064,770,605	$2,004,935,384	$59,835,221	2.90	$1,463,135	40.90
2015/16	$1,354,396,904	$1,314,930,310	$39,466,594	2.91	$689,427	57.25
2016/17	$1,168,796,689	$1,134,029,985	$34,766,704	2.97	$4,433,897	7.84
2017/18	$1,182,597,797	$1,147,225,207	$35,372,589	2.99	$1,127,467	31.37
2018/19	$1,126,824,600	$1,093,077,212	$33,747,388	2.99	$831,576	40.58
2019/20	$1,767,801,960	$1,713,877,801	$53,924,159	3.05	$807,995	66.74
2020/21	$2,494,301,700	$2,419,630,628	$74,671,072	2.99	$3,153,626	23.68
SUM / AVERAGE	$20,282,618,005	$19,662,648,963	$619,969,042	3.06	$20,874,504	29.70

Notes: (1) Statistically significant change in planted acreage/harvested acreage and in farm prices due to sorghum checkoff.; and (2) No statistically significant change in yields due to sorghum checkoff.

Table 8. Sorghum Checkoff-Funded Crop Improvement Research: Impacts and Benefit-Cost Ratio (Continued)

Impact on Production Directly

Year	Elasticity	Actual Sorghum Production (Bushels)	Incremental Sorghum Production (Bushels)	Increase Production Due to USCP (%)	Farm Revenue with USCP in Place ($)	Farm Revenue without to USCP ($)	Incremental Farm Revenue Due to USCP ($)	Increase Farm Revenue Due to USCP (%)	USCP Crop Research Expenditures ($)	Benefit-Cost Ratio
2008/09	0.03350	381,605,000	12,783,768	3.35	$1,202,055,750	$1,157,511,507	$44,544,243	3.71	$1,373,806	32.42
2009/10	0.03350	345,464,000	11,573,044	3.35	$1,616,771,520	$1,556,859,270	$59,912,250	3.71	$810,534	73.92
2010/11	0.03350	212,993,000	7,135,266	3.35	$1,258,788,630	$1,212,142,052	$46,646,578	3.71	$887,740	52.55
2011/12	0.03350	247,742,000	8,299,357	3.35	$1,605,368,160	$1,545,878,482	$59,489,678	3.71	$1,130,698	52.61
2012/13	0.03350	392,331,000	13,143,089	3.35	$1,718,409,780	$1,654,731,150	$63,678,630	3.71	$2,749,082	23.16
2013/14	0.03350	432,575,000	14,491,263	3.35	$1,721,648,500	$1,657,849,854	$63,798,646	3.71	$1,415,521	45.07
2014/15	0.03350	596,751,000	19,991,159	3.35	$2,064,758,460	$1,988,245,284	$76,513,176	3.71	$1,463,135	52.29
2015/16	0.03350	480,261,000	16,088,744	3.35	$1,354,336,020	$1,304,148,769	$50,187,251	3.71	$689,427	72.80
2016/17	0.03350	361,871,000	12,122,679	3.35	$1,168,843,330	$1,125,529,830	$43,313,500	3.71	$4,433,897	9.77
2017/18	0.03350	364,986,000	12,227,031	3.35	$1,182,554,640	$1,138,733,044	$43,821,596	3.71	$1,127,467	38.87
2018/19	0.03350	341,460,000	11,438,910	3.35	$1,126,818,000	$1,085,061,821	$41,756,179	3.71	$831,576	50.21
2019/20	0.03350	372,960,000	12,494,160	3.35	$1,767,830,400	$1,702,320,404	$65,509,996	3.71	$807,995	81.08
2020/21	0.03350	447,810,000	15,001,635	3.35	$2,494,301,700	$2,401,871,060	$92,430,640	3.71	$3,153,626	29.31
SUM or AVERAGE		4,978,809,000	166,790,102	3.35	$20,282,484,890	$20,963,781,141	$751,602,363	3.71	$20,874,504	36.01

To provide a measure of the impact of crop improvement activities on farm revenue, we develop a model specification for sorghum farm prices (equation (5) above). As given in Table 9, the goodness-of-fit for this relationship is 0.9974. Hence, more than 99% of the variation in sorghum farm prices is accounted for by this econometric analysis. Drivers of sorghum farm prices are corn farm prices, sorghum production, sorghum prices at the terminal market in Kansas City, and USCP crop improvement expenditures. As well, qualitative factors associated with marketing years 1982, 1987, 1999,2002, 2006, 2010, 2014, 2016, and 2018 also affect sorghum farm prices. A one percent change in corn price generates a 0.67% change in sorghum prices in the same direction, while a one percent change in sorghum production generates a non-statistically significant change in sorghum prices in the opposite direction. Also, a one percent change in downstream prices generates a 0.30% change in sorghum farm prices in the same direction.

The impact of USCP funds committed to crop improvement activities on farm prices is not felt all at once but, instead, the impact is distributed over the current year and the previous four years. As such, a one percent change in crop improvement expenditures generates cumulatively a 0.0037% change in sorghum farm prices in the same direction. As shown in Table 8, crop improvement expenditures led to the increase in sorghum farm prices by 1 to 2 cents per bushel over the period of 2008 to 2021. Importantly, this change in sorghum farm prices is statistically different from zero.

Funds committed to crop improvement activities led to a higher sorghum farm price each year by an annual average on the order of 1 to 2 cents per bushel. From the second evaluation, funds committed to crop improvement activities led to a higher sorghum farm price each year by an annual average on the order of 2 to 3 cents per bushel. From the first evaluation, funds committed to crop improvement activities, the impact on sorghum farm prices was not statistically different from zero.

To provide a check on the impacts of crop improvement activities, we provide a model of sorghum production in the United States directly (equation (6) above). As exhibited in Table 10, the goodness-of-fit associated with this model is 0.8557. Consequently, roughly 86 percent of the variation in sorghum production is accounted for by the econometric analysis. The sorghum farm price to corn farm price ratio is a statistically significant factor affecting sorghum production. A one percent change in this ratio leads to a one percent increase in sorghum production. The significance of the trend variables indicates that sorghum production in the United States is increasing but at a decreasing rate. Additionally, qualitative factors associated with marketing years 1983, 1985, 2006, 2011, and 2012 also affected sorghum production.

The impact of USCP funds committed to crop improvement activities on sorghum production again is not felt all at once but, instead, the impact is distributed over the current year and the previous six years. A one percent change in crop improvement expenditures generates cumulatively a 0.0335% change in sorghum production. As shown in Table 8, that translates into a rise of 166.8 million bushels of sorghum over the period 2008 to 2021, tantamount to a 3.35% increase in production due to the crop improvement activities of the USCP. This increase is larger than the 2.68% percent increase previously described when modeling production as the product of harvested acreage and yield. As well, the incremental increase in sorghum production of 166.8 million bushels is larger than the 133.3 million bushels previously described when modeling production as the product of harvested acreage and yield.

Table 9. Econometric Analysis of Sorghum Farm Prices in the United States, 1960 to 2021

Dependent Variable: LOG(SORGHUM_FARM_PRICE)
Method: Least Squares

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.140771	0.284485	-0.494828	0.6240
LOG(CORN_FARM_PRICE)	0.672768	0.047453	14.17754	0.0000
LOG(PRODUCTION_US)	-0.004461	0.013631	-0.327267	0.7455
LOG(SORG_PRICE_NO2_KC)	0.300909	0.044624	6.743169	0.0000
D2006	0.111150	0.024411	4.553359	0.0001
D2010	-0.078683	0.024701	-3.185397	0.0032
D1987	-0.119909	0.022470	-5.336520	0.0000
D2014	0.089775	0.023526	3.816014	0.0006
D2016	-0.120843	0.024654	-4.901603	0.0000
D2002	0.080959	0.023637	3.425015	0.0017
D1982	-0.052753	0.022847	-2.308966	0.0273
D1999	-0.057808	0.022840	-2.530956	0.0163
D2018	-0.062651	0.024161	-2.593037	0.0141
PDL01	0.000631	0.000155	4.069607	0.0003

R-squared	0.997393	Mean dependent var	0.963573
Adjusted R-squared	0.996366	S.D. dependent var	0.362437
S.E. of regression	0.021849	Akaike info criterion	-4.567193
Sum squared resid	0.015754	Schwarz criterion	-4.016085
Log likelihood	121.3290	Hannan-Quinn criter.	-4.359807
F-statistic	971.1167	Durbin-Watson stat	1.755714
Prob(F-statistic)	0.000000		

Lag Distribution of LOG(USCP_TOTAL_LOG)	i	Coefficient	Std. Error	t-Statistic
. * |	0	0.00053	0.00013	4.06961
. * |	1	0.00084	0.00021	4.06961
. *|	2	0.00095	0.00023	4.06961
. * |	3	0.00084	0.00021	4.06961
. * |	4	0.00053	0.00013	4.06961
	Sum of Lags	0.00368	0.00091	4.06961

Source: Calculations by the authors using EVIEWS 11.0.

As a result of crop improvement activities of the USCP, sorghum production rose 2.68% to 3.35% between 2008/09 and 2020/21, a total increase in sorghum production of 133.3 to 166.8 million bushels over that period. This impact is much larger than those gleaned from the second evaluation wherein the efforts of USCP led to increases of sorghum production of 0.25%. That said, this impact is smaller than those gleaned from the first evaluation wherein the efforts of USCP led to increases of production of 3.2% to 4.6%.

Returns to Producers from Checkoff Expenditures on Research

The results from estimating the supply model and the associated impacts of USCP research expenditures on acreage, yields, production, and price derived from those models as summarized in

Table 10. Econometric Analysis of Sorghum Production in the United States, 1960 to 2021

Dependent Variable: LOG(PRODUCTION_US); Method: Least Squares

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	20.49126	0.120329	170.2932	0.0000
@TREND	0.013832	0.008655	1.598216	0.1168
@TREND^2	-0.000565	0.000154	-3.673992	0.0006
LOG(SORGHUM_FARM_PRICE(-1)/CORN_FARM_PRICE(-1))	1.004545	0.400281	2.509602	0.0157
D2011	-0.635502	0.155614	-4.083838	0.0002
D2012	-0.580742	0.154576	-3.757000	0.0005
D1985	0.457193	0.154695	2.955446	0.0049
D2006	-0.431883	0.158902	-2.717929	0.0092
D1983	-0.375574	0.155030	-2.422586	0.0194
PDL01	0.003190	0.000955	3.341259	0.0017

R-squared	0.855677	Mean dependent var	20.14210
Adjusted R-squared	0.827440	S.D. dependent var	0.363115
S.E. of regression	0.150839	Akaike info criterion	-0.784772
Sum squared resid	1.046614	Schwarz criterion	-0.423102
Log likelihood	31.97361	Hannan-Quinn criter.	-0.644553
F-statistic	30.30325	Durbin-Watson stat	2.112857
Prob(F-statistic)	0.000000		

Lag Distribution of LOG(USCP_CROP_IMPROV_LOG)	i	Coefficient	Std. Error	t-Statistic
. * |	0	0.00279	0.00084	3.34126
. * |	1	0.00479	0.00143	3.34126
. * |	2	0.00598	0.00179	3.34126
. *|	3	0.00638	0.00191	3.34126
. * |	4	0.00598	0.00179	3.34126
. * |	5	0.00479	0.00143	3.34126
. * |	6	0.00279	0.00084	3.34126
	Sum of Lags	0.03350	0.01003	3.34126

Source: Calculations by the authors using EVIEWS 11.0.

Table 8 indicate that funds committed by USCP to crop improvement activities generates nearly $620 million of additional farm revenue or a 3.06% increase in farm revenue over 2008 to 2021 when modeling production as the product of harvested acreage and yield. But when modeling sorghum production directly, funds committed by USCP to crop improvement activities generates roughly $752 million of additional farm revenue or a 3.71% increase over the period 2008 to 2021. This impact on the farm value of U.S. sorghum production is much larger than those gleaned from the previous two evaluations.

Given that the USCP expended $20.87 million on crop improvement research over that same period, the benefit-cost ratio (BCR) for USCP crop improvement research investments over the period 2008 to 2021, net of the research expenditures, is calculated to be 28.70 when modelling production as the product of harvested acreage and yield. That is, for every dollar invested in crop improvement research, producers realize a net return of nearly $28.70. This set of calculations rests on the changes in harvested acres and yields (and hence production) as well as the changes in farm prices attributed to the checkoff. But when modeling sorghum production directly, the benefit-cost ratio (BCR) for USCP crop improvement research investments over the period 2008 to 2021, net of the research expenditures, is calculated to be 35.01. That is, for every dollar invested in crop improvement research, producers realize a net return of $35.01. Based on the second evaluation, for every sorghum checkoff dollar invested in crop improvement, the net return to stakeholders was about 7.6 to 1. That is for every checkoff dollar invested in crop improvement, the return to producers (net of the checkoff expenditures) was $7.57. Based on the first evaluation, efforts made by USCP in committing funds to crop improvement activities were positive in enhancing overall farm revenue. The net return to stakeholders was 20.1 to 1. That is for every checkoff dollar invested in crop improvement, the return to producers (net of the checkoff expenditures) was $20.08.

Impacts and Returns from USCP Expenditures to Enhance the Demand for U.S. Sorghum

The analysis of the impact of USCP programs on the demand for sorghum (either in domestic markets or in international markets) relies on a structural econometric model approach (essentially single-equation regression analysis). This analysis specifically examines the relationship between USCP expenditures and market development uses, renewables, and sustainability (feed demand and food and industrial demand) and export demand[1].

Empirical findings from previous studies support the hypothesis that market development and promotion expenditures have carryover or lagged effects (Nerlove and Waugh, 1961; Lee and Brown, 1992; Ward and Dixon, 1989; Williams, Capps, and Palma, 2008; and Williams, Capps, and Dang, 2010; Capps, Williams, and Málaga, 2013; Williams, Capps, and Lee, 2014; and Capps, Williams, and Welch, 2017). That is, expenditures in one period have impacts not only demand in the current period but also demand in future periods. However, theory provides relatively little guidance as to the structure and length of these dynamic processes. Whatever the specification used, however, accounting for the time lag between the market development and promotion expenditures and any changes in sorghum use that may occur is critical.

The use of polynomial distributed lags (PDLs) is consistent with the quantitative evaluation of checkoff programs in general to account for the time lag in the impact of checkoff expenditures (Lee and Brown, 1992; Forker and Ward, 1993; Williams, Capps, and Palma, 2008; Williams, Capps, and Dang, 2010; Capps, Williams, and Málaga, 2013; Capps Williams, and Hudson, 2016; and Capps, Williams, and Welch, 2017). Given lags between market development expenditures and market impact, and demand impacts, short-run as well as long-run effects of the checkoff expenditures can be captured as well as average length of time before changes in expenditures made by USCP affect the level of domestic uses or exports of sorghum.

Regardless of the approach taken, the analysis must measure the shift in the demand attributed to the market development and promotion efforts of USCP. To carry out this task and to avoid confounding of effects, the analysis must account and control for all possible drivers of the demand for sorghum. In this way, the effects of the market development, renewables, sustainability associated with promotion activities separate from those of any other factor that affects the demand for sorghum can be isolated and measured.

[1] Seed demand is not analyzed owing to the relatively small size of seed use in the industry.

Impacts of Promotion on Feed Use as well as Food and Industrial Use of Sorghum

To analyze the impacts of USCP funds committed to market development, renewables, and sustainability for feed use and food and industrial use, separate single-equation econometric specifications for feed use and food and industrial use of sorghum are developed and estimated. The results are then used to calculate the returns to producers from expenditures to promote each category of demand.

Feed Use of Sorghum

Animal agriculture is a key market for sorghum production in the United States. Sorghum is utilized in the beef, swine, dairy, and poultry industries. Sorghum grain, stalks, and leaves can be utilized in various feed ingredients. In the livestock industry, checkoff funds have been expended to develop education materials, conducting research, and visiting livestock operations as well as feed manufacturers to heighten awareness of the benefits of the use of sorghum.

The econometric model specification, in essence, is a derived demand function for feed use of sorghum, given by equation (7):

(7) log (feed use_t) = g (log (sorghum price no2 at Kansas $City_t$ / corn price no2 at $Chicago_t$), log (number of grain consuming $units_t$), log (feed use_{t-1}), PDL log (USCP renewables, sustainability and market development $expenditures_t$)), D1976, D1980, D1983, D1996, D2009, D2011) + v_t

This specification is similar to the econometric model for feed use developed by Roy and Ireland (1975). The data associated with this analysis cover market years 1975 to 2021. Dummy variables pertaining to qualitative events that occurred in marketing years 1976, 1980, 1983, 1996, 2009, and 2011 are included in this specification as well to account for structural shifts in feed use.

As given in Table 11, the goodness-of-fit associated with the specification in equation (7) is 0.9524 meaning that slightly more than 95% of the variability in feed use is accounted for by the model specification. Determinants of feed use are the ratio of sorghum prices (no. 2) at the Kansas City terminal market to corn prices (no. 2) at the Chicago terminal market, the number of grain-consuming animal units, and feed use in the previous year, along with the previously mentioned qualitative variables. A one percent rise in the ratio of downstream sorghum prices to corn prices leads to a decrease in sorghum feed use by nearly 1.80%. At the same time, a one percent rise in grain consuming animal units is associated with a decrease in feed use of sorghum by 2.23%. This finding reflects in part increases in efficiency over time, that is, more grain per pound of feed. Inertia was evident in feed use owing to the significance of the estimated coefficient of feed use in the previous year.

Roughly 45% of the adjustment to the "desired" level of feed use is made after one year. Also, the results suggest that expenditures directed to renewables, sustainability, and market development made by USCP for feed use is not felt all at once but, instead, the impact is distributed over the current year and the previous year. The cumulative impact of a one percent change in these expenditures generates a 0.0058% change in sorghum feed use in the opposite direction. But this result is not statistically different from zero. Hence the impact of expenditures made by the USCP geared toward increasing feed use is essentially zero over the period 2008 to 2021. A logarithmic transformation is used to account for diminishing marginal returns of USCP expenditures on feed use of sorghum.

Table 11. Econometric Analysis of the Derived Demand for Sorghum for Feed Use, 1975 to 2021

Dependent Variable: LOG(FEED_RESIDUAL_USE)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	13.31068	2.607441	5.104880	0.0000
LOG(SORG_PRICE_NO2_KC/CORN_PRICE_NO2_CHIC)	-1.797338	0.573894	-3.131828	0.0035
LOG(GRAIN_CONS_ANIMAL_UNITS)	-2.227947	0.504131	-4.419381	0.0001
LOG(FEED_RESIDUAL USE(-1))	0.553873	0.088455	6.261599	0.0000
D1996	0.535087	0.169982	3.147901	0.0034
D2011	-0.628393	0.173283	-3.626404	0.0009
D1980	-0.481717	0.172191	-2.797567	0.0083
D1983	-0.450893	0.178492	-2.526126	0.0162
D2009	-0.461720	0.174616	-2.644197	0.0122
D1976	-0.425624	0.179978	-2.364874	0.0237
PDL01	-0.004362	0.005080	-0.858764	0.3963

R-squared	0.952362	Mean dependent var	5.489537
Adjusted R-squared	0.938751	S.D. dependent var	0.671079
S.E. of regression	0.166083	Akaike info criterion	-0.547691
Sum squared resid	0.965424	Schwarz criterion	-0.110407
Log likelihood	23.59689	Hannan-Quinn criter.	-0.383882
F-statistic	69.97002	Durbin-Watson stat	1.923166
Prob(F-statistic)	0.000000		

Lag Distribution of LOG(USCP_RENEW_HIGH_VAL1)	i	Coefficient	Std. Error	t-Statistic
* . |	0	-0.00291	0.00339	-0.85876
* . |	1	-0.00291	0.00339	-0.85876
	Sum of Lags	-0.00582	0.00677	-0.85876

Source: Calculations by the authors using EVIEWS 11.0.

In the previous two evaluations of the sorghum checkoff, the impact of USCP expenditures on sorghum feed use was negative and statistically different from zero. That is, the efforts made by USCP did not stem the decline in feed use. In this analysis, now we find no impact whatsoever of USCP expenditures associated with feed use.

Food and Industrial Use of Sorghum

The econometric model specification, in essence, is a derived demand function for food and industrial use of sorghum given by the equation (8):

(8) log (food and industrial use$_t$) = h (log(sorghum price in terminal market in Kansas City$_t$), log(corn price in terminal market in Chicago$_t$), log(industrial production index$_t$),PDL of log (USCP renewables, sustainability, and market development expenditures$_t$), D1983, D1985, D1986, D2001, D2007, D2014, D2017, D2020, and D2021) + e_t

Ethanol can be made from grain sorghum within some technical limitations. In the ethanol industry, checkoff funds have been expended to develop awareness of the benefits of the use of sorghum as a fuel and feedstock. Renewables include renewable fuels and renewable chemicals. Additionally, celiac and gluten intolerance is on the rise. The Center for Celiac Research estimates that approximately 7.5% of the U.S. population suffers from gluten sensitivity. In 2010, 12% of new products are claimed to be "gluten free," up from one percent in 2001 (Martinez, 2013). U.S. sales of gluten-free foods have risen from $4.8 billion in 2009 to $15.6 billion at the end of 2016 (Douillard, 2017). The largest increase in health and nutrition-related claims over the period 2001 to 2010 was for "no gluten" (Martinez, 2013).

Sorghum also is a viable replacement for corn in pet food. According to the 2017/18 National Pet Owners Survey conducted by the American Pet Products Association, Inc. (APPA), 68% of U.S. households own a pet (APPA, 2017a). Given the steady historical growth trends in pet food and other product sales, from $17 billion in 1994 to an estimated $69 billion in 2017, strong growth in pet food and products sales are likely to continue (APPA, 2017b). Brands of pet foods currently using sorghum include IAMS, Eukanuba, Pet Wants, Mr. Bucks Pet Food, Hills Pet Nutrition, Newman's Own Organics, Blackwood, Adirondack, Verus, Victor Super Premium Dog Food, GNC, and Muenster Natural (United Sorghum Checkoff Program, 2017).

Finally, many chemicals can be produced from corn, sorghum, and other sugar sources. The global renewable chemicals industry has experienced notable growth from 2009 to 2015, forecasted to reach $76 billion in 2015, up from $37 billion in 2009 (Informa Economics, 2013). At present, the global renewable chemicals market is expected to reach $102.76 billion in 2022, growing at a compound annual growth rate of 11.29% between 2017 and 2022 (Zion Market Research, 2017).

Dummy variables pertaining to qualitative events that occurred in 1983, 1985, 1986, 2001, 2007, 2014, 2017, 2020, and are included in this specification as well to account for structural shifts in food and industrial use. As exhibited in Table 12, this econometric relationship accounted for 97% of the variation in sorghum use for food and industrial purposes. The econometric results indicate that prices in downstream markets for sorghum and for corn are influential factors for food and industrial uses of sorghum. A one percent increase in sorghum prices (no. 2) at the Kansas City terminal market gave rise to a 4.74% decline in food and industrial use of sorghum. Similarly, a one percent increase in corn prices (no. 2) Chicago terminal market leads to a 4.86% increase in food and industrial use of sorghum. Corn, as expected, is a notable substitute for sorghum in food and industrial uses. This result is mainly due to the use of sorghum and corn for ethanol production. Without question, the end use of sorghum for food and industrial purposes is very sensitive to changes in corn and sorghum prices at principal terminal markets.

As well, the demand for sorghum in food and industrial uses is quite sensitive to changes in industrial production. The base year for the industrial production index is 2007 (Federal Reserve Bank of St. Louis, 2022). A one percent rise in the industrial production index leads to a 2.69% rise in sorghum for food and industrial use, all other factors invariant.

The results in Table 12 also indicate that USCP funds committed to renewables, sustainability, and market development are positively linked to sorghum food and industrial use demand. This impact is distributed over the current year and the previous year. The cumulative impact of a one percent increase in USCP funds generated a 0.0333% increase in the demand for sorghum for food and industrial purposes over the period 2008 to 2021. This effect unequivocally was not only positive but

Table 12. Econometric Analysis of Derived Demand for Sorghum for Food and Industrial Uses, 1975 to 2021

Dependent Variable: LOG(FOOD_ALC_IND_USE)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-6.046386	0.663391	-9.114361	0.0000
LOG(SORG_PRICE_NO2_KC)	-4.744537	0.781344	-6.072280	0.0000
LOG(CORN_PRICE_NO2_CHIC)	4.857733	0.809046	6.004271	0.0000
LOG(IND_PROD_INDEX)	2.689625	0.142225	18.91111	0.0000
D2014	-1.474826	0.219945	-6.705428	0.0000
D2020	-1.565250	0.234281	-6.681082	0.0000
D2021	-2.176576	0.210340	-10.34789	0.0000
D1985	0.619859	0.194826	3.181603	0.0032
D1986	-0.715633	0.206808	-3.460382	0.0015
D1983	-0.605668	0.207934	-2.912785	0.0065
D2017	-0.503141	0.204207	-2.463879	0.0193
D2001	-0.495981	0.199439	-2.486873	0.0183
D2007	-0.557701	0.222967	-2.501265	0.0177
PDL01	0.025003	0.006950	3.597754	0.0011

R-squared	0.968991	Mean dependent var	3.293433
Adjusted R-squared	0.956394	S.D. dependent var	0.899772
S.E. of regression	0.187891	Akaike info criterion	-0.260119
Sum squared resid	1.129697	Schwarz criterion	0.296424
Log likelihood	19.98273	Hannan-Quinn criter.	-0.051635
F-statistic	76.92050	Durbin-Watson stat	1.865672
Prob(F-statistic)	0.000000		

Lag Distribution of LOG(USCP_RENEW_HIGH_VAL1)	i	Coefficient	Std. Error	t-Statistic
. * |	0	0.01667	0.00463	3.59775
. * |	1	0.01667	0.00463	3.59775
	Sum of Lags	0.03334	0.00927	3.59775

also statistically significant. That said, in previous evaluations of the sorghum checkoff, the estimated food and industrial use promotion elasticity was higher, 0.0468 in the first evaluation and 0.0718 in the second evaluation.

Table 13 shows the impacts to the USCP expenditure of checkoff funds to promote food and industrial uses of sorghum. The estimated food and industrial use promotion elasticity of 0.0333 implies that the sorghum checkoff funds spent for that purpose generated an average annual increase in sorghum use of 2.42 million bushels over the period 2008 to 2021, a total of 31.42 million bushels for food and industrial use. This finding is lower than the finding from the first evaluation wherein sorghum checkoff investments increased food and industrial use by 4.1 million bushels on average each year as well as the finding from the second evaluation wherein sorghum checkoff investments increased food and industrial use by 6.0 million bushels on average each year.

Table 13. Impact and Returns to USCP Expenditures Associated with Food and Industrial Use of Sorghum

Year	Elasticity	Food and Industrial Use Million Bushels	Incremental Food and Industrial Use Million Bushels	Sorghum Price NO2 KC $/Bushel	Incremental Food and Industrial Use Dollars	USCP Renewables, Sustainability, and Market Development Dollars	Sorghum Farm Price $/Bushel	Ratio of Farm Price to Terminal Market Price
2008/09	0.03334	89.257	2.976	$3.22	$9,590,431	$992,333	$3.15	0.98
2009/10	0.03334	84.350	2.812	$6.18	$17,378,568	$902,466	$4.68	0.76
2010/11	0.03334	84.226	2.808	$6.33	$17,774,210	$726,019	$5.91	0.93
2011/12	0.03334	94.347	3.146	$6.71	$21,099,790	$807,748	$6.48	0.97
2012/13	0.03334	69.010	2.301	$4.36	$10,031,613	$640,224	$4.38	1.00
2013/14	0.03334	13.971	0.466	$3.88	$1,809,063	$1,729,488	$3.98	1.02
2014/15	0.03334	136.139	4.539	$3.35	$15,187,073	$1,965,485	$3.46	1.03
2015/16	0.03334	114.110	3.804	$3.06	$11,635,967	$1,507,315	$2.82	0.92
2016/17	0.03334	60.000	2.000	$3.27	$6,543,508	$1,975,404	$3.23	0.99
2017/18	0.03334	105.000	3.501	$3.41	$11,936,337	$2,420,009	$3.24	0.95
2018/19	0.03334	74.000	2.467	$3.46	$8,525,683	$1,509,158	$3.30	0.95
2019/20	0.03334	9.000	0.300	$5.95	$1,785,497	$1,741,776	$4.74	0.80
2020/21	0.03334	9.000	0.300	$6.59	$1,977,395	$4,597,527	$5.57	0.85
Average	0.03334	72.493	2.417	$4.60	$10,405,780	$1,654,996	$4.36	0.95
Sum		942.410	31.420		$135,275,137	$21,514,952		

At Terminal Market	$135,275,137	$21,514,952
At Farm Level	$128,847,715	
BCR Terminal Level		6.29
BCR Farm Level		5.99
Elasticity of Price Transmission*		0.952891

*A 1 percent change in terminal price leads to a 0.95% change in farm price.

Given prices of sorghum at the Kansas City terminal, the value of that additional sales in dollars over the period 2008/09 to 2020/21 amounted to $135.3 million. The cumulative dollar amount of expenditures to promote food and industrial uses made by USCP over that period amounted to $21.5 million.

To determine the returns to producers from this checkoff investment**,** we can use the ratio of the farm price of sorghum to the sorghum no. 2 price at Kansas City. On average, this ratio is equal to 0.95 over the period of analysis, 1975 to 2021. Thus, the $135.3 million in additional dollars at the terminal market associated with the USCP investment is equivalent to a farm value of $128.8 million.

Impacts of Promotion on Sorghum Exports

Promotional activities to expand the demand for U.S. sorghum exports have been conducted over the years by the U.S. Grains Council (USGC) using USCP funds allocated for export promotion and matching funds through the Foreign Market Development (FMD) program and the Market Access Program (MAP) administered by the Foreign Agriculture Service (FAS) of the U.S. Department of Agriculture. USGC is the FAS cooperator in the FMD and MAP export market development programs. USCP essentially leverages its export funds through the USGC. Thus, this analysis of the impacts of USCP sorghum export promotion efforts consider the effects of the total of USCP and FAS (FMD and MAP) funds as well as Agricultural Trade Promotion (ATP) funds[2] expended to promote sorghum exports. Both USCP and FAS expenditures for sorghum exports were provided by USGC for the period 2008/09 through 2020/21 (Shultz, 2022). Data prior to 2008 concerning funds provided by FAS to promote sorghum exports were not available.

As discussed previously, from 1975 to 2006, sorghum exports ranged from 4.4 million metric tons to 8.3 million metric tons. Then China jumped heavily into global sorghum markets beginning in 2014/15 driving U.S. exports to slightly less than 6.1 million metric tons on average over the past eight years. Exports represented close to 42% of total disappearance over the period 1975to 2021. Over the past eight years, however, this proportion ranged from 27% to 78%, averaging close to 60%.

The econometric specification for total U.S. exports includes as drivers the U.S. export price (unit value) of sorghum, the trade weighted average export prices of sorghum from Argentina and Australia, non-U.S. world sorghum production, trade weighted real per capita GDP (in 2010 U.S. dollars for China, Japan, and Mexico), U.S. exports in the previous year, and total sorghum export promotion expenditures (including funds from USCP, FMD and MAP and ATP from FAS for sorghum export promotion).

The level of total sorghum export promotion expenditures since the existence of the USCP ranged from $2.6 million to $3.9 million over the period 2008 to 2021. Dummy variables corresponding to years 1980, 1986, 2009, 2011, 2012, 2013, 2017, 2018, and 2019 are proxies for structural changes that occurred in international trade related to total U.S. sorghum exports.

The econometric model accounts for slightly more than 89% of the variation in total U.S. exports of sorghum (Table 14). A one percent change in the lag of the U.S. sorghum export price relative to the

[2] MAP funds were available beginning in 1986. ATP funds associated with sorghum export promotion were available beginning in 2019. ATP funds for sorghum export promotion were estimated based on shares of FMD and MAP promotion expenditures allocated to sorghum for 2019, 2020, and 2021.

lag of the trade weighted average export prices of Argentina and Australia results in a modest 0.20% change in the level of U.S. sorghum exports in the opposite direction over the period of analysis. Hence, price sensitivity is not a major issue in the aggregate of U.S. sorghum exports, relative to the trade weighted average export prices of Argentina and Australia. Also, a one percent change in non-U.S. world sorghum production leads to a proportional 1.00% change in aggregate U.S. exports of sorghum in the opposite direction over the same period. At the same time, changes in the trade-weighted per capita GDP of major trading partners of sorghum have a statistically significant negative impact on total U.S. sorghum exports. A one percent change in the trade-weighted per capita GDP of China, Mexico, and Japan, leads to a 0.26% drop in total U.S. sorghum exports. Inertia also is present in total U.S. exports of sorghum as evident by the significance of the coefficient associated with level of U.S. exports of sorghum in the previous year. Roughly 64% of the "desired" level of total U.S. exports takes place within a year.

Importantly, sorghum export promotion expenditures have a statistically significant and positive impact on U.S. sorghum exports. The impact of the combined sorghum promotion expenditures of FAS, ATP, and USCP today are not felt all at once but instead are distributed over a period of one year.

Holding other factors constant, a one percent increase in total export promotion expenditures results in a cumulative 0.02436% in U.S. sorghum exports. Unlike the previous two evaluations, sorghum export promotion expenditures (USCP and FAS) positively and significantly affected total sorghum exports. In the previous two evaluations the impacts on investments to enhance sorghum exports were not significantly different from zero. As exhibited in Table 15, because of the promotion activities, U.S. sorghum exports are higher by slightly more than 1.7 million metric tons over the period 2008 to 2021. Given the export prices of sorghum over this period, the incremental export dollars attributed to sorghum promotion amounts to nearly $377 million. Further, given that sorghum export promotion expenditures totaled $44.5 million, the net benefit-cost ratio is calculated to be 7.46. For every dollar spent on export promotion of sorghum, the return on investment is $7.46. In the past two evaluations, sorghum promotion efforts were not statistically different from zero.

Table 14. Econometric Analysis of Total U.S. Exports of Sorghum, 1975 to 2021

Dependent Variable: LOG(US_EXPORTS_TOTAL_FAS)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	23.01166	4.079272	5.641119	0.0000
LOG(US_SORG_EXPORT_PRICE(-1)/WGT_ARG_AUS_EXPORT_PRICE(-1))	-0.201823	0.164134	-1.229624	0.2281
LOG(US_EXPORTS_TOTAL_FAS(-1))	0.363708	0.089186	4.078100	0.0003
LOG(TRADE_WEIGHTED_RGDNEW)	-0.256499	0.083778	-3.061661	0.0045
LOG(NON_US_WORLD_SORG_PROD)	-1.003366	0.308227	-3.255289	0.0027
D2012	-1.441400	0.149958	-9.612018	0.0000
D2009	-0.916829	0.158944	-5.768261	0.0000
D2013	-0.792556	0.172320	-4.599319	0.0001
D2011	-0.578458	0.149216	-3.876661	0.0005
D1980	0.458862	0.141864	3.234516	0.0029
D2019	-1.167875	0.150337	-7.768377	0.0000
D1986	-0.362029	0.144092	-2.512484	0.0174
D2018	-0.418530	0.156695	-2.670994	0.0119
D2017	-0.382846	0.163886	-2.336056	0.0261
PDL01	0.018270	0.004366	4.184984	0.0002

R-squared	0.893413	Mean dependent var	15.48671
Adjusted R-squared	0.845277	S.D. dependent var	0.350446
S.E. of regression	0.137848	Akaike info criterion	-0.867818
Sum squared resid	0.589060	Schwarz criterion	-0.271522
Log likelihood	34.95981	Hannan-Quinn criter.	-0.644442
F-statistic	18.56015	Durbin-Watson stat	2.189352
Prob(F-statistic)	0.000000		

Lag Distribution of LOG(FAS_EXPORTS_DOL_LOG+USCP_EXPORTS_LOG+ATP_FUNDING_SORGHUM_LOG)	i	Coefficient	Std. Error	t-Statistic
. * |	0	0.01218	0.00291	4.18498
. * |	1	0.01218	0.00291	4.18498
	Sum of Lags	0.02436	0.00582	4.18498

Source: Calculations by the authors from the use of EVIEWS 11.0.

Table 15. Impact of the USCP on Exports of Sorghum (Dollars from FAS, USGC, and ATP)

Year	Elasticity	Exports MT	Incremental Exports MT	Export Price of Sorghum $/MT	Incremental Exports Dollars
2008	0.02436	7,019,320	170,991	$215.68	$36,879,260
2009	0.02436	3,619,320	88,167	$191.19	$16,856,579
2010	0.02436	4,153,141	101,171	$171.72	$17,373,001
2011	0.02436	3,830,020	93,299	$262.98	$24,535,847
2012	0.02436	1,591,813	38,777	$282.80	$10,966,012
2013	0.02436	1,902,700	46,350	$282.10	$13,075,271
2014	0.02436	5,309,985	129,351	$231.34	$29,924,115
2015	0.02436	8,907,770	216,993	$235.22	$51,041,159
2016	0.02436	8,655,174	210,840	$205.82	$43,395,097
2017	0.02436	5,993,122	145,992	$179.11	$26,148,708
2018	0.02436	5,056,269	123,171	$193.17	$23,792,887
2019	0.02436	2,288,435	55,746	$185.32	$10,330,900
2020	0.02436	5,143,170	125,288	$190.53	$23,871,050
2021	0.02436	7,188,740	175,118	$276.92	$48,493,595
		TOTAL	1,721,253		$376,683,480

Year	FAS Exports Dollars	USCP to USGC Export Dollars	ATP Dollars	Combined Export Dollars
2008	$2,869,290	$0	$0	$2,869,290
2009	$3,546,605	$306,000	$0	$3,852,605
2010	$3,002,468	$228,000	$0	$3,230,468
2011	$3,476,113	$400,000	$0	$3,876,113
2012	$2,921,542	$381,000	$0	$3,302,542
2013	$2,722,699	$356,000	$0	$3,078,699
2014	$2,762,516	$390,000	$0	$3,152,516
2015	$2,746,626	$390,000	$0	$3,136,626
2016	$2,469,044	$656,500	$0	$3,125,544
2017	$2,362,296	$306,000	$0	$2,668,296
2018	$2,101,140	$512,000	$0	$2,613,140
2019	$2,033,464	$306,000	$563,128	$2,902,592
2020	$2,275,352	$336,600	$635,075	$3,247,027
2021	$2,525,647	$306,000	$656,299	$3,487,946
TOTAL	$37,814,802	$4,874,100	$1,854,502	$44,543,404
			BCR:	**8.46**

CONCLUDING REMARKS AND RECOMMENDATIONS

This report provides the third independent evaluation of the effectiveness of the United Sorghum Checkoff Program (USCP). USCP was only recently established in 2008 with the objective of investing producer dollars to increase profitability for the sorghum industry. Hence, the overall objective of this report is to provide USCP stakeholders with a meaningful and reliable evaluation of the impacts of USCP activities on the U.S. sorghum industry. The results of the report provide the basis for developing actions/strategies needed to improve producer profitability via demand and productivity opportunities.

Major Conclusions

The major points associated with this updated evaluation are as follows:

- Since its inception in 2008, the USCP generated additional planted and harvested acreage, modest increases in farm prices, and increases in farm revenue. However, funds committed by USCP to crop improvement activities had no statistically significant impact on sorghum yields.
- Without the USCP, planted acreage would be lower by two million acres, and harvested acreage would be lower by 1.5 million acres. Since sorghum production is the product of harvested acreage and yield, the efforts of USCP led to increases in production of 2.68%. With the checkoff program, sorghum production would be lower by 2.68%. Funds committed by USCP to crop improvement activities generated increases in sorghum production of 133.3 million bushels since the inception of the USCP. If we model sorghum production directly, that is not as the product of harvested acreage and yield, efforts of USCP increased production by 3.35%. Over the period 2008 to 2021 then, funds committed by USCP to crop improvement activities generated increased in sorghum production of 166.8 million bushels.
- As a result of the effort made by USCP in crop improvement activities, sorghum farm prices increased 1 to 2 cents per bushel.
- Funds committed by USCP to crop improvement activities generated a 3.06% increase in farm revenue. This figure hinges on the changes in harvested acres and yields (and hence production) as well as the changes in farm prices attributed to the checkoff. If sorghum production is modeled directly, then funds committed by USCP to crop improvement activities generated a 3.71% increase in farm revenue. Consequently, funds committed by the USCP to crop improvement activities generated $620 million to $752 million of additional farm revenue. As such, for every dollar invested in crop improvement activities, a return of $29 to $36 was evident.
- Funds committed to market development, renewables, and sustainability made by USCP were not able to abate the downward trend in domestic feed use of sorghum. From marketing years 1975 to 1999, feed use relative to total disappearance of sorghum ranged from 51.46% to 76.35%. However, since then, this proportion varied from 17.84% to 49.80%. Over the last three marketing years, feed use relative to total disappearance of sorghum was 25.88%, 23.24%, and 26.45% respectively.
- Funds committed to market development, renewables, and sustainability were positively linked to sorghum for food and industrial uses. This impact was not felt at one time but instead this impact was distributed over a period of one year. The cumulative impact of a one percent change

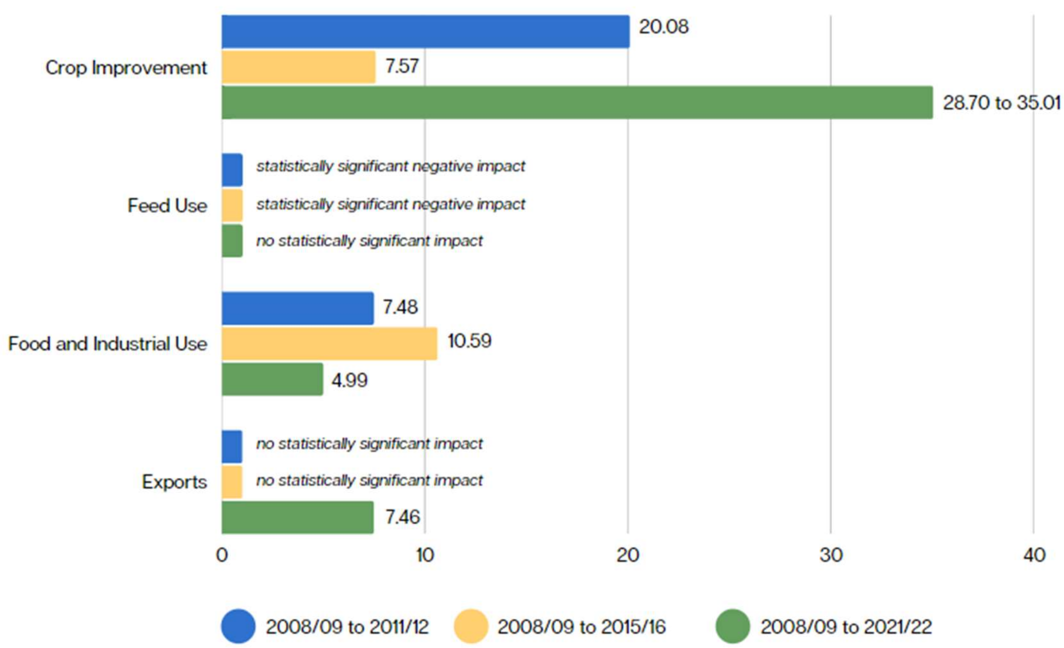
in USCP funds generated a 0.0333% increase in the use of sorghum for food and industrial purposes since the inception of the USCP. This investment of $21.5 million in funds committed by USCP generated a farm value of $128.8 million, a net benefit-cost ratio or return-on-investment of 5 to 1.

- Historically, U.S. sorghum exports represented roughly 42% of total disappearance over the period 1975 to 2021. But since 2013, this proportion ranged from 27% to 79%, averaging close to 60%. Hence, total sorghum exports have been on the rise in recent years. Mexico, Japan, and more recently China represented the top destinations for U.S. sorghum exports.

- The principal rivals to the United States in terms of sorghum exports are Argentina and Australia. Historically, exports from the United States, Argentina, and Australia have comprised 90% to 98% of world sorghum exports. Argentina presents the main competitive threat to U.S. sorghum exports.

- The USCP provides funds directly to the USGC. Those funds in turn are used in conjunction with Foreign Agriculture Service (FAS) dollars, largely through Foreign Market Development (FMD), Market Access Program (MAP) since 1986 and Agricultural Trade Program (ATP) since 2019. Consequently, the USGS leverages USCP dollars with FAS dollars. The effect of aggregate (USCP and FAS) export promotion expenditures on U.S. sorghum exports was positive and statistically significant. U.S. sorghum exports were higher by slightly more than 1.7 million metric tons over the period 2008 to 2021. Given the export prices of sorghum over this period, the incremental export dollars attributed to sorghum promotion amounted to nearly $377 million. Further, given that sorghum export promotion expenditures totaled $44.5 million, the net benefit-cost ratio is calculated to be 7.46. For every dollar spent on export promotion of sorghum, the return on investment was $7.46. In the past two evaluations, sorghum promotion efforts were not statistically different from zero.

- A graphical summary of the return-on-investment or benefit-cost ratios across the three respective evaluations is provided:



Caution must be exercised in making comparisons of various evaluations across years. The economic phrase/condition, *ceteris paribus*, meaning all other factors invariant, does not hold. Data for the underlying endogenous and exogenous variables which come from various government sources have been revised and updated, and now six additional years of data are available not only pertaining to these variables but also pertaining to the data associated with the programmatic expenditures of the United Sorghum Checkoff Program.

- A checkoff evaluation requires time for the activities put in place to take hold in various markets as well as historical data dealing with expenditures associated with programmatic activities. Given that the USCP only has been in existence since 2008, indications continue to point to not only *"movement in the right direction"* but also added momentum in achieving the goal of enhancing profitability in the sorghum industry. This added momentum is attributed to a critical mass funds necessary to bring about desired outcomes for the sorghum industry.

Recommendations

The analysis and conclusions lead to several important recommendations for management of the U.S. sorghum checkoff program.

- The study results suggest increased funding to crop improvement activities which have significantly boosted acreage, sorghum production, and the farm value of production. While yields show no statistically significant effect from sorghum checkoff investments in research activities, the response of yields to research is often slow. In addition, given the need to enhance or at least maintain the competitiveness of the sorghum industry relative to other feed grains and sorghum produced by U.S. sorghum export competitors, a focus on research activities aimed at increasing sorghum yields is likely to be a critically important and strategic choice for the investment of sorghum checkoff funds. To compete with corn, sorghum needs higher yields, additional nutrient value, and/or lower costs of production. Attention might well need to be centered on sorghum as a naturally drought-tolerant, input-efficient crop.

- With limited resources, maximum returns can be obtained by allocating funds for demand promotion based on the highest and best uses for sorghum. The results of this study suggest increased funds allocated to enhancing the demand for sorghum in food and industrial uses rather than for livestock feed would lead to higher producer profits. Opportunities for enhancing producer profitability appear to exist in the use of sorghum to produce ethanol, gluten-free products, pet foods, aquaculture, and renewable chemicals. These uses appear to be growth areas in the near to intermediate future. Further, efforts could focus on the visibility of sorghum not only as a healthy choice for cooking and baking but also as a gluten-free nutritious grain.

- Priorities for any funds invested in feed demand promotion include research to enhance the quality of sorghum as a feed grain to better compete with corn as well as the promotion of non-genetically modified (non-GMO) sorghum for livestock feeding.

- The results of this study also suggest increased funding for sorghum export promotion. Maintaining or growing the competitiveness of U.S. sorghum in international markets is likely critical to the future viability and profitability of the U.S. sorghum industry. Any funds allocated to export promotion would likely be most successful in enhancing producer profitability if focused on three priorities: (1) maintaining market share and export volume in China; (2) recapturing market share and volume in Japan and in Mexico; and (3) seeking market share and export volume in sub-Saharan Africa, most notably Sudan. Differentiating U.S. sorghum from other competitive coarse grains and from sorghum supplies from other regions also is likely critical to building long-term demand for U.S. sorghum.

- It is imperative for USCP to maintain quality records on funds committed to various activities over time to support effective evaluation of the sorghum checkoff program. An efficient and accurate record management system and database of checkoff expenditures made over time and across production research and promotional activities (feed use, food use, pet use, exports by destination, ethanol production, etc.) would greatly facilitate efforts to effectively evaluate the performance of the sorghum checkoff program going forward.
- In the same vein, this program evaluation did not include sorghum checkoff expenditures made by state programs or historical relating to stake checkoff program expenditures prior to the 2008 implementation of the United Sorghum Checkoff Program because those data were not available. Efforts to retrieve those data were largely unsuccessful. Consequently, the results of this study may not reflect the full impact of the total amount of producer checkoff funds spent to promote the profitability of the sorghum industry.

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