August 8, 2022

Ms. Cheryl Laskowski
Branch Chief, Transportation
California Air Resources Board
P.O. Box 2815
Sacramento, California 95812

RE: Potential Changes to the Low Carbon Fuel Standard

Ms. Laskowski,

Thank you for the opportunity to comment on the proposed changes to the LCFS. NSP is a trade association representing 50,000 U.S. sorghum farmers on federal and state legislative and regulatory matters. NSP also speaks for the sorghum industry overall, advocating on behalf of the supply chain participants that rely on sorghum for the future of their businesses.

The proposed changes continue to move California's fuel market in a positive direction while at the same time mitigated the effects of a changing climate. As climate-smart commodities, sorghum and the ethanol produced from it have a tremendous opportunity and role to play in this space. Sorghum uses one-third less water than corn and tolerates the heat more effectively. Furthermore, the crop's farmers practices conservation tillage on 74 percent of their acres.

With these facts in mind, there are four issues our farmers submit for ARB staff consideration. These include indirect land use change (ILUC) issues, emissions factor (EF) issues, nitrogen fertilizer issues and an overall need for farm-specific carbon intensity (CI) scores.

Indirect Land Use Change

We applaud ARB for lowering ILUC values over time and urge staff to continue doing so for sorghum in parallel with corn. As can be seen in Figure 1, the ILUC emissions values for the two fuels move in tandem as corn and sorghum are substitutes for one another in both ethanol production and livestock feeding.

Furthermore, as can be seen in Figure 2, sorghum acres have not been significantly affected by increases in ethanol production. In fact, as ethanol production has increased, sorghum acres in Kansas and Texas, where all sorghum ethanol is produced, have trended downward. ILUC is predicated on the principle that producing more sorghum in the U.S. moves acres of other crops to international locations. Clearly, this has not occurred with sorghum as acres have declined.

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Finally, as can be seen in Figure 3, soil organic carbon emissions in no-till systems are radically lower in the Sorghum Belt than the Corn Belt. Note the values depicted are for corn rather than sorghum; however, we would expect similar values for sorghum because of sorghum's relatively larger root system and the fact that it is grown in rotation with wheat. Such rotations tend to work synergistically to build a large amount of biomass and thus accumulate a large amount of soil organic carbon. The report from which this figure was taken is also attached to these comments. It was prepared by Lifecycle Associates and found sorghum should have an ILUC value at least the same as that of corn and possibly lower.

Emissions Factors

We urge ARB to allow for different EFs by geography. The latest Intergovernmental Panel on Climate Change (IPCC) guidelines included disaggregated emissions factors for dry climates, which the panel defined as climates in which evapotranspiration exceeds precipitation. This condition is met in every major area of the Sorghum Belt, including in every sorghum ethanol demand shed.

Figure 4 illustrates this fact and highlights the need for EFs matching those included by the IPCC. In these guidelines, the default EFs are 1.26 percent for biomass and 1.37 percent for fertilizer, and the disaggregated EFs for dry climates are 0.50 percent for biomass and 0.56 percent for fertilizer. Because the condition for these disaggregated EFs as spelled out by the IPCC is met in every major area of the Sorghum Belt, ARB staff should strongly consider adopting these EFs for the sorghum pathways.

Nitrogen Fertilizer

Sorghum nitrogen application rates continues to trend downward. Figure 5 highlights this trend using data from various sources. NSP continues to maintain close contact with the Argonne National Laboratory (ANL), and we have shared these data with the lab, as well. Based on the most recent nine datapoints included on the chart, the average nitrogen application rate per bushel is 410.70 grams per bushel. We have recommended a similar value to ANL for inclusion into their next update of the GREET model. The reports from which these data were taken are attached to these comments.

Farm-Specific Carbon Intensity Scores

Finally, we urge ARB to continue considering allowing Tier 2 pathways for farm-specific CI scores. Sorghum farmers predominately use no-till farming practices and do not irrigate, making them leaders in climate-smart farming. For this reason, we need to continue finding ways to reward these farmers and incentivize others to make improvements, as well.

NSP recently submitted a $68.7 million grant application to USDA under the Climate-Smart Agriculture and Forestry Partnership Program. An overview of our application is attached to these comments. In short, we are planning to launch a five-year, 150,000-acre beta test of a future in which ARB allows and even encourages Tier 2 pathways for farm-specific CI scores based on farm-specific practices. If funded, this project will enable us to better understand the challenges and opportunities associated with such a future and prepare to help meet ARB's ambitious goals for mitigating the effects of a changing climate.

Thank you for the opportunity to comment on these important issues. Please do not hesitate to contact me if you have additional questions.

Regards,

Tim Lust

Tim Lust
CEO

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Figure 1. Indirect Land Use Change Emissions for Corn and Sorghum Ethanol in Four Models. (EPA, ARB)

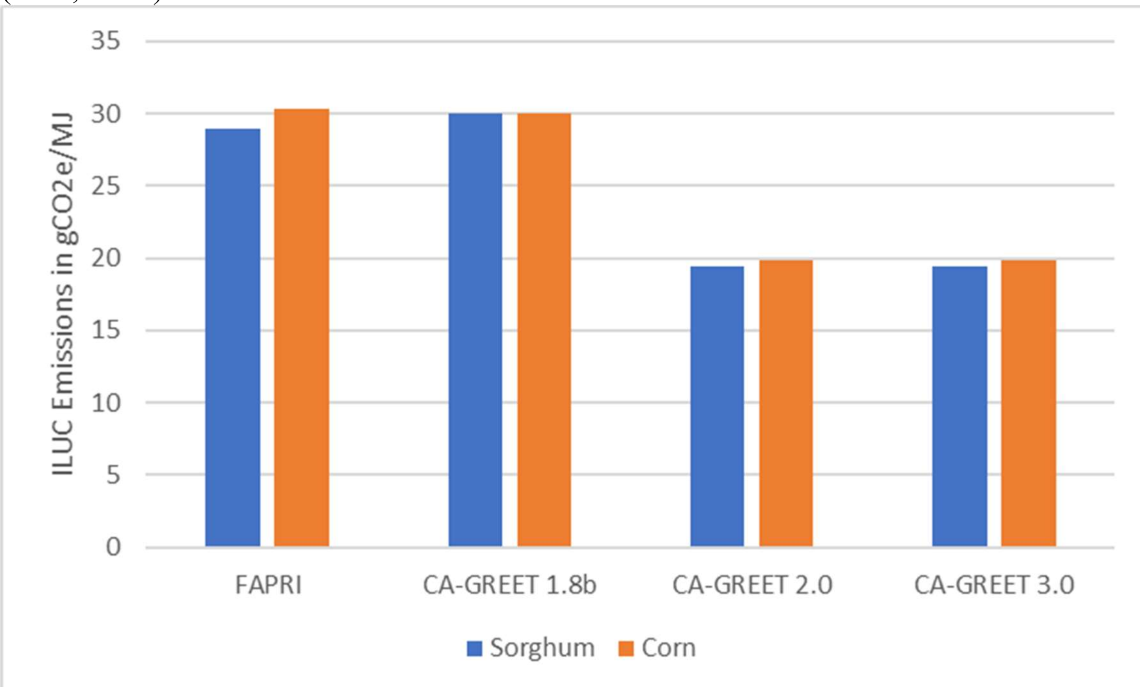


Figure 2. U.S. Ethanol Production and Sorghum Acreage in Kansas and Texas. (DOE, USDA)

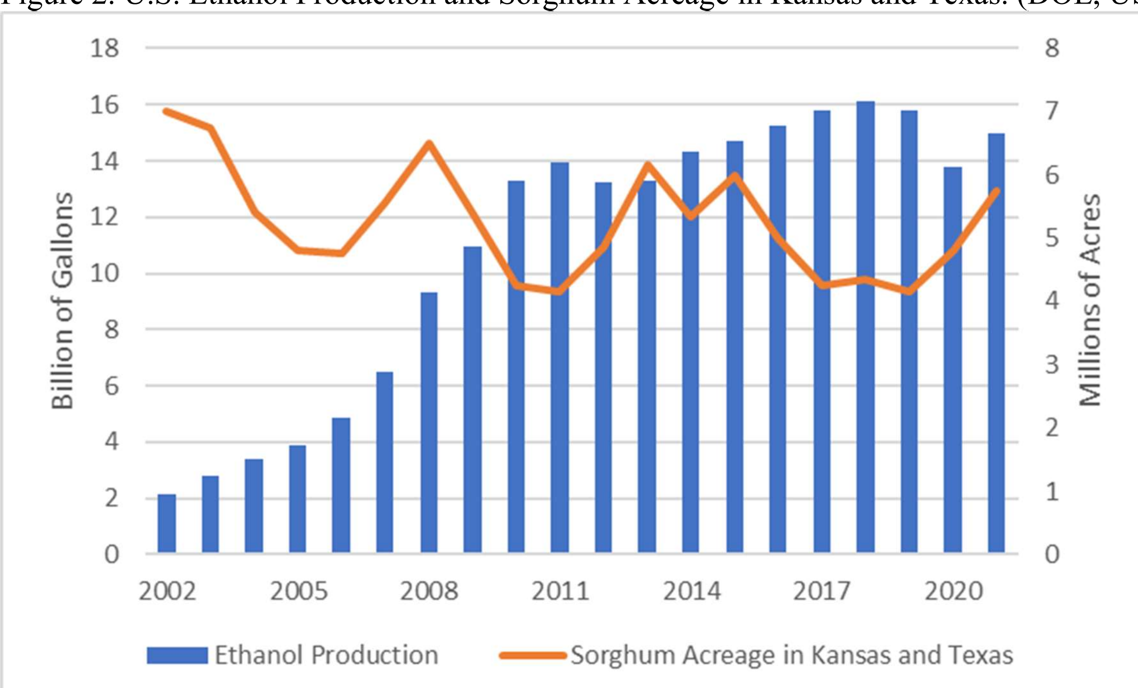


Figure 3. Soil Organic Carbon Emissions in the Corn Belt Compared to the Sorghum Belt. (Lifecycle Associates)

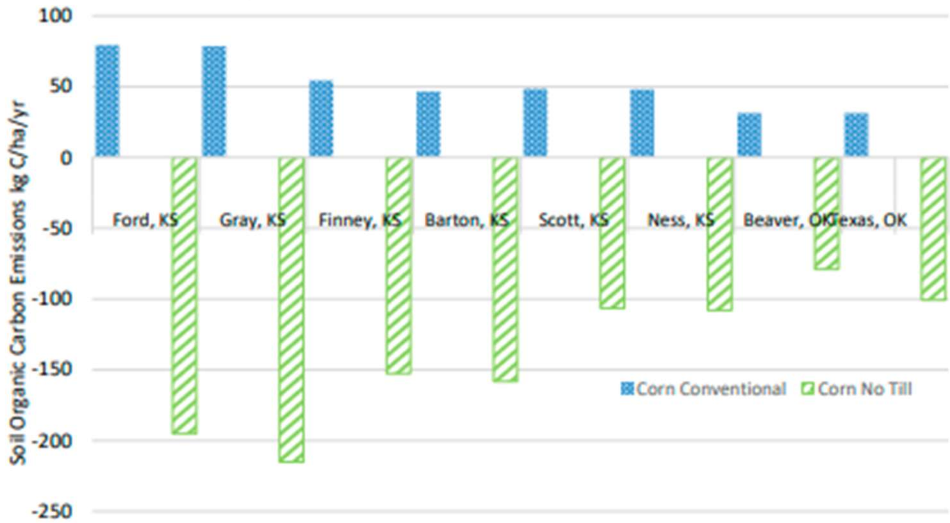


Figure 24. CCLUB results for corn grown conventionally and with no-till in high sorghum-producing states.

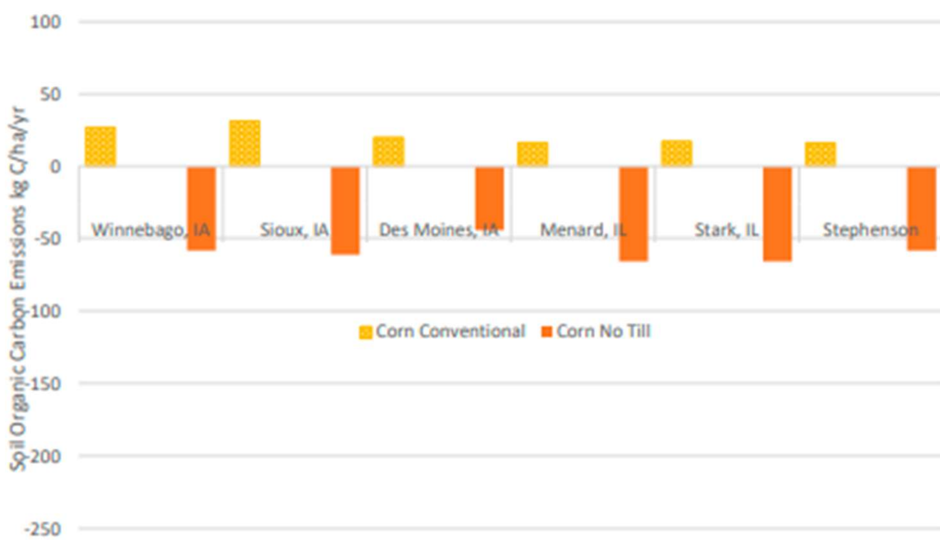


Figure 25. CCLUB results for corn grown conventionally and with no-till in high corn-producing states.

Figure 4. Evapotranspiration Compared to Precipitation in the U.S. (USGS)

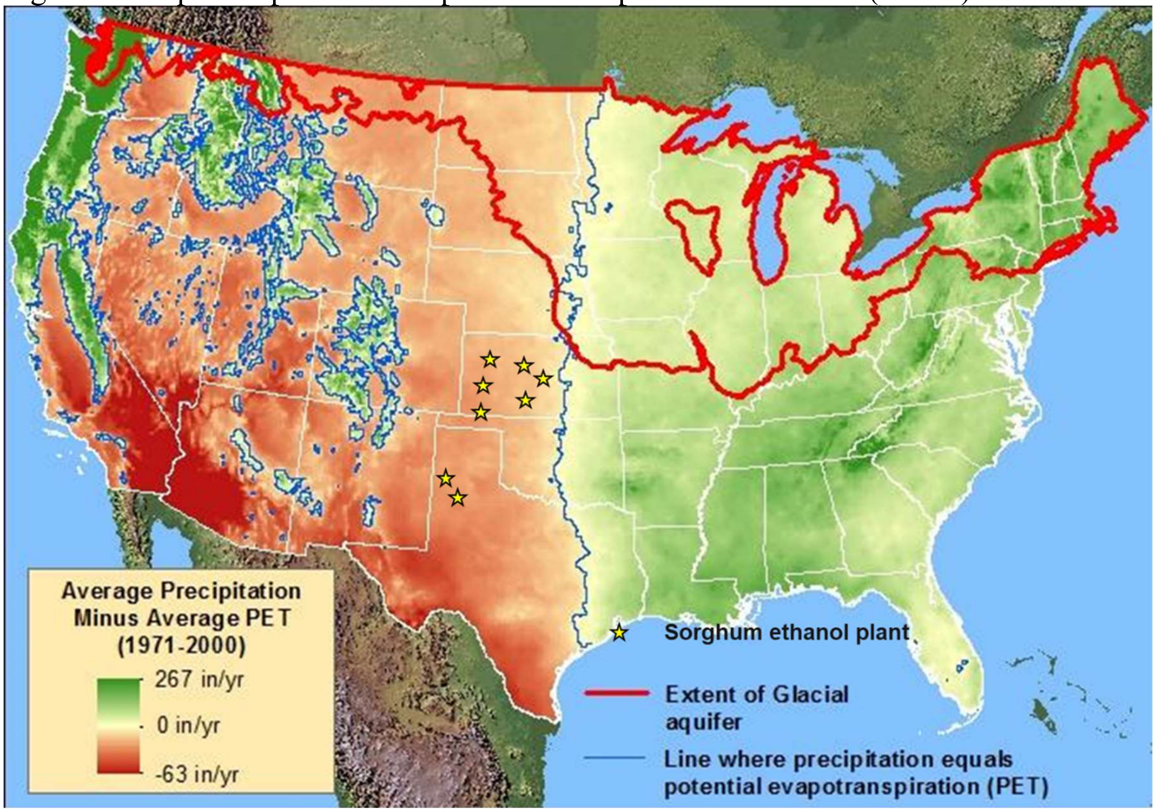
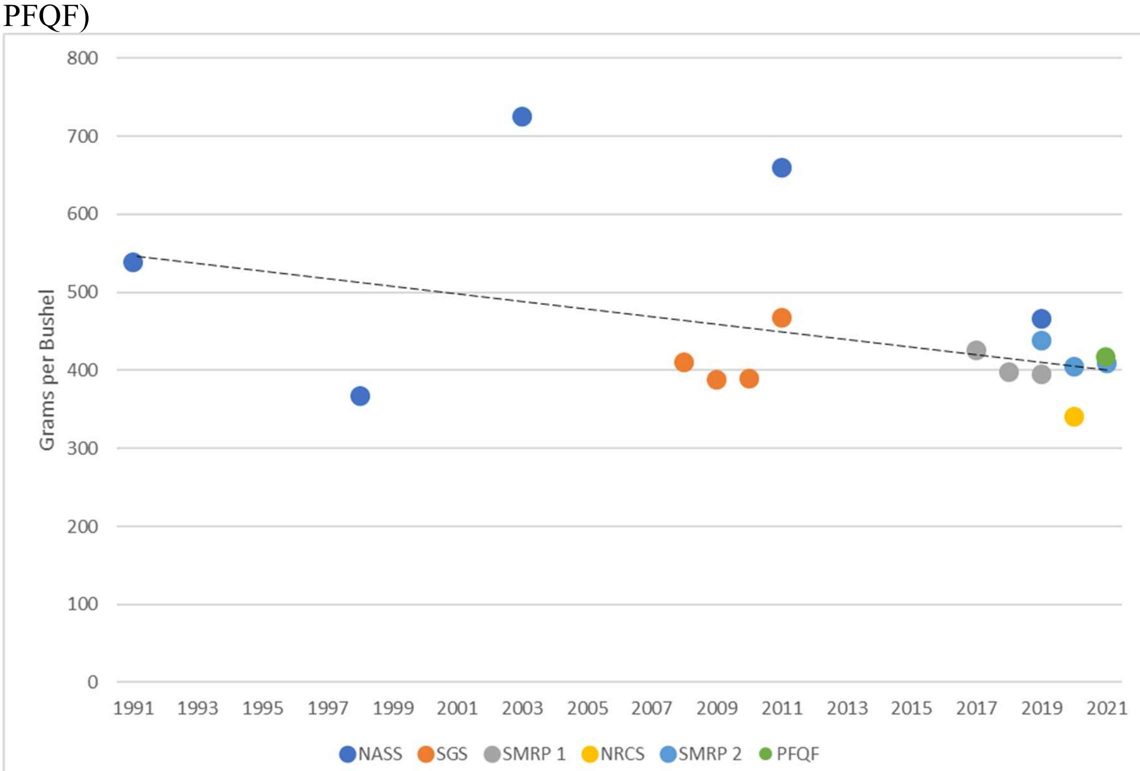


Figure 5. Nitrogen Fertilizer Application Rates for Sorghum. (NASS, SGS, SMRP, NRCS PFQF)



Evaluation of Indirect Land Use Conversion for Grain Sorghum

Prepared for:
The Sorghum Checkoff

LCA.8169.225.2022

Prepared by:
Lucy Buchan
Stefan Unnasch
July 15, 2022

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ACKNOWLEDGEMENT

Life Cycle Associates, LLC performed this study under contract to the Sorghum Checkoff. John Duff was the project manager.

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TERMS AND ABBREVIATIONS

AEZ-EF	Agro-Economic Zone Emission Factor
CA	California
CARB	California Air Resources Board
CCLUB	Carbon Calculator for Land Use Change from Biofuels Production
CI	Carbon Intensity
CO_2e	Carbon Dioxide-Equivalent
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization
FAPRI	Food and Agricultural Policy Research Institute- Center for Agricultural and Rural Development
FASOM	Forest and Agricultural Sector Optimization Model
GHG	Greenhouse Gas
GREET	Greenhouse Gases Regulated Emissions and Energy Use in Transportation
GTAP-BIO	Global Trade Analysis Project-Biological
iLUC	indirect Land Use Conversion ("i" to emphasize "indirect" aspect of LUC)
ILUC	Indirect Land Use Conversion (capitalized version for sentence beginnings)
kWh	kilo-Watt Hour
LCA	Life cycle analysis
LCFS	Low Carbon Fuel Standard
LUC	Land Use Conversion
MJ	Megajoule
RFS2	Renewable Fuel Standard Program

1. Introduction

Sorghum is a resilient crop that is primarily grown as an alternative to corn where farming conditions (water stress and high temperatures) do not support sufficiently profitable corn growth and yield (Staggenborg et al., 2008). Sorghum farming practices typically employ similar inputs as corn farming on a per tonne and per acre basis. As a result of being grown under less-optimal farming conditions, however, sorghum's yield is usually lower than that of corn. Consequently, sorghum is potentially perceived and treated in transportation policy and regulatory contexts, such as the California Air Resources Boad (CARB) Low Carbon Fuel Standard program (LCFS) and the U.S. Environmental Protection Agency's ((EPA) Renewable Fuel Standard program (RFS2), as a comparatively less-efficient crop that requires greater acreage to produce comparable yield. Notably, in some instances, sorghum can be grown as a double crop[1], resulting in incremental production of food and fuel, and thereby having a favorable land use efficiency.

Since the estimated amount of land converted for biofuel feedstock production factors significantly into the calculations of greenhouse gas (GHG) emissions associated with biofuels and with RFS2 and LCFS compliance, it is an important factor to carefully evaluate and track. This Report reviews U.S. EPA RFS and CARB LCFS GHG analysis, associated models, and data pertaining to existing iLUC values for corn and sorghum, and establishes support for a stance on biofuel policies indicating that iLUC values for sorghum should be no greater than those for corn in future regulatory updates.

1.1 Indirect Land Use Conversion - Background

In addition to GHGs that are directly emitted from the production and use of biofuels, emissions associated with increased demand for biofuel feedstocks is referred to as indirect land use change or iLUC. Some analysts attribute the increase in emissions to a change in regulatory policies such as clean fuel standards; however, in the case of sorghum used in ethanol production, the feedstock is a substitute for grain corn both in feed and fuel markets. A presumed increase in acreage needed to meet increased demand for feedstock could lead to non-agricultural or underproductive lands being converted to cropland. ILUC is estimated from the conversion of land with carbon that may have remained sequestered in soils and cover vegetation. Biomass removal and well as tillage of below ground biomass are part of the iLUC estimate.

ILUC is treated as an agro-economic phenomenon where increasing worldwide demand for biofuels stimulates a corresponding increase in the price and demand for the crops used to produce those fuels. To meet such demand, farmers may:

1 Double cropping occurs on 2-3% of total US cropland (USDA, 2014).

- Grow more biofuel feedstock crops on existing cropland by reducing or eliminating crop rotations or fallow periods, incorporating cover crops or planting double crops, and by adopting other regenerative practices that improve soil and growing conditions;
- Convert existing agricultural lands from food to fuel crop production;
- Convert lands in non-agricultural uses to fuel crop production; or
- Take steps to increase yields beyond that which would otherwise occur.
- Shift the uses and consumption of feed and fiber

Land use change (LUC) effects are predicted to occur when the acreage of agricultural production is expanded to support increased biofuel production. Lands in both agricultural and non-agricultural uses may be converted to the cultivation of biofuel crops. Some land use change impacts are indirect or secondary. When biofuel crops are grown on acreage formerly devoted to food and livestock feed production, supplies of the affected food and feed commodities are reduced. These reduced supplies lead to increased prices, which, in turn, stimulate the conversion of non-agricultural lands to agricultural uses. The land conversions may occur both domestically and internationally as trading partners attempt to make up for reduced imports from the United States. The land use change will result in increased GHG emissions from the release of carbon sequestered in soils and land cover vegetation. These emissions constitute the land use change impact of increased biofuel production.

Not all biofuels have been linked to indirect land use change impacts. Biofuels produced by using waste products as feedstocks are treated as having insignificant land use effects. The use of corn stover as a feedstock for cellulosic ethanol production, for example, is not likely to produce a land use change effect due to the changes in the demand for feed and fiber. Feedstocks such as native grasses grown on land that is not suitable for agricultural production are unlikely to cause land use change impacts. Waste stream feedstocks such yellow grease, waste cooking oils and municipal solid waste, are not considered as drivers of land use change impacts even though their use requires new sources of oleochemicals.

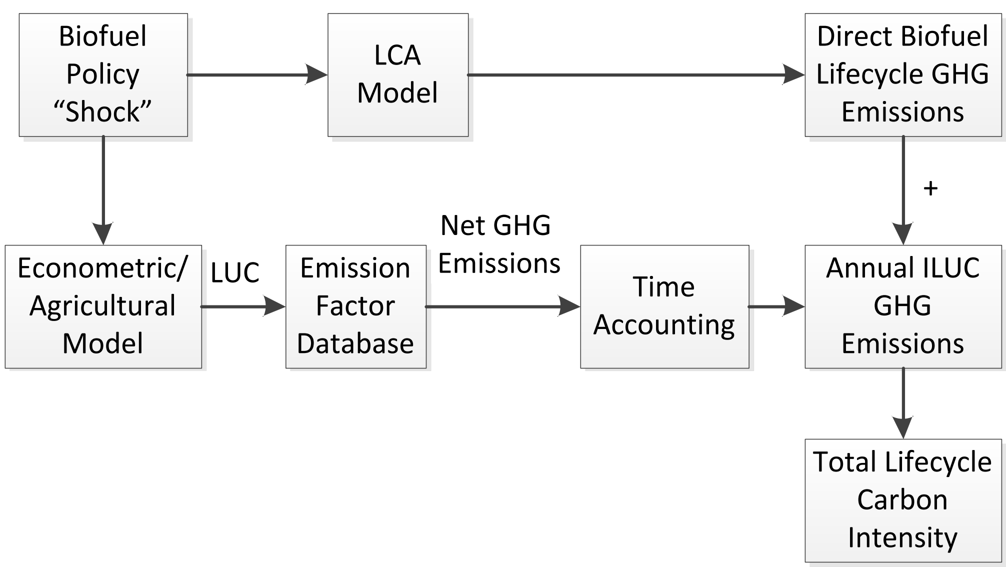

Figure 1. Modeling Flow for Determination of Total Biofuel Lifecycle Carbon Intensity, Including Both Direct and Indirect Effects.

The correlation between LUC and an expansion in biofuel is typically estimated with agro-economic models. ILUC corresponds to the emissions resulting from land conversion associated with new demand for biofuels. Economic models that simulate market behavior (particularly those in the agricultural sector) are often linked to predict the location of land cover change and the emissions associated with conversion to crops as illustrated in Figure 1. Results from economic models that predict the location and type of land conversion are combined with emission estimates associated with land conversion. The results are amortized over a time horizon to develop an iLUC estimate.

1.1.1 Range of iLUC Estimates

iLUC values have evolved over time with refinements in modeling and contributions from numerous researchers. Figure 2 shows a range of values estimated for corn ethanol. The results from different studies have not provided a strong consensus on the most representative value which depends on numerous factors including the extent of biofuel usage as well as agricultural modeling and land conversion emission factors. Analysis of iLUC values found in various publications support both higher (Malins et al 2021; Lark et al., 2022) and lower (Scully et al., 2021; Taheripour et al., 2021; Taheripour et al., 2022) values. The debate over iLUC includes evaluations of land cover predictions as well as carbon stocks for different land cover types.

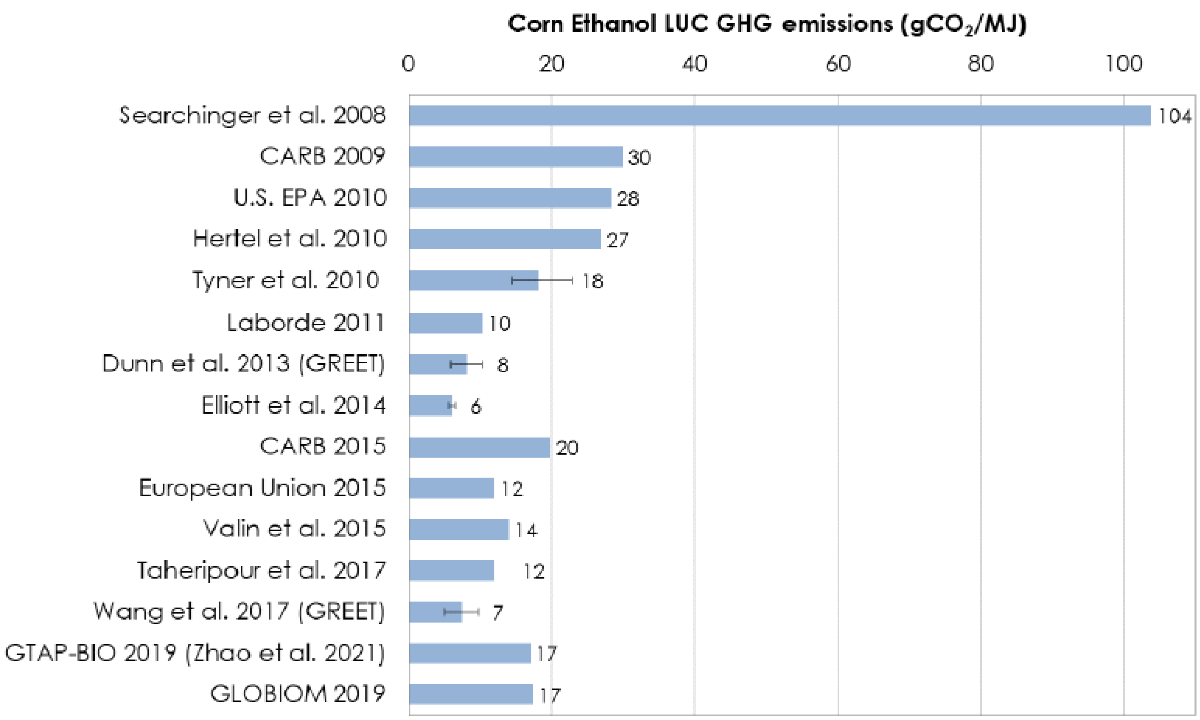

Figure 2. Range of iLUC estimates for corn ethanol.

1.2 Overview of iLUC Assessments in U.S. Biofuel Policies

The RFS2 and the LCFS programs require that transportation fuel GHG reduction targets be met through the use of alternative fuels. The GHG emissions are determined through life cycle assessments (LCAs), which account for all energy and emission flows during the life of the fuel, i.e., “cradle to grave”. The GHG reductions are measured through comparison of LCA results of an alternative fuel to its conventional counterpart (such as gasoline or diesel). The net GHG is determined in terms of a carbon intensity (CI), which includes all GHG emissions, measured in CO_2 equivalency.

Implementing LCAs requires clearly defining boundaries, assumptions, and acquiring numerous data inputs. LCA Results are highly dependent on these inputs and thus, can differ depending on their relative scope. Because of their importance in policy, LCA methodologies implemented for the RFS2 and the LCFS have been critically reviewed by stakeholders and experts in an effort to ensure that the life-cycle GHG emissions of alternative fuels are fairly represented. The assumptions that generate the greatest uncertainties, and have the largest impacts on biofuel LCAs, are those regarding co-product allocation, agricultural emissions (particularly N_2O emissions) and indirect land use changes (iLUC). ILUC refers to changes in land cover that occur as a result of increasing the amount of biomass for a particular fuel feedstock in order to increase biofuel production.

Both EPA and CARB calculate emissions associated with iLUC by linking results from agro-economic models to their life cycle assessment (LCA) models (Table 1). Changes in biofuel production volumes are input to predict how much land will be required to compensate for the crop that has been displaced by the production of biofuels. CARB (2015), for example, has associated a considerable impact in indirect land use conversion (iLUC) for sorghum (19.4 gCO_2e/MJ) and a slightly higher iLUC value for corn (19.8 gCO_2e/MJ). Since iLUC values affect the carbon intensities associated with fuel feedstock in the RFS and LCFS, it is important that they are as accurate as possible, both now and in the future.

Table 1. Comparison of Agro-Economic Models for Land Use Conversion Analysis.
Source: Broch and Hoeckman, 2011.

Model	GTAP	FAPRI	FASOM
Application	CARB-LCFS	EPA RFS2	EPA RFS2
Type	Global computational general equilibrium model (CGE) with explicit treatment of land.	Global partial equilibrium model of agricultural sector.	Partial equilibrium model of U.S. forestry and agriculture incorporating GHG emissions
Regions	18 international AEZs	54 International regions	11 U.S. Regions
Fuel demand	Biofuel shock with surrogate petroleum tax subsidy.	Demand for feedstock modeling of blend wall price effects.	Demand for feedstock on agricultural system
Price/ yield response	0.2-0.3 price/ yield elasticity plus exogenous yield multiplier	0.074 long run price/ yield elasticity	No price response
Area/ yield response	0.66-0.75 area expansion multiplier	0.977 area expansion multiplier	Yield projections for new land in U.S.
Co-product treatment	Feed co-product is subtracted from bio-fuel feedstock requirements	DGS and SBM are treated as separate agricultural commodities	DGS and SBM are treated as separate agricultural commodities
Co-product power	New power for agriculture and biorefineries included in GREET calculations with region-specific emission factors	Credit for power export from biorefineries using GREET emission factors	U.S. agricultural system power modeled by FASOM with new power consumption from biorefineries
Carbon Accounting	Emission factors from Woods Hole database.	MODIS satellite data and Winrock analysis of land conversion factors	Endogenous, direct emission factors comparable to GREET. Land emissions from CENTURY

EPA's (2010) approach to linking agro-economic databases to their emission factor databases to estimate the net GHG emissions associated with fuel production involves two different pathways to determine domestic LUC and international LUC (Figure 3). Domestic changes are determined through the Forest and Agricultural Sector Optimization Model (FASOM) economic model. FASOM is linked to the DAYCENT/ CENTURY and FORCARB databases to determine the net iLUC. International iLUC is modeled with the Food and Agricultural Policy Research Institute-Center for Agricultural and Rural Development (FAPRI) model. The land use results from FAPRI are linked to emission factors from the Winrock databases, which are aggregated according to historical land use changes measured through MODIS satellite imagery. Although EPA has not updated its iLUC methodology, it has published new GHG emission values for selected biofuels. To determine the iLUC emissions associated with each fuel, the results from a reference case, or the "business as usual scenario", is compared to the control case which includes the policy volume targets. The change in each fuel volume type is modeled individually to estimate the changes attributable to that fuel. The resulting net carbon intensity of each fuel is the sum of all the outputs listed on the right-hand side of Figure 3.

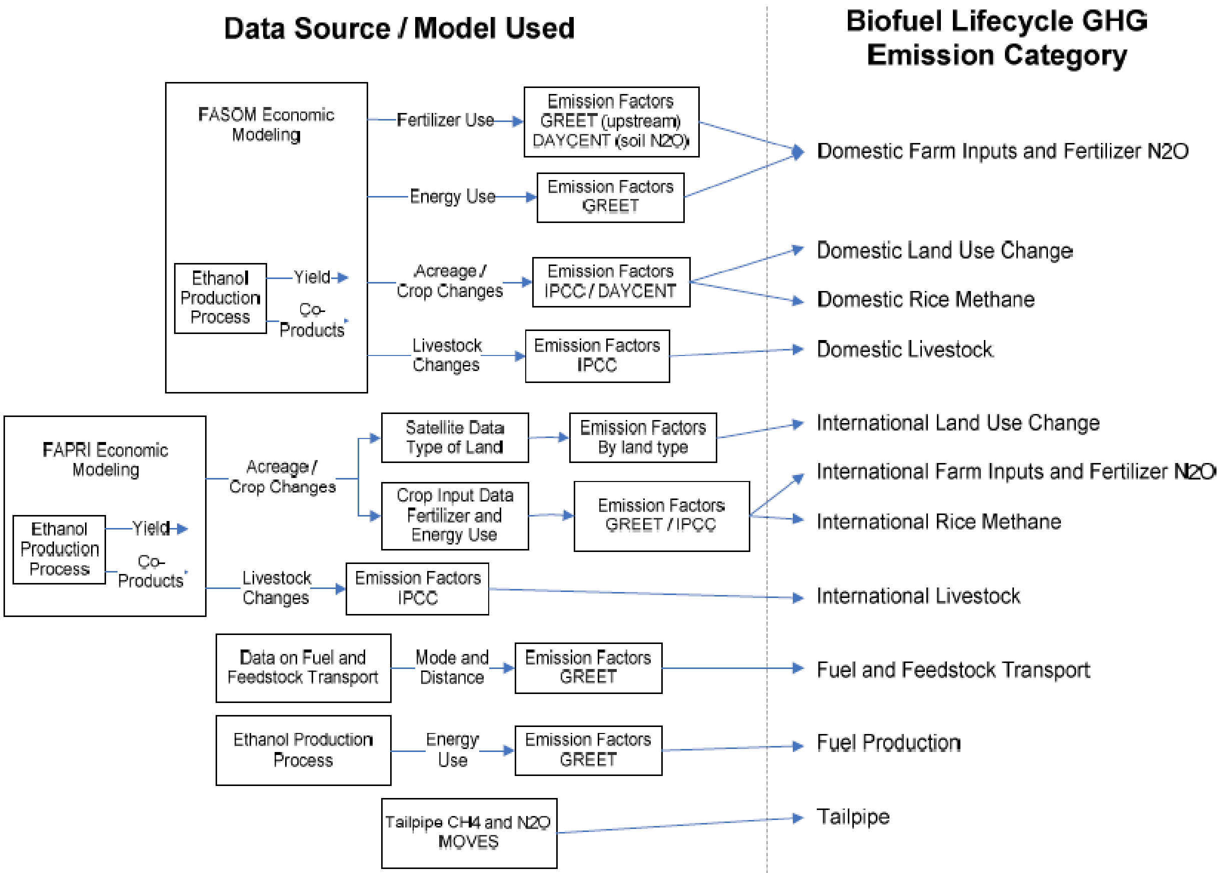

Figure 3. System boundaries and modeling flow chart for biofuel LCA in EPA RFS2
Source: Broch and Hoekman, 2011.

The research and analysis behind CARB's updated[2] sorghum iLUC value was based on running the Global Trade Analysis Project (GTAP) agro-economic model, modified to account for biofuels and their co-products, and referred to as the GTAP-BIO model (CARB, 2014). Estimated carbon emissions associated with modeled land use change are calculated using a carbon emissions model called the Agro-Ecological Zone Emission Factor (AEZ-EF) linked to emission factors from the Woods Hole database. CARB's original 2009 modeling results were vetted by extensive stakeholder review through the CARB Environmental Expert Workgroup before the LCFS regulation was adopted. Stakeholders raised the issue of uncertainty in the output values for iLUC. Staff, working with the University of California, developed a Monte Carlo approach for estimating total uncertainty of iLUC resulting from variability in individual parameters. The assumptions and input parameters used in the GTAP-BIO and AEZ-EF models provided the basis for the 2014 rule making.

[2] CARB's original analysis in 2009 was updated in 2014.

2. iLUC Analysis for Grains

ILUC estimates have evolved considerably since the original assessments performed over 14 years ago. Factors affecting iLUC include the response to yield improvements and price, characterizations of agricultural land type, treatment of co-product credits, characterization of soil carbon stocks, and soil carbon accumulation due to different farming practices. The most notable refinements have included updates to the GTAP database as well as more detailed net soil carbon assessments based on county-by-county farm data. Figure 4 illustrates the temporal trend of values estimated for LUC and iLUC in association with corn ethanol production using different agro-economic models.

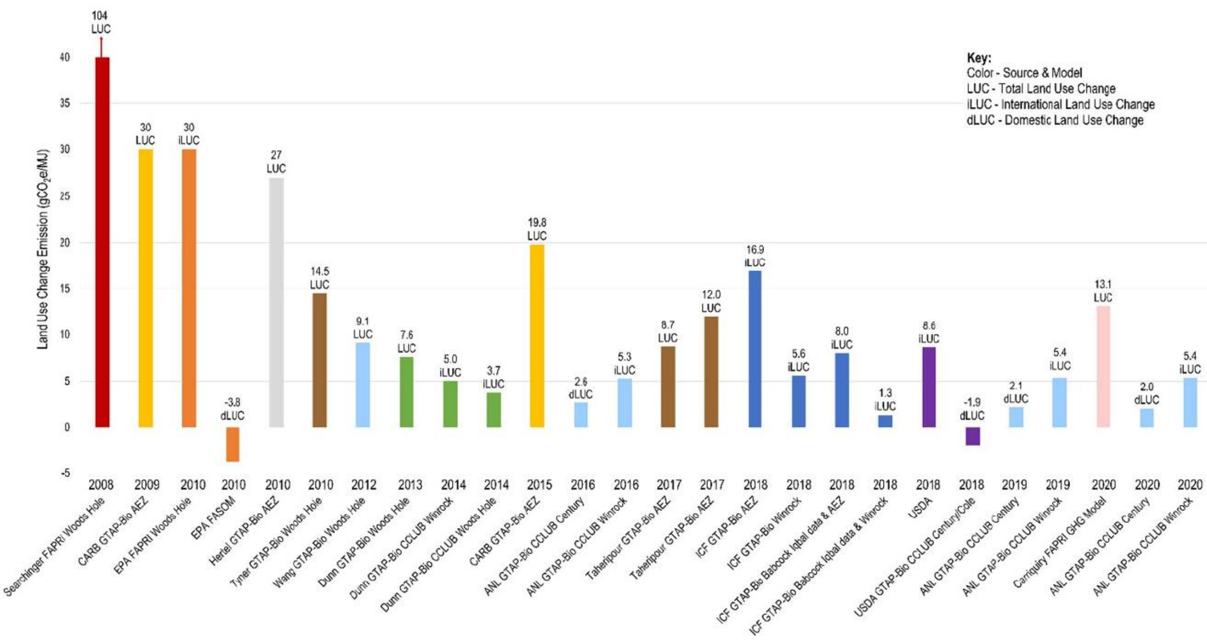

Figure 4. Estimated GHG emissions associated with corn ethanol-related LUC.
Source: Scully et al., 2021

The iLUC is generally considered to include the international and the domestic land use change. Figure 5 illustrates the emissions associated with iLUC for the RFS2 (US EPA, 2010) and the LCFS programs (CARB 2009, 2014). EPA's analysis resulted in a slightly lower iLUC for sorghum than for corn as shown in Figure 5. As part of the 2009 LCFS rulemaking, CARB developed ILUC results that were of a similar order of magnitude as EPA's and assigned the same ILUC to both corn and sorghum. Subsequently, in 2014, CARB performed separate ILUC analyses, which resulted in a slightly lower iLUC for sorghum than for corn, comparable to the magnitude of difference calculated by the EPA. Regardless of the year and model used, the outcome of each of the aforementioned analyses resulted in the ILUC of sorghum-based ethanol being comparable or slightly lower than that of corn-based ethanol.

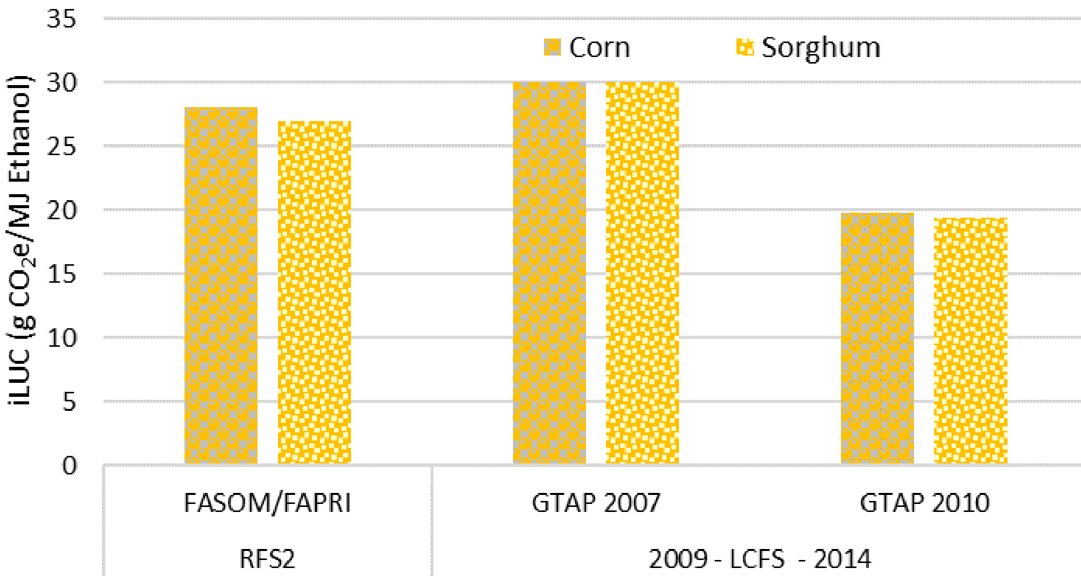

Figure 5. Indirect land use change emissions for corn and sorghum ethanol in three models.

2.1 U.S. EPA Regulatory Impact Analysis Rulemaking

The U.S. Environmental Protection Agency (EPA) conducted a Regulatory Impact Analysis (RIA) to assess the impacts of an increase in the production, distribution, and use of renewable fuels sufficient to meet volumes specified in the revised Renewable Fuels Standard (RFS2), as mandated by the Energy Independence and Security Act (EISA) of 2007. Pathways for ethanol produced from grain sorghum feedstock were approved in a rule published on December 17, 2012 (the ''December 2012 RFS Rule''). This Rule was based on a life cycle assessment to determine the overall impact on global greenhouse gas (GHG) emissions that would be associated with an increase in renewable fuels. The primary[3] reference case was a projection of renewable fuel volumes expected in 2022 that was made prior to EISA implementation by the US Energy Information Administration (EIA) in their 2007 Annual Energy Outlook (AEO, 2007). Research conducted since the RIA demonstrates that corn ethanol emissions are significantly lower than those predicted in the RIA for 2022 (Qin et al., 2018).

2.1.1 Regulatory Impact Analysis Summary

In the U.S., 27 million wet tons of sorghum residue were projected to be available in 2022 for cellulosic ethanol production (based on Beach et al., 2010). The RIA, however, focuses on sweet sorghum rather than grain sorghum. The RIA estimated the top counties in close proximity to each other, with sufficient acreage in sweet sorghum production to annually produce 0.1 billion gallons of ethanol. They projected a decline in U.S. sorghum planted acreage and production in response to increases in both corn ethanol and soybean biodiesel production (Figure 6). In

[3] A 2009 reference case was also considered, however, it reflects the initial impacts of implementation of the RFS2 standards, and projected crude oil prices for 2022 were $116/barrel, in contrast to the 2007 reference benchmark value of $53/barrel, which is closer to the observed market values for the past 5 years ($50-$75/barrel).

comparison to corn, projected diesel use for sorghum farming was about a gallon less per acre on average, and gasoline consumption was about a gallon per acre greater (Figure 7, Figure 8). Average electricity consumption was approximately 2 kWh/acre less for sorghum than for corn, and average carbon dioxide emissions from grain drying were projected to be substantially lower for sorghum than for corn (Figure 9, Table 2).

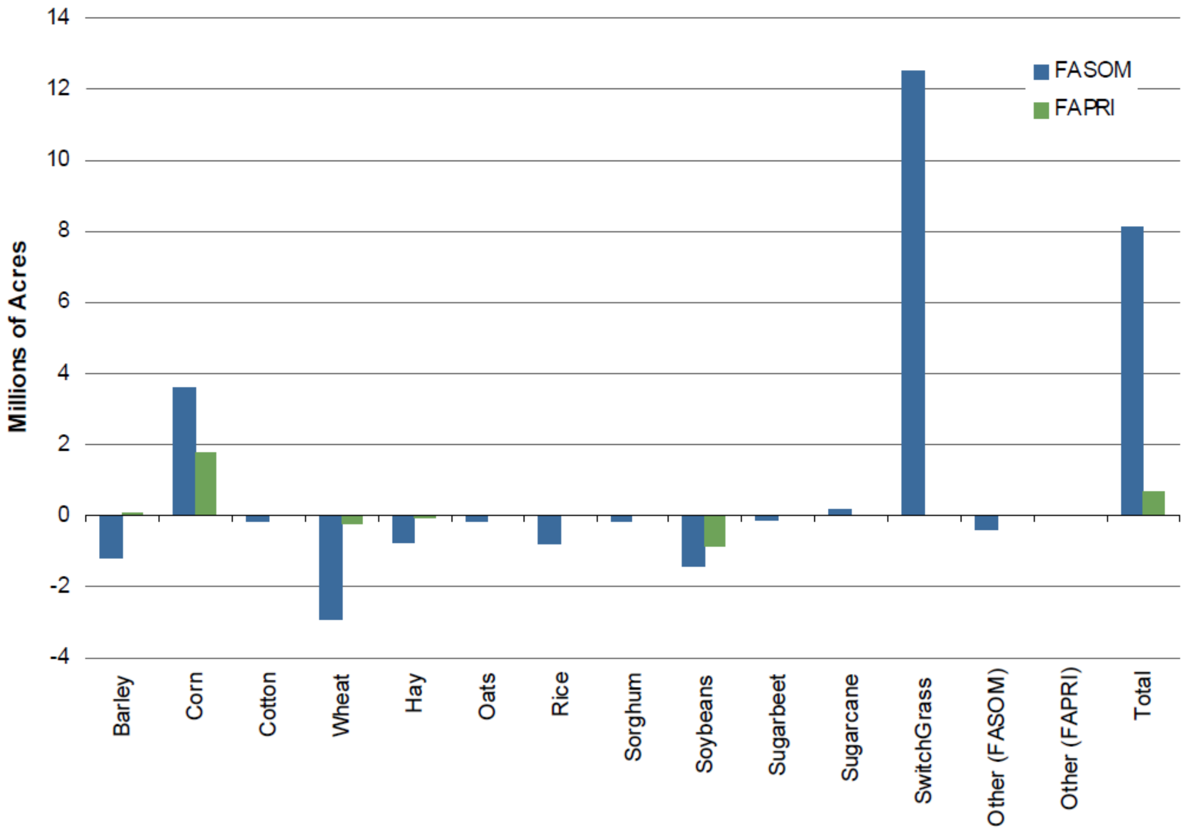

Figure 6. Estimated change in U.S. crop acres in 2022 relative to the Annual Energy Outlook 2007 reference case.
Source: EPA, 2010.

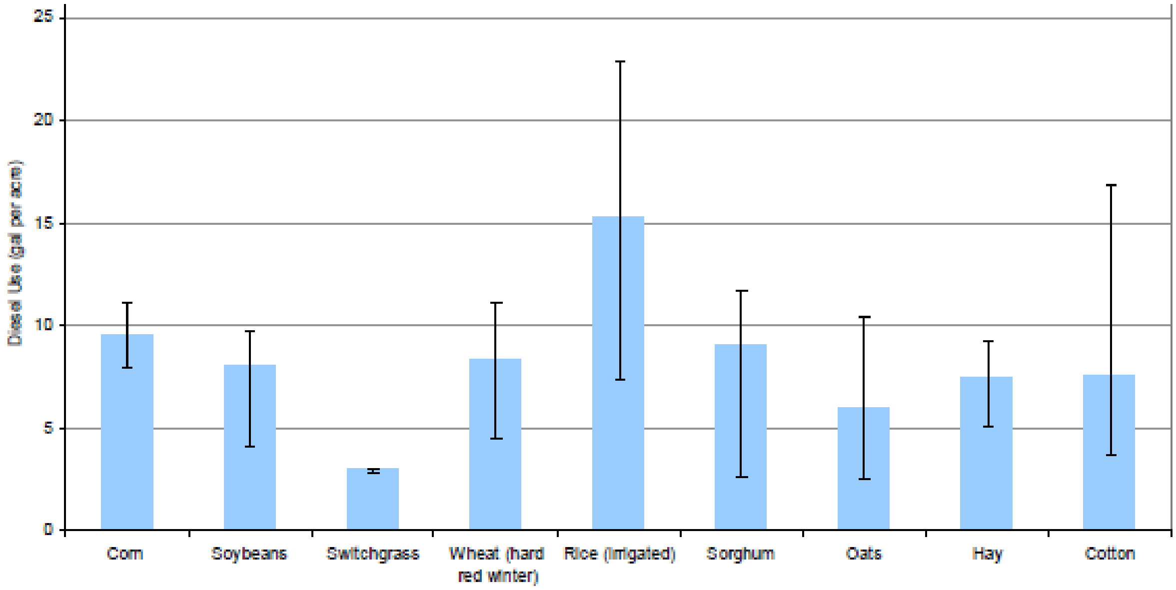

Figure 7. Projected diesel use (2022) for non-irrigated no-residue crop harvesting in the U.S.
Source: EPA, 2010.

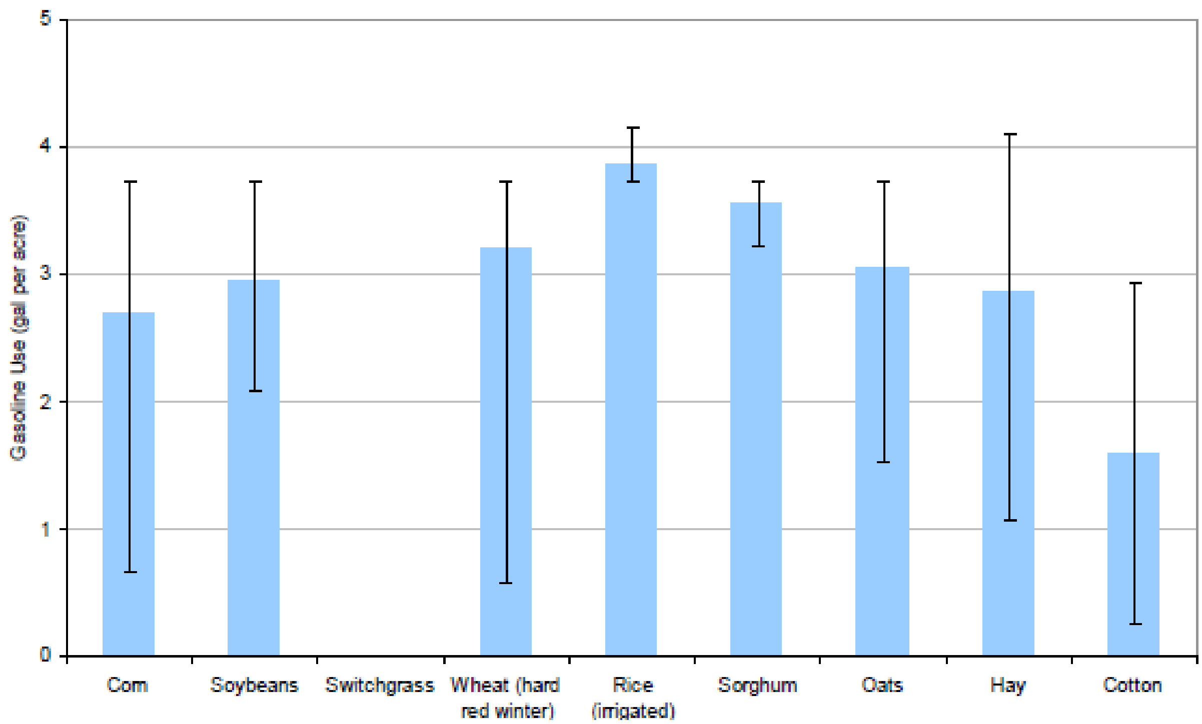

Figure 8. Projected gasoline use (2022) for non-irrigated no-residue crop harvesting in the U.S.
Source: EPA, 2010.

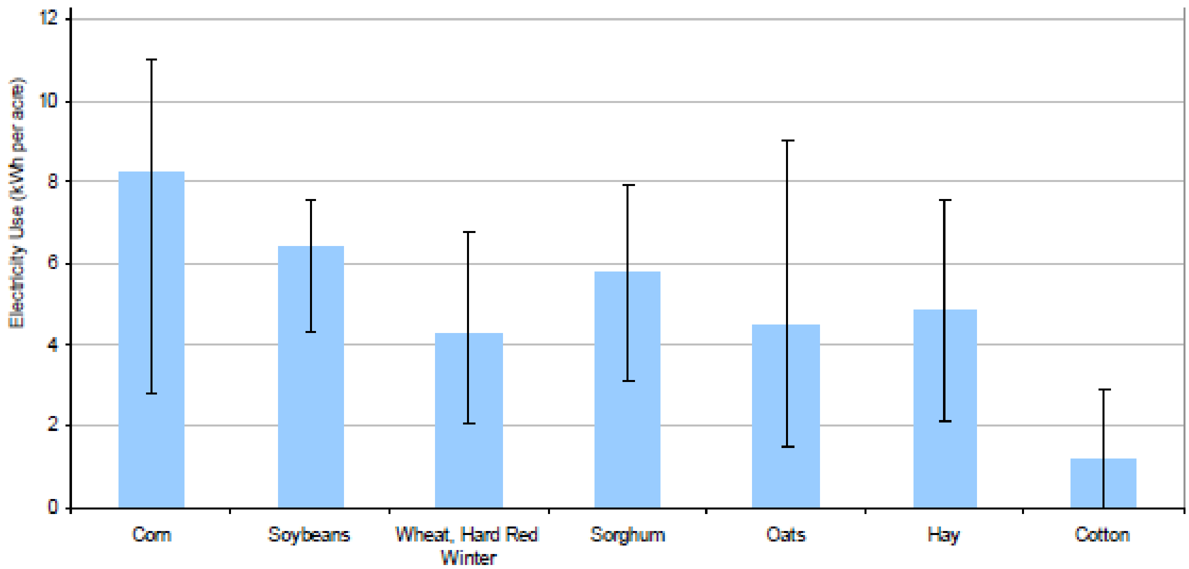

Figure 9. Projected electricity use (2022) for non-irrigated no-residue crop harvesting in the U.S.
Source: EPA, 2010.

Table 2. FASOM Average Carbon Dioxide Emissions from Grain Drying by U.S. Market Region.
Source: EPA, 2010.

Crop	Corn Belt	Great Plains	Lake States	Northeast	Pacific NW East Side	Pacific Southwest
Dryland						
Corn	161.4	135.9	202.2	160.5	NA	NA
Sorghum	99.4	22.3	NA	54.3	NA	17.7
Irrigated						
Corn	NA	185.1	NA	NA	132.6	121.6
Rice	1,216.6	NA	NA	NA	NA	1667.3
Sorghum	NA	33.0	NA	NA	NA	NA

Figure 10 illustrates the annual hectares of sorghum under cultivation in the United States with a range from 1.5 to 3 million over the associated time span. Also shown is the price of ethanol, which is not correlated in any clear way with sorghum acreage. If taken by itself, there is little to be drawn in the relationship between sorghum acres and ethanol price. Sorghum acreage represents approximately 2% of corn acreage, and both have remained relatively flat over the past two decades. A comparison of Figure 10 and **Figure 11** illustrates that the relationship between corn acreage and ethanol price does not reflect an increase in corn acres induced by a more than tripling of ethanol prices from 2002 to 2012., During this timeframe, despite soaring ethanol prices (likely in response to U.S. fuel policies), sorghum production initially declined, and even upon increased production, it did not achieve a level corresponding to the ethanol price signal.

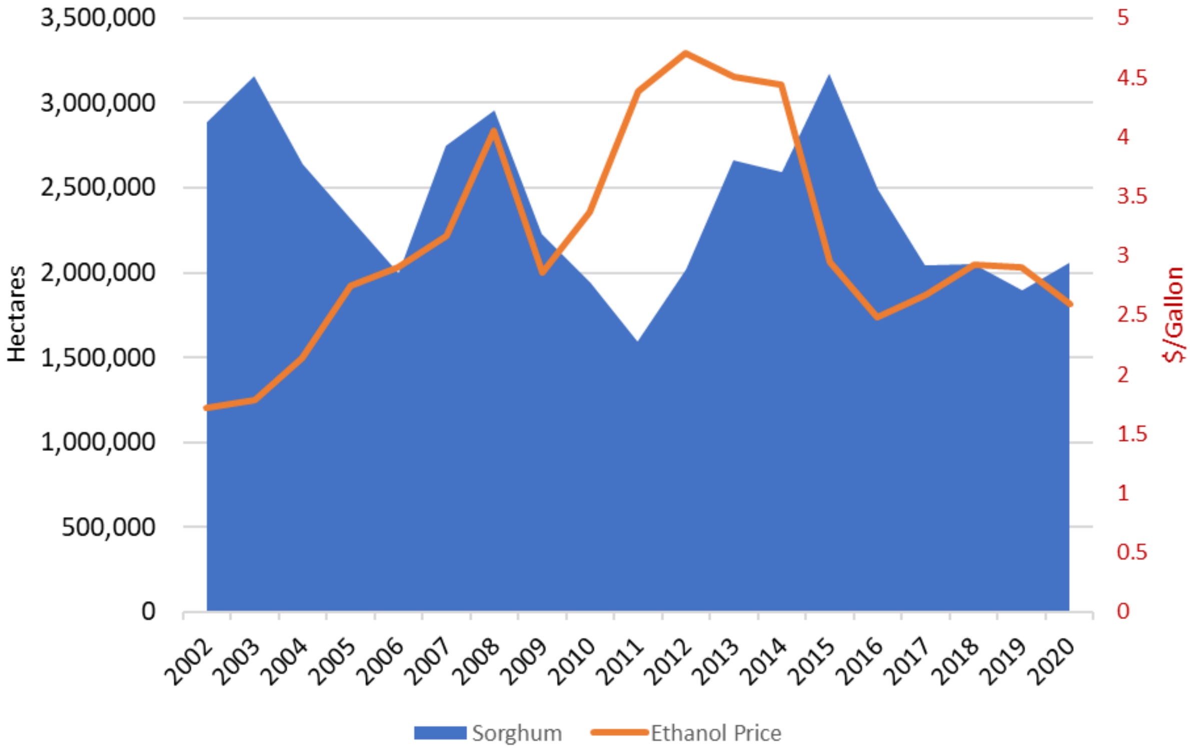

Figure 10. U.S. Sorghum crop area versus ethanol price.
Source: FAO Stat, 2022.

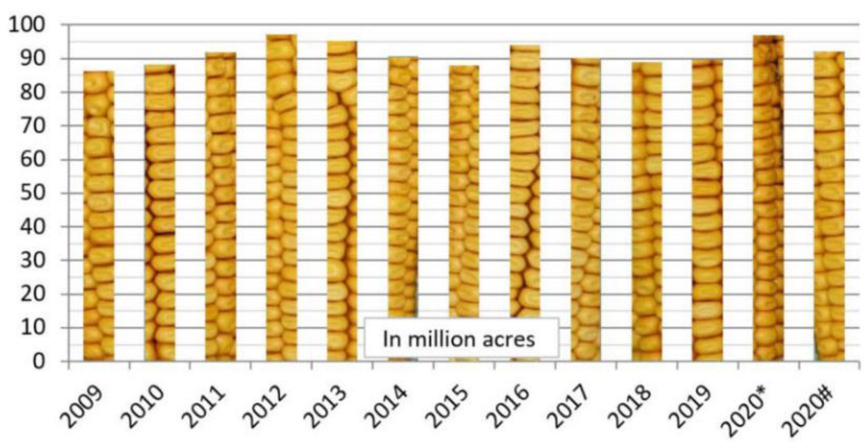

Figure 11. USDA Annual Corn Acreage.
Source: https://www.foodbusinessnews.net/articles/16341-usda-2020-corn-wheat-soybean-acres-below-trade-expectations

2.2 Evolution of the Global Trade Analysis Project Model

The Global Trade Analysis Project (GTAP) is a computable general equilibrium model (CGE[4]) developed at Purdue University. The model uses a database containing global data describing

[4] A CGE model represents the entirety of the global economy (or macroeconomy) and searches for a simultaneous equilibrium on all relevant markets.

bilateral trade patterns, production, consumption and intermediate use of commodities and services. It constrains primary production factors such as capital, labor and land to model the global economy and capture interdependencies between agriculture, the upstream and food industry, as well as the commercial economy and service sectors. The intraregional and interregional linkages of markets and actors are taken into account along with the resulting feedback effects.

Since its application in biofuel LCA, the model has been continually updated to more accurately model biofuel and biofuel crop markets. The most recent database for LUC modeling is the GTAP Version 10 Land Use Database (Aguiar et al., 2019), which includes baseline land cover data by land type and agro-ecological zone (AEZ) for the years 2004, 2007, 2011 and 2014. The GTAP model has also been improved for the treatment of biofuels and by products, called GTAP-BIO (Taheripour et al., 2008). The database has been modified to include data on production, consumption and trade of biofuels including grain-based ethanol, sugarcane ethanol, and biodiesel from oilseeds. Tyner et al. (2010) has updated the GTAP-BIO model (GTAP-BIO-ADV) for recent work to improve the analysis of corn ethanol. GTAP-BIO accounts for the vast majority of corn ethanol-related LUC estimates (Scully et al., 2021).

GTAP uses a Constant Elasticity of Transformation (CET) supply function to estimate the supply of land across cropland, forestry, and grazing land (Gibbs et al., 2010). The CET function used in GTAP is based entirely on U.S. data, but is applied to all the world regions. GTAP can be used to predict LUC in 18 agro-ecological zones (AEZ) and 20 regions including 121 countries worldwide (Taheripour, 2022). The CET function is used to predict how much land is transferred between forests, pastures and croplands, and its LUC outputs are the area of land converted under each category. It has been noted that because GTAP simulates a land scarcity regime, in which biofuel demand results in new land to be cleared (rather than a net land surplus regime in which increased demand for biofuels would result in less land reversion), the methodology is flawed, and should instead be able to account for the possibility of a net reduction in total agricultural lands (Roundtable on Sustainable Fuels, 2008). However, historic patterns show that demand for biofuel crops has outpaced yield improvements, so corn and soybean production are likely to be in the land scarcity regime in the near term.

2.3 CA LCFS Analyses

CARB calculates LUC effects for crop-based biofuels using the GTAP-BIO and AEZ-EF models. Figure 9 illustrates U.S. AEZs. LUC values for size feedstock/finished biofuel combinations are included in the LCFS Regulation (CARB, 2018) (Table 3). These estimates of feedstock emissions are included in estimates of emissions associated with finished fuels for producers participating in the LCFS.

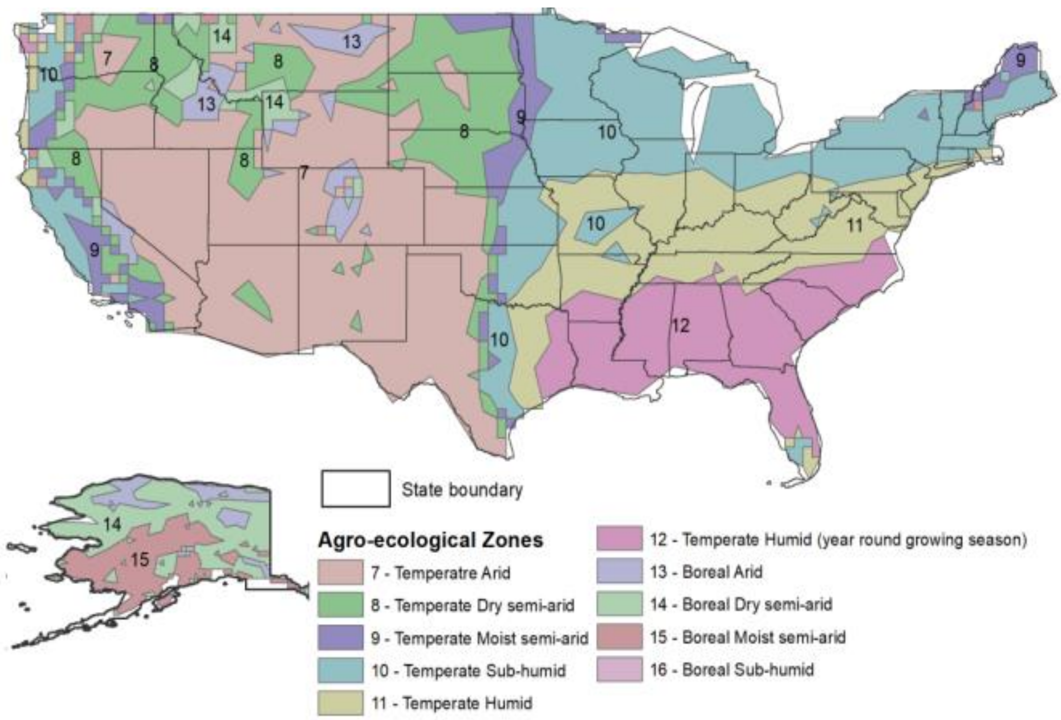

Figure 12. Agro-ecological zones in the U.S.
Source: Kwon et al., 2020.

Table 3. Land Use Change Values Included in the CA LCFS.
Source: CARB, 2014 (Table 6).

Biofuel	LUC (gCO_2/MJ)
Corn Ethanol	19.8
Sugarcane Ethanol	11.8
Soy Biomass-Based Diesel	29.1
Canola Biomass-Based Diesel	14.5
Grain Sorghum Ethanol	19.4
Palm Biomass-Based Diesel	71.4

Land Use Change Effects for Sorghum Ethanol

Starting with the 2004 U.S. sorghum ethanol production level of 0.0005 billion gallons, CARB staff analysis added 400 million gallons of sorghum ethanol shock for a total shock of 0.4005 billion gallons of U.S. sorghum ethanol (

Table 4, Figure 13).

Table 4. CA LCFS iLUC Modeling Results for Sorghum
Source: CARB, 2014 (Table H-10).

Scenario	World-Wide Land Converted (ha)			Land Converted in the U. S. (ha)			iLUC (gCO_2/MJ)
	Forest	Pasture	Cropland-Pasture	Forest	Pasture	Cropland-Pasture	
1	-19,249	-35,614	-152,858	-2,877	-2,664	-137,596	26.0
2	-16,760	-38,348	-154,751	-2,409	-3,270	-139,263	24.6
3	-15,751	-28,567	-145,808	-2,694	-2,409	-133,051	22.1
4	-13,519	-30,988	-147,557	-2,212	-3,107	-134,599	20.9
5	-12,191	-21,125	-137,882	-2,462	-2,048	-127,722	18.2
6	-10,567	-23,210	-139,478	-2,070	-2,774	-129,137	17.4
7	-9,777	-16,306	-131,988	-2,194	-1,946	-123,581	15.7
8	-8,398	-17,960	-133,429	-1,884	-2,450	-124,877	14.9
9	-7,620	-12,403	-125,912	-2,016	-1,747	-119,163	13.3
10	-6,473	-13,698	-127,205	-1,704	-2,206	-120,324	12.7
11	-17,851	-32,199	-153,219	-2,678	-2,045	-137,849	24.9
12	-15,327	-35,076	-155,134	-2,221	-2,909	-139,510	23.4
13	-14,546	-25,396	-146,100	-2,505	-1,950	-133,243	21.2
14	-12,303	-27,711	-147,879	-2,025	-2,531	-134,810	19.8
15	-11,306	-18,956	-138,181	-2,241	-1,665	-127,936	17.6
16	-9,505	-20,812	-139,814	-1,823	-2,293	-129,355	16.5
17	-9,031	-14,594	-132,251	-2,073	-1,505	-123,785	15.1
18	-7,636	-16,304	-133,710	-1,722	-2,078	-125,074	14.3
19	-7,152	-10,803	-126,120	-1,938	-1,407	-119,293	12.9
20	-5,962	-12,120	-127,423	-1,551	-1,800	-120,483	12.2
21	-24,898	-44,570	-152,056	-3,582	-3,522	-137,229	30.7
22	-22,380	-47,629	-153,909	-3,085	-4,389	-138,850	29.3
23	-20,329	-35,449	-145,095	-3,275	-3,142	-132,676	26.0
24	-18,348	-37,950	-146,774	-2,837	-3,878	-134,173	24.9
25	-15,973	-27,102	-137,309	-3,002	-2,829	-127,404	21.4
26	-14,137	-28,937	-138,847	-2,565	-3,462	-128,777	20.3
27	-12,805	-21,290	-131,479	-2,699	-2,660	-123,295	18.1
28	-11,480	-22,947	-132,876	-2,396	-3,121	-124,547	17.4
29	-10,102	-15,827	-125,436	-2,478	-2,370	-118,857	15.2
30	-8,933	-17,166	-126,713	-2,156	-2,934	-120,001	14.6
					Average iLUC (gCO_2/MJ)		**19.4**

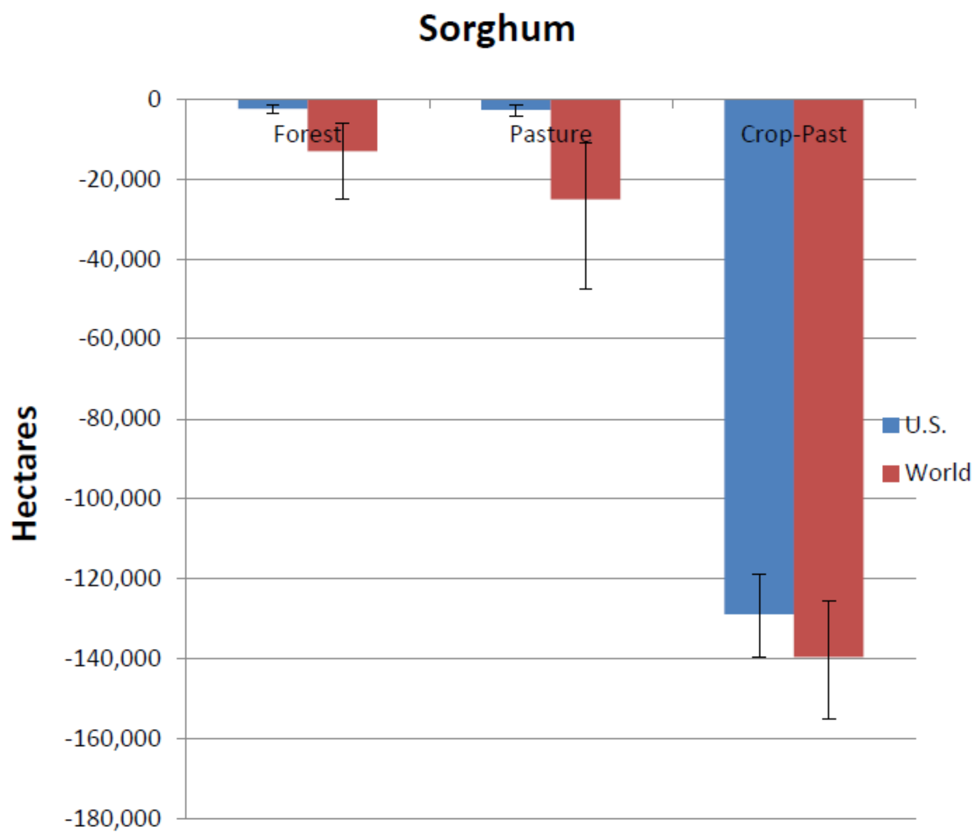

Figure 13. CA LCFS Land Conversion Model Predictions for Sorghum Ethanol.
Source: CARB, 2014 (Table H-10).

Land Use Change Effects for Corn Ethanol

For the CA LCFS GTAP-BIO AEZ-EF model runs, an ethanol production increase of 11.59 billion gallons was assumed for all the modeling runs (
Table 5, Figure 14).

Table 5. CA LCFS iLUC Modeling Results for Corn
Source: CARB, 2014 (Table H-6).

Scenario	World-Wide Land Converted (ha)			Land Converted in the U. S. (ha)			iLUC (gCO_2/ MJ)
	Forest	Pasture	Cropland-Pasture	Forest	Pasture	Cropland-Pasture	
1	-679,524	-1,505,426	-2,506,087	-97,860	-84,389	-1,925,473	28.1
2	-589,400	-1,609,064	-2,566,630	-81,593	-108,799	-1,975,693	26.2
3	-558,686	-1,237,442	-2,283,720	-92,070	-76,823	-1,794,270	23.4
4	-481,687	-1,327,540	-2,339,330	-77,192	-99,437	-1,841,030	21.8
5	-432,457	-965,628	-2,036,552	-85,096	-68,498	-1,643,313	18.5
6	-369,332	-1,040,551	-2,086,458	-71,719	-88,782	-1,685,961	17.3
7	-345,421	-784,225	-1,852,660	-79,454	-61,998	-1,526,570	15.2
8	-292,193	-848,116	-1,898,136	-67,263	-80,671	-1,565,934	14.1
9	-264,442	-620,432	-1,666,646	-73,259	-55,382	-1,403,790	12.1
10	-220,520	-674,327	-1,707,522	-62,308	-72,198	-1,439,634	11.2
11	-627,263	-1,379,371	-2,516,588	-91,386	-70,478	-1,931,292	26.6
12	-536,722	-1,481,523	-2,577,768	-74,994	-93,773	-1,981,956	24.7
13	-515,504	-1,133,500	-2,293,019	-86,069	-64,192	-1,799,643	22.2
14	-438,089	-1,222,011	-2,349,199	-71,008	-85,563	-1,846,810	20.6
15	-398,639	-884,243	-2,044,556	-79,630	-57,100	-1,648,182	17.6
16	-335,317	-958,065	-2,094,974	-66,158	-76,364	-1,691,200	16.3
17	-317,823	-717,813	-1,859,697	-74,356	-51,590	-1,531,038	14.4
18	-264,492	-780,925	-1,905,642	-62,036	-69,336	-1,570,738	13.4
19	-242,760	-568,315	-1,672,745	-68,610	-45,979	-1,407,838	11.5
20	-198,707	-621,187	-1,714,014	-57,560	-61,974	-1,443,985	10.6
21	-892,880	-1,839,556	-2,480,812	-119,115	-108,703	-1,914,876	34.3
22	-803,191	-1,946,081	-2,540,034	-103,125	-134,962	-1,964,431	32.4
23	-734,015	-1,512,311	-2,261,531	-111,872	-99,309	-1,784,429	28.4
24	-657,526	-1,604,739	-2,315,949	-97,260	-123,515	-1,830,565	26.9
25	-568,773	-1,179,392	-2,017,772	-103,252	-88,776	-1,634,382	22.4
26	-506,430	-1,256,748	-2,066,635	-90,125	-110,577	-1,676,452	21.2
27	-455,684	-956,380	-1,836,344	-96,236	-80,530	-1,518,359	18.3
28	-403,097	-1,022,992	-1,880,901	-84,312	-100,550	-1,557,177	17.3
29	-350,740	-755,549	-1,652,757	-88,601	-72,201	-1,396,338	14.5
30	-307,418	-811,583	-1,692,817	-77,892	-90,287	-1,431,683	13.7
						Average iLUC (gCO_2/MJ)	**19.8**

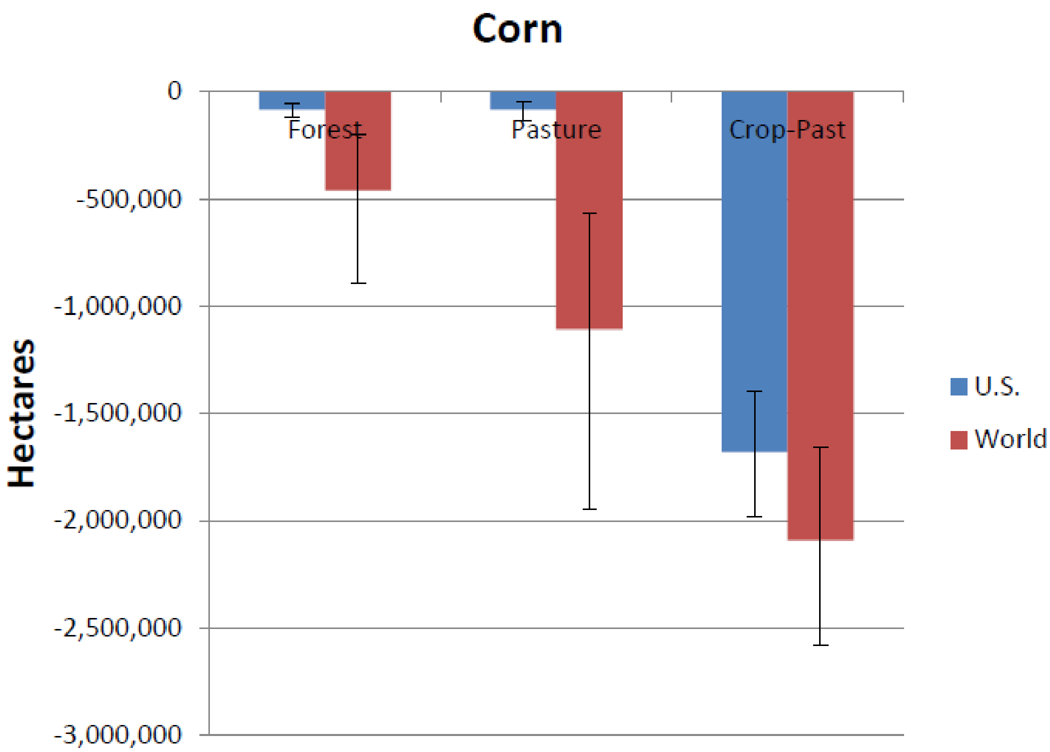

Figure 14. CA LCFS Land Conversion Model Predictions for Corn Ethanol.
Source: CARB, 2014 (Figure H-6).

Comparison of iLUC Values from GTA-BIO AEZ-EF Model Runs

Interestingly, Table 6 illustrates that the average from scenario runs for sorghum ethanol is considerably lower than for corn ethanol.

Table 6. iLUC Values Adopted in CA LCFS, 2018.
Source: CARB, 2014 (Table H-12).

Biofuel	Average from Scenario run (gCO_2/MJ)	Mean from Uncertainty Analysis (gCO_2/MJ)
Corn Ethanol	19.8	21.8
Sugarcane Ethanol	11.8	14.1
Soy Biodiesel	29.1	27.4
Canola Biodiesel	19.4	13.2
Sorghum Ethanol	14.5	22.8
Palm Biodiesel	71.4	72.5

Figure 15 and Figure 16 portray the results from the probabilistic Monte Carlo simulations for corn and sorghum ethanol, respectively, and illustrate the similarity in the resulting distributions.

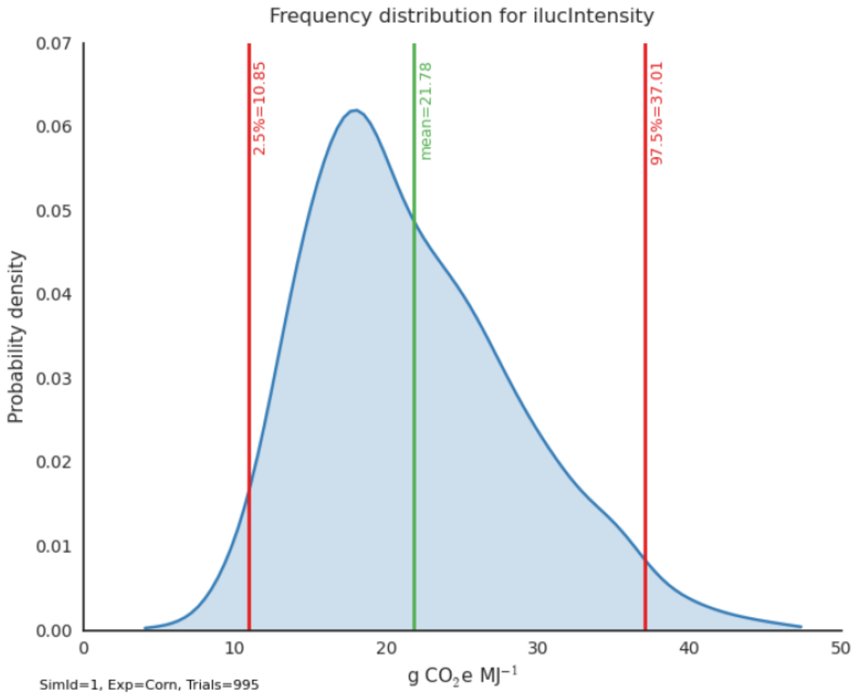

Figure 15. Probability distribution for corn ethanol from Monte Carlo simulations in GTAP-BIO.
Source: CARB, 2014 (Figure H-12).

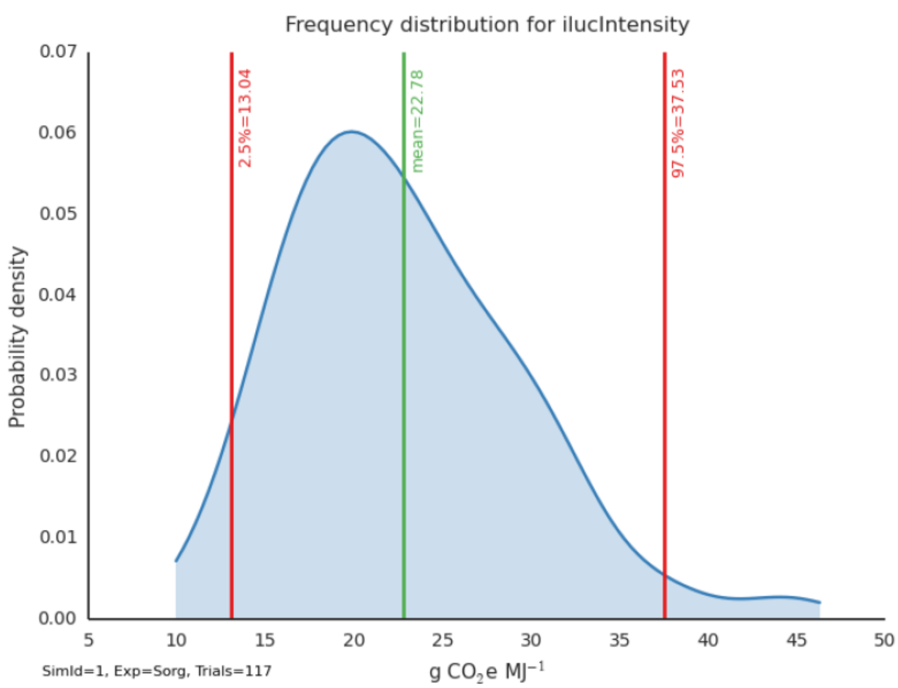

Figure 16. Probability distribution for sorghum ethanol from Monte Carlo simulations in GTAP-BIO.
Source: CARB, 2014 (Figure H-16).

2.4 CCLUB Model

The Carbon Calculator for Land Use Change from Biofuels Production (CCLUB) was developed by Argonne National Laboratory as an integral component of their Greenhouse Gases Regulated Emissions and Energy use in Technologies (GREET) model (Wang et al, 2020) to analyze GHG emissions from LUC and land management change (LMC) in the context of the overall biofuel life-cycle analysis. The CCLUB model calculates CO_2e emissions (accounting for carbon dioxide, nitrous oxide, and methane) associated with LUC/LMC using soil carbon data at the county level (Kwon et al., 2020). To date it has been implemented for four ethanol pathways -corn grain, corn stover, miscanthus, and switchgrass – and for a soy biodiesel pathway. It has not, however, been implemented for a sorghum ethanol pathway. ANL has performed preliminary analysis of iLUC using CCLUB but this analysis has not been published.

CCLUB Update Process

Argonne National Laboratories regularly updates CCLUB. The latest value for corn ethanol LUC, based on the CCLUB GTAP 2013 model, is 3.9 g CO_2e/MJ (Scully et al., 2021), which is almost half of the value estimated from the CCLUB GTAP 2011 model (7.4 g CO_2e/MJ), and approximately one-fifth that of the value in the current CA LCFS regulation (CARB, 2018).

2.5 DayCent Model

DayCent (Figure 17 and Figure 18) is the daily time step version of the Century biogeochemical model (Parton et al., 1994) which operates on a monthly time step. Both models simulate plant-soil nutrient cycling to in turn simulate carbon and nutrient dynamics among the atmosphere, vegetation and soil. The model calculates the flow of carbon, nitrogen, phosphorus, and sulfur using key submodels that include soil water content and temperature by layer, plant production and allocation of net primary production (NPP), decomposition of litter and soil organic matter, mineralization of nutrients, N gas emissions from nitrification and denitrification, and CH_4 oxidation in non-saturated soils. As discussed in Section 1.2 and illustrated in Figure 3, DayCent was linked to the FASOM model as part of the U.S. EPA's Renewable Fuel Standard approach.

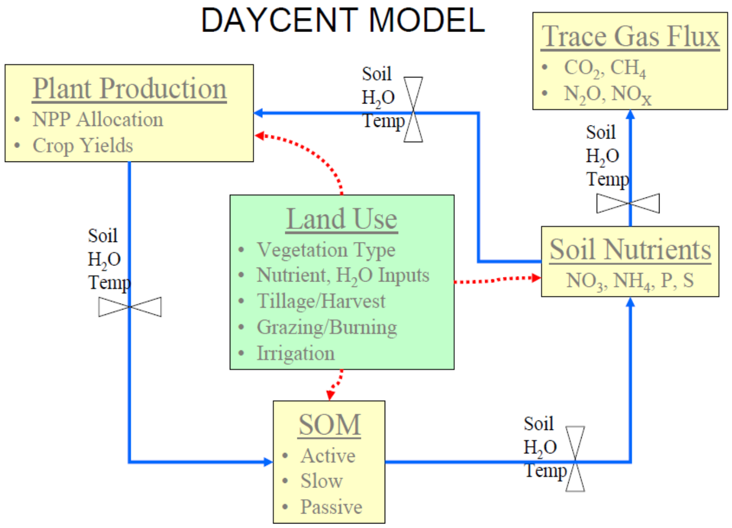

Figure 17. DayCent model primary inputs and outputs.
Source: Ojima in Zhang and Paustian.

The issue of soil carbon storage is illustrated in comments in the literature regarding LUC modeling. The authors of critiques of CCLUB, which represents the newest iLUC analysis from GTAP, (Malins, 2020) argue that the Winrock data for domestic crop conversion is more accurate (which is an option to utilize in GTAP). Much of the debate around LUC estimates, as presented in GTAP, pertains to the use of emission factors associated with soil carbon release. CCLUB uses the CENTURY emission factors as U.S. defaults, and Winrock emission factors as international defaults. **Figure 19** shows the comparison of different emission factors, which support the argument that the higher Winrock emission factors for domestic LUC would be an appropriate estimate; however, this argument is inconsistent with EPA's GHG accounting for the U.S. GHG inventory, which uses FASOM. Shifting to greater corn production from other crops, along with the deployment of low carbon farming practices, stores carbon, as reflected in FASOM and CCLUB. Accordingly, criticisms of the more recent versions of GTAP are at odds with the regulatory results in the 2010 RIA (which utilizes FASOM) and in CCLUB showing negative LUC emissions. Alternatively, the framework for assessing agricultural emissions in the U.S. GHG Inventory can be reassessed.

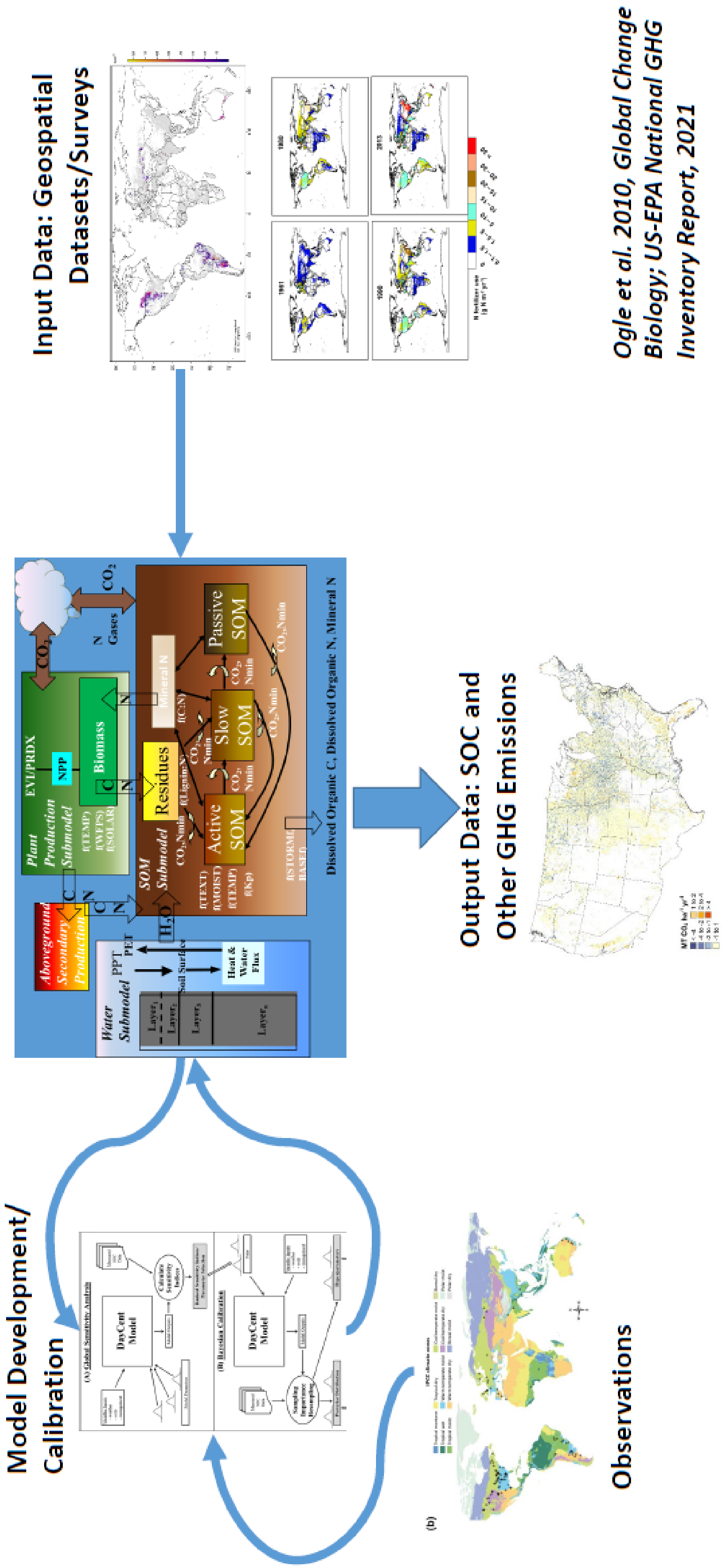

Figure 18. DayCent ecosystem modeling platform.
Source: Ogle, 2022.

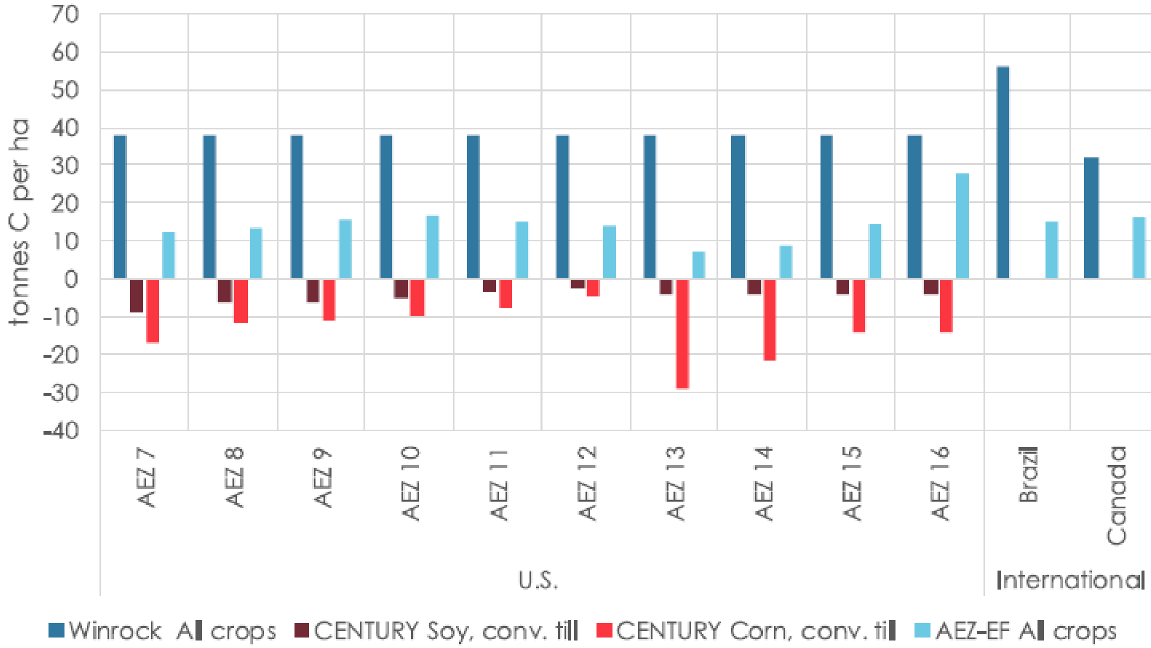

Figure 19. Carbon loss following cropland pasture conversion using Winrock, CENTURY and AEZ-EF emission factor models.
Source: Malins, et al., 2020

A significant outcome of the recently held EPA biofuels workshop (EPA, 2022) was consistent alignment between presentations on the potential for U.S. soil carbon accumulation and the U.S. State Department's strategy for GHG emissions reductions through climate-smart agricultural practices (**Figure 20**).

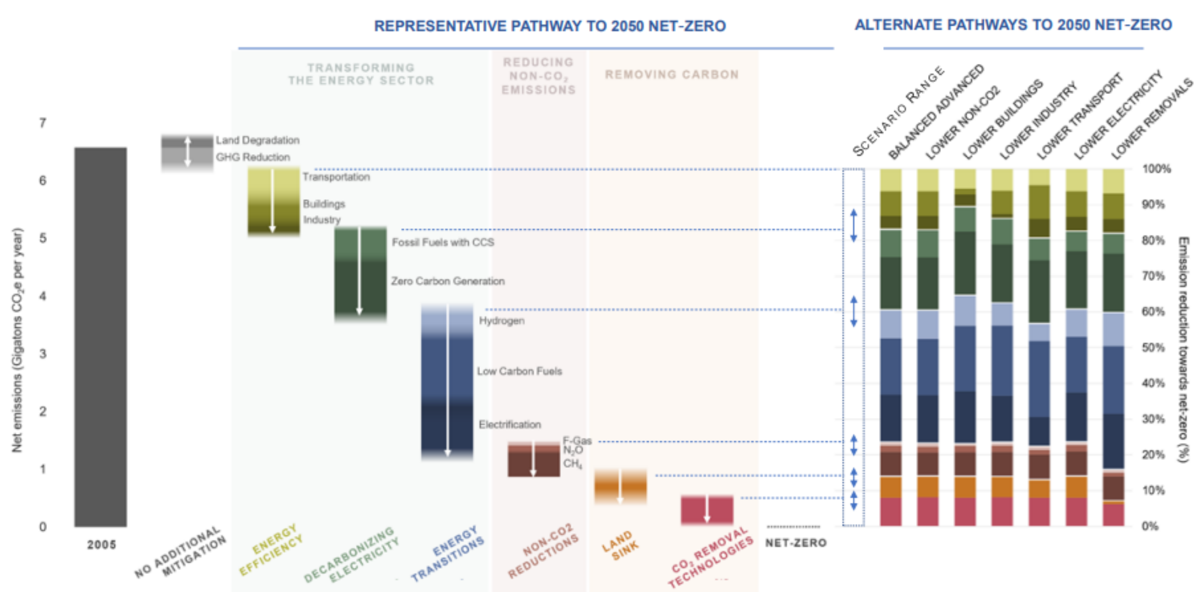

Figure 20. U.S. State Department includes emission reductions based on FASOM in projections to achieve 2050 Net-Zero in the United States.
Source: U.S. State Department, 2021.

Figure 21 illustrates the trends for tillage activity in the U.S., demonstrating the trend for adoption of reduced till and no till across multiple crops in the past decade plus.

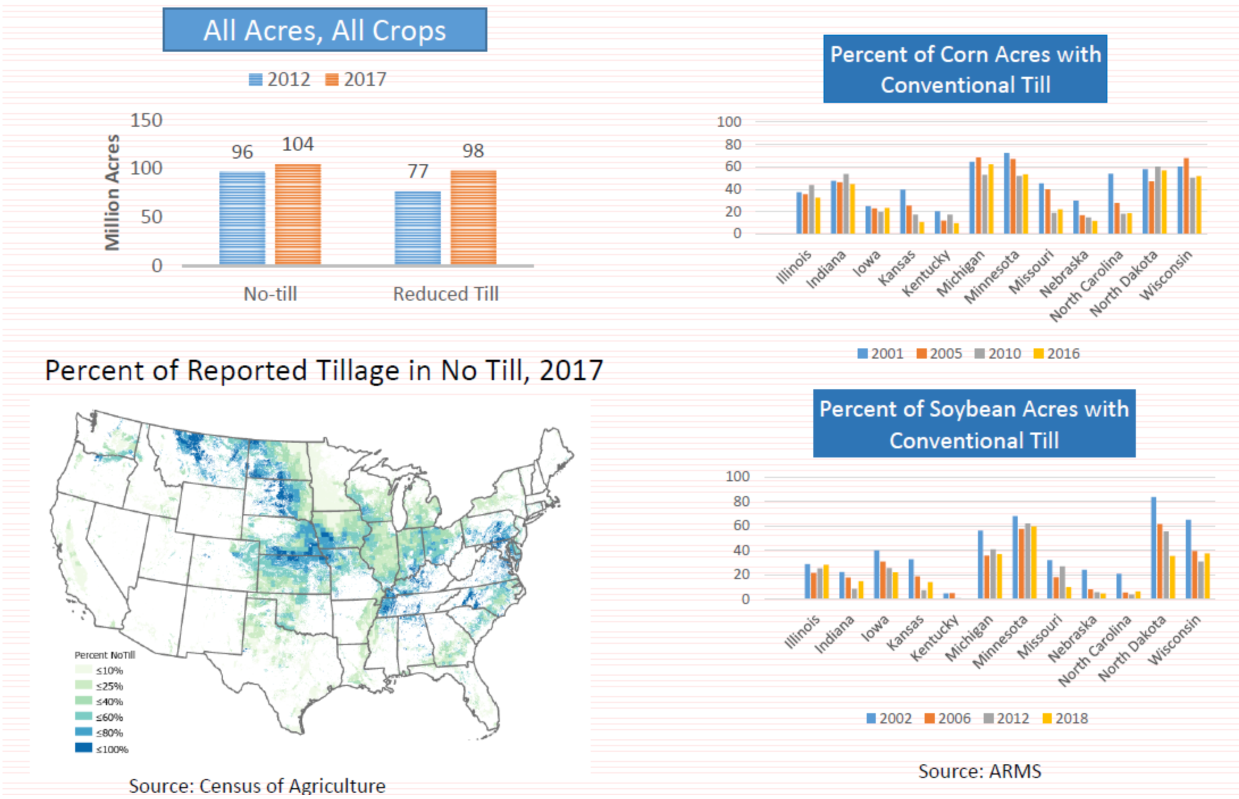

Figure 21. Trends in agriculture tillage.
Source: Hohenstein, 2022.

DayCent analysis is consistent with the CENTURY data used in the FASOM model that predicted a negative U.S. soil carbon change (carbon storage, see Figure 1.1). The relationship between this important prediction in the 2010 RIA and ongoing research was not covered in EPA's recent workshop. The relationship between EPA's FASOM modeling, the U.S. agriculture inventory, and all of the estimates used to determine GHG reductions associated with regenerative agriculture, however, are closely linked. EPA could perform a side-by-side comparison of soil carbon estimations among the modeling systems currently deployed for U.S. GHG accounting and compare those to the predictions in the 2010 RIA; however, this may be a challenging exercise. The latest Purdue analysis provides a revised estimate of iLUC as described in Section 2.2.

3. Model Inputs

This section discusses the inputs incorporated into models that are employed to estimate iLUC.

3.1 GTAP-BIO (CARB)

The input parameters to GTAP for modeling land use changes include:

- Baseline year
- Fuel production increase
- Land use change analysis: the change in biofuel production expected in response to policy.
- Crop yield elasticity: which defines how much a crop yield will increase in response to a price increase (as prices increase, farmers have more incentive to intensify production of their existing crops). A higher elasticity means a greater yield increase in response to a price increase.
- Elasticity of crop yields with respect to area expansion: yields on newly converted land will be lower than corresponding yields on existing crop land.
- Elasticity of harvested acreage response: the extent to which land cost changes affect changes of cropping patterns on existing agricultural lands.
- Elasticity of land transformation across cropland, pasture and forest land: the extent of which types of lands change.
- Trade elasticity of crops: express the likelihood of substitution among imports from all available exporters.

Recent studies, including Scully et al. (2021) recognize that LCAs that reflect the updates listed below, have improved the analysis of iLUC analysis based on the GTAP model. LCAs that incorporate such updates yield a central best estimate of carbon intensity for corn ethanol of 51.4 gCO_2e/MJ (range of 37.6 to 65.1 gCO_2e/MJ) which is 46% lower than the average carbon intensity for neat gasoline. The largest components of total carbon intensity are ethanol production (29.6 gCO_2e/MJ, 58% of total) and farming practices net of co-product credit (13.2 gCO_2e/MJ, 26%), while land use change is a minor contributor (3.9 gCO_2e/MJ, 7%).

(1) market-driven changes in corn production that lowered the intensity of fertilizer and fossil fuel use on farms;
(2) more efficient use of natural gas and recent electric generation mix data for energy consumed at ethanol refineries; and
(3) land use change analyses based on hybrid economic-biophysical models that account for land conversion, land productivity, and land intensification.

3.2 CCLUB

CCLUB inputs include farm management practices including tillage, and sources illustrated in **Figure 22**.

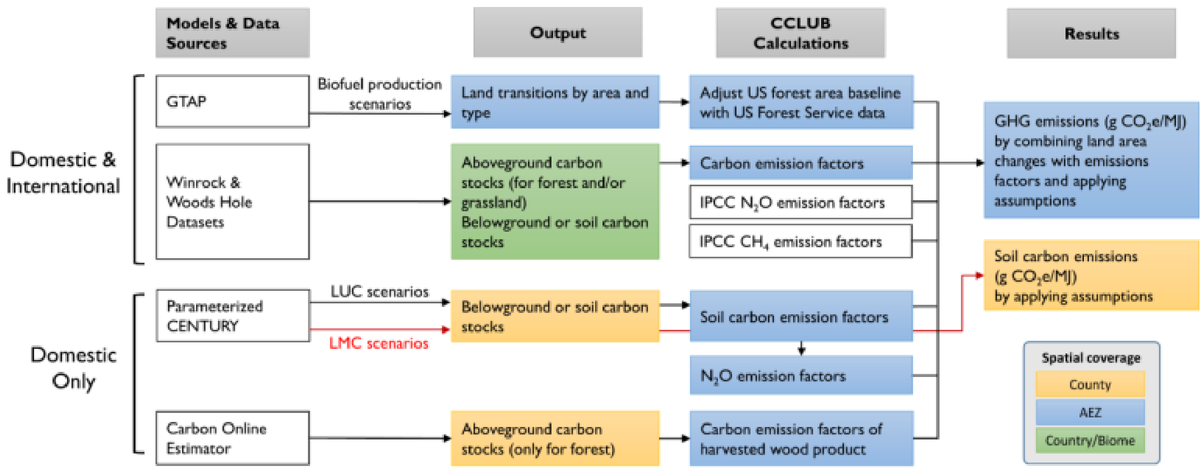

Figure 22. CCLUB model primary inputs and outputs.
Source: Kwon et al., 2020.

The CCLUB analysis of soil carbon storage for corn and sorghum growing regions provides insight into the potential for soil carbon storage. We ran CCLUB (ANL, 2021) for corn for the top-producing sorghum counties in three of the top producing sorghum states (Kansas, Texas, and Oklahoma) and corn states (Iowa and Illinois) that were identified from the USDA National Agricultural Statistics Service (NASS) Quick Stats Database for the years 2018-2020.

3.3 DayCent

Primary inputs to the DayCent model are illustrated in **Figure 23**.

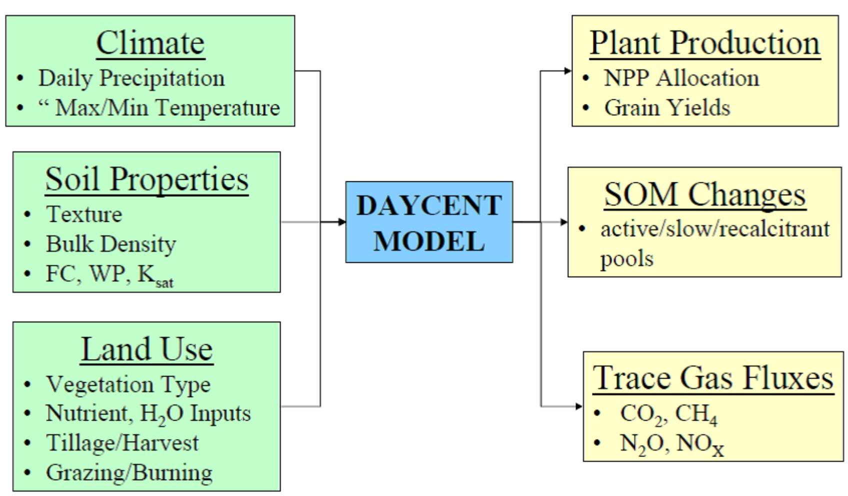

Figure 23. DayCent model primary inputs and outputs.
Source: Ojima in Zhang and Paustian.

4. Results

Running the CCLUB model to compare the GHG emissions associated with LUC and iLUC for farming in corn and sorghum growing regions provides insights in the potential iLUC implications of sorghum. The CCLUB model provides regionally specific estimates of the land use emissions associated with different grain growing regions in the US. The model provides an assessment of the direct soil carbon changes generally associated with a carbon storage component. Examining the net GHG emissions for different grain growing regions provides insight into the potential iLUC for sorghum. Note that the CCLUB model only produces the iLUC results for corn and not for sorghum, nonetheless, the changes in emissions provide an estimate of the effect associated with different crop-growing regions. ILUC values have been employed in several fuel policies. Notably, U.S. policies, such as the CA LCFS (CARB 2015), and EPA RFS (EPA, 2010) report iLUC values for corn and sorghum that are relatively similar (19.8 and 19.4; 26.3 and 28.0, g CO_2e/MJ fuel respectively). As discussed previously, CARB's initial iLUC values (CARB, 2009), which were based on the original GTAP model, were substantially higher than the EPA's and were subsequently reduced using updated versions of GTAP-BIO (CARB, 2015).

4.1 Baseline CCLUB Analysis

Results from running the most recent version (2013) of the CCLUB model for corn ethanol (Table 7) indicate that domestic GHG emissions are negative, and when added to the positive emissions associated with international estimated GHG emissions, result in a much lower iLUC value than currently employed in the LCFS.

Table 7. CCLUB Results for Corn Ethanol – GTAP 2013 Database

LUC Emissions	Forest	Grassland	Cropland-Pasture	Young Forest-Shrub	Sum
Carbon Emissions					
--Domestic Emissions	0.8	-0.1	-3.0	0.1	-2.3
--International Emissions	0.7	3.1	1.8	0.0	5.5
				Total	3.3
N_2O & CH_4 Emissions					
--Domestic Emissions	0.0	0.0	0.0	0.0	0.0
--International Emissions	0.2	0.1	0.2	0.0	0.4
				Total	0.5
Total GHG Emissions					
--Domestic Emissions	0.8	-0.1	-3.0	0.1	-2.3
--International Emissions	0.8	3.2	1.9	0.0	6.0
				Total	3.7

4.2 Effect of Crop Growing Region on Soil Carbon Storage

In order to compare the relative capacity of corn and sorghum to sequester carbon in soil, we ran the CCLUB model in ANL's FD-CIC calculator. The latest version of this calculator (2021) estimates soil organic carbon (SOC) sequestration potential based on corn and not sorghum cultivation. Therefore, to make this comparison, we identified the top producing states and counties for both corn and sorghum (NASS Quickstats, 2022), and ran the model in each of these counties for conventional till and no-till. A comparison of Figure 24 and Figure 25 illustrates that SOC sequestration potential is considerably greater in the top sorghum-growing states than in the top corn-growing states. This may be due to several factors, including sorghum's deeper root structure, and the potential for higher SOC sequestration rates observed in marginal lands (Minasny et al., 2017; Lamb et al., 2021; Bates et al., 2022). Such results lend support for fuel policies to favorably consider the potential for lower carbon-intensive LUC values associated with sorghum production compared to that of corn.

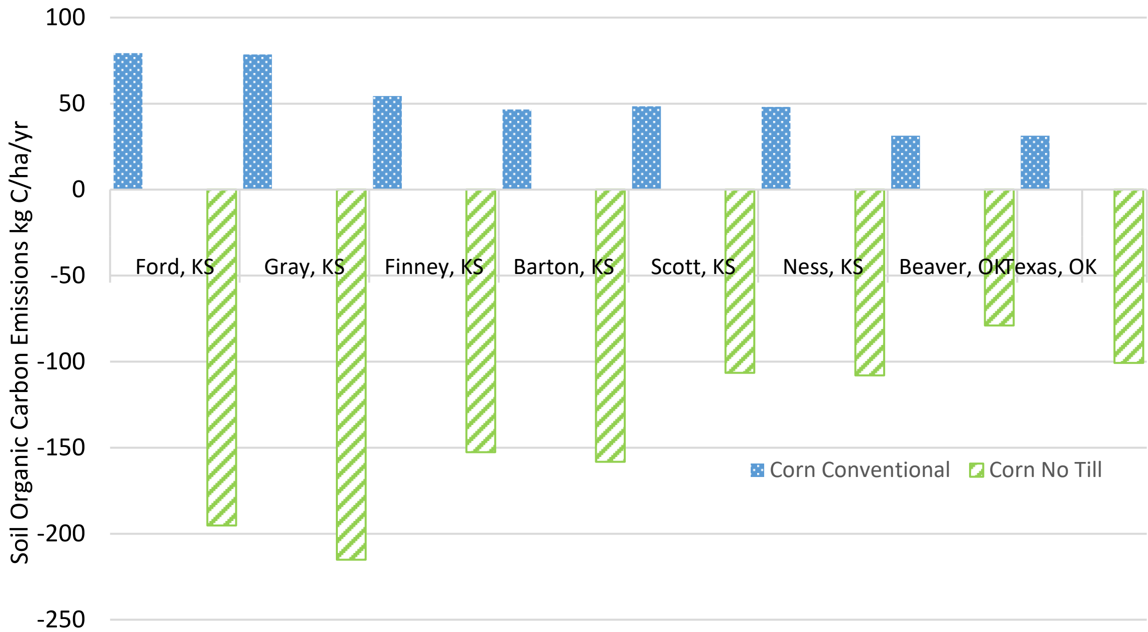

Figure 24. CCLUB results for corn grown conventionally and with no-till in high sorghum-producing states.

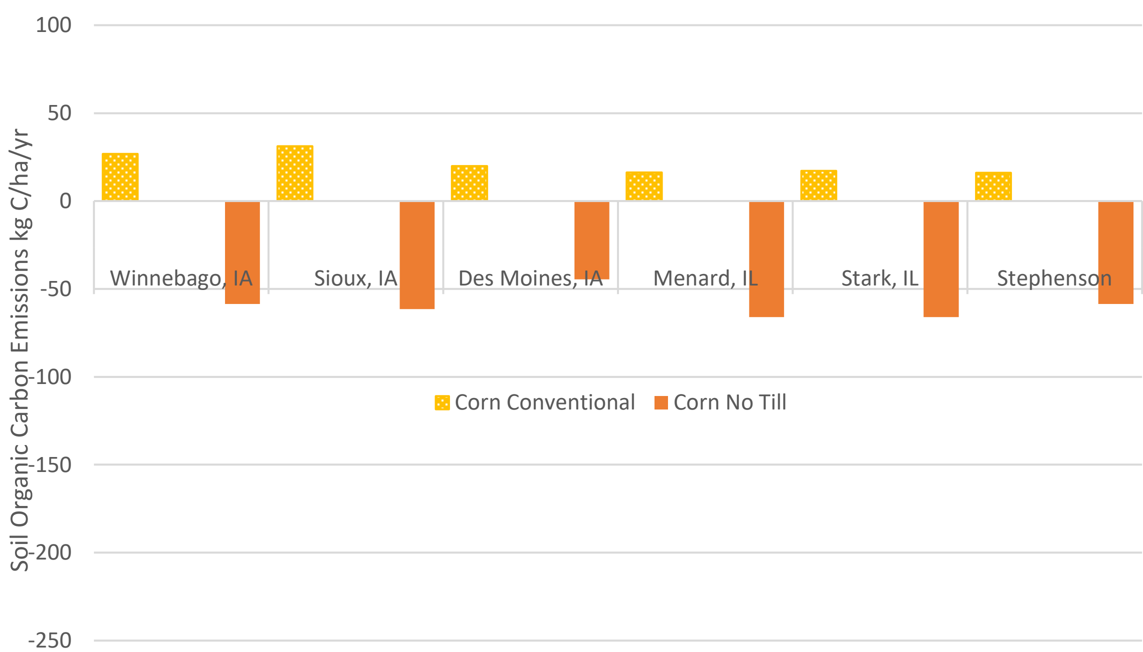

Figure 25. CCLUB results for corn grown conventionally and with no-till in high corn-producing states.

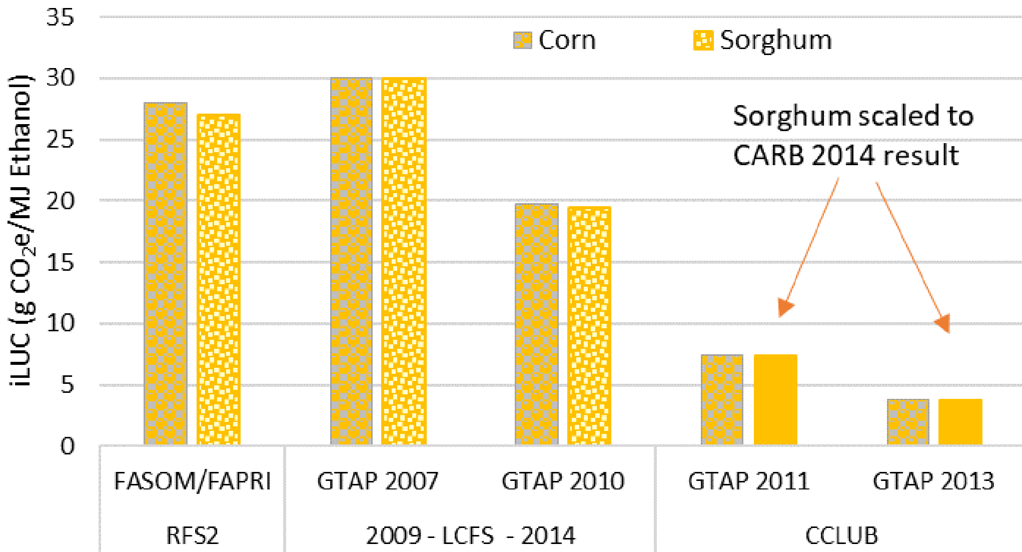

Figure 26. Comparison of iLUC calculations from the EPA RFS2, the CA LCFS, and CCLUB.

Figure 26 compares the prior iLUC results from EPA and CARB to the newer results from ANL's CCLUB model. These results have been frequently published and show that the newer estimates predict a lower iLUC then previously presented. Also shown on the chart are the sorghum results scaled to the same ratio of sorghum to corn in the 2014 LCFS results. ANL plans[5] to further develop the FD-CIC model to cover LUC estimates for other crops, including sorghum, which could provide additional insights.

4.3 iLUC Assessment: Influential Factors

Variability among the LUC estimates can be attributed primarily to differences in four main components: the agro-economic model, economic data year, and land intensification, and yield price elasticity (YPE) (also referred to as YDEL) (Scully et al., 2021). Economic data year refers to the baseline point in time used in agro-economic models for estimating corn ethanol LUC and is significant because it establishes the year in which the agro-economic model is 'shocked' with an expansion of a specified volume of corn ethanol. Land intensification is the practice of using existing cropland more efficiently and is defined as activities undertaken with the intention of enhancing the productivity or profitability per unit area of land. YPE refers to percent change in crop yield change per unit of land.

Of these identified model components, the YPE parameter has received the most feedback from stakeholders, particularly those from biofuel industries. This is because this parameter has special significance in the GTAP-BIO analysis: it has the largest influence on outputs from the model. YPE is a parameter in the GTAP-BIO model which determines how much crop yield will increase in response to a price increase for the crop. It measures sensitivity of yield with respect to a crop price change assuming all other things constant. For example, if price yield elasticity is 0.25, a 10 percent

[5] H. Kwon, personal communication, April 28, 2022.

increase in the price of the crop relative to input cost will result in a 2.5 percentage increase in crop yield.

CARB (2014 – *Attachment 1*) summarized the review of YPE used in the GTAP-BIO model as follows:

“The assignment of a value for YPE for use in the GTAP-BIO model poses important challenges:

- Large majority of data for price and yields are for corn grown in the United States. There are no data for corn production outside the United States. Furthermore, most of the analysis has been for data from the Mid-Western region of the United States.
- Researchers use different econometric methods to derive relationship between yield and price. They sometimes report contrasting values even when using the same data.
- Most of the data used in published studies used data for crop yields and prices for periods that do not represent the current timeframe for biofuel production for the LCFS (2004-2012).
- Besides corn, GTAP-BIO includes paddy rice, wheat, canola, soybeans, palm, sorghum, etc. As currently used, any input value of YPE is used for all crops and regions in the model. Using YPE derived from corn for all crops (and regions) may bias the results one way or the other. The most optimal approach is to use crop and region specific YPEs derived from appropriate econometric treatment of data. However, there are currently no data available to estimate YPE by crop and by region. Hence it is not possible to use regional and crop-specific YPE in the GTAP-BIO model at the present time.
- The model uses the same value of YPE for irrigated vs. rain-fed crops. It is likely that there are different responses to price changes between these two types of agricultural practices in different regions of the world.
- There is limited data for double-cropping for crops for all regions of the world. As suggested by stakeholders, double-cropping can be accounted by using a higher input value of YPE. However, in the current version of the GTAP-BIO model, net increase in crop yields includes effects related to price changes, crop switching, and extensification. Any change in the value of YPE must be calibrated to ensure that only double cropping effects are accounted by any increases in the value of YPE.

Taking all these into consideration and with a wide range of likely values for YPE from published literature, staff used a range of values between 0.05 and 0.35 to conduct scenario runs for all biofuels studied for the LCFS. These input values are used for all crops and regions for the 30 scenario runs conducted for each of the 6 biofuels.”

Taheripour et al (2017) reviewed crop yield data from 19 global regions and recommended a YPE range of 0.175–0.325. Scully et al (2021) examined YPE for corn reported in 20 studies published from 1976 to 2017. They calculated a simple average of 0.23, and determined a YDEL central best estimate of 0.25 and a credible range of 0.175–0.325. Eighteen of the analyses that they reviewed had YPE values within that range.

Since sorghum, as a biofuel feedstock, is a substitute for corn, the use of the corn-based YPE is reasonable. However, the prevalent practice of farming rain-fed sorghum as an alternative to irrigated corn, where the latter isn't considered to be profitable, and the potential for planting sorghum as a double crop, present key differences that support a case for a lower YPE value for sorghum, which could reduce the associated iLUC values estimated in GTAP-BIO. Such scenarios support the argument that the sorghum iLUC value should not exceed that of corn, and arguably could be lower than corn.

5. Discussion

Sorghum is a water-smart, climate resilient crop. Ninety-four percent of U.S. sorghum acres cultivated in the past three years are rain-fed, and the 6% of sorghum acres that are irrigated are done so efficiently given sorghum's water-sipping attributes (SMRP, 2022). Sorghum reduces greenhouse gas emissions and sequesters carbon. Sorghum translocates carbon deeper into soils with its dense and robust root structure. Through breeding innovations, sorghum farmers have successfully adopted no-till or minimum-till practices on 97% of sorghum acres (SMRP, 2022) – meaning carbon is sequestered for longer and deeper than in most cropping systems. Sorghum stalks left in the fields as crop residues contribute to soil health in multiple ways, including by providing organic matter for integration into the soil, enhancing soil structure by reducing compaction and, and by reducing effects of wind erosion and evaporation, thereby retaining soil moisture.

Since CARB last published their iLUC evaluation results, several researchers have studied relationships that improve our understanding of the linkages between, and impacts related to changes in corn ethanol markets and iLUC values, and come to varied conclusions. The following describe several recent studies.

The Coordinating Research Council funded a critical review of CARB's 2015 iLUC methodology (Sierra Research, 2016), and concluded that several of CARB's decisions pertaining to methods for establishing GTAP-BIO parameters and associated ranges led to higher iLUC values and GHG emissions. Lewandrowski et al. (2020) found that iLUC emissions for corn ethanol trend downwards over time and are significantly lower (by 33 – 60%) than the values adopted in the 2010 RFS.

Gautam et al. (2020) ran the DayCent model and found that in rainfed lower midwestern and southern states, sorghum production systems, productivity and carbon sequestration were considerable, indicating support for these bioenergy production systems as land use-based climate mitigation strategies (Figure 27). They concluded that 10.2 million ha of cultivated rainfed land in these same regions demonstrated high productivity with net C sequestration (>10 Mg/ha). The data associated with this study provide spatially explicit support for the analysis of sorghum iLUC.

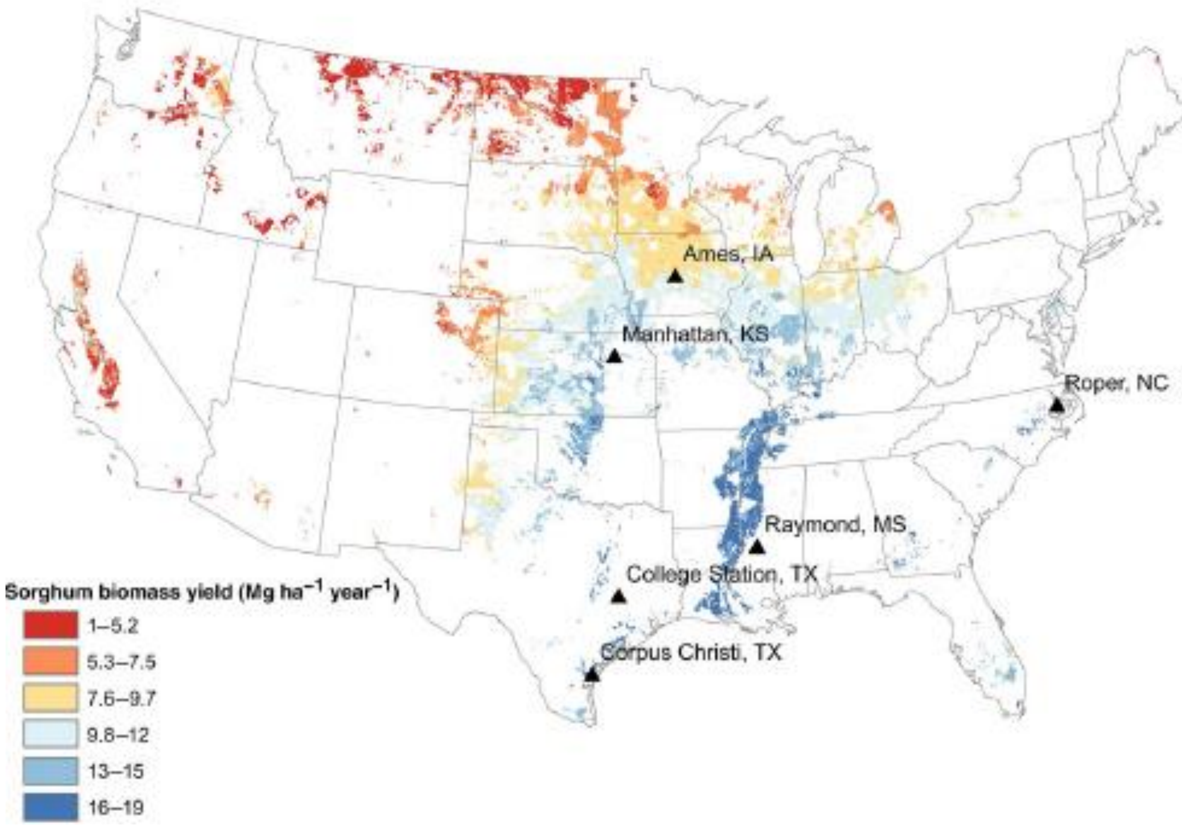

Figure 27. Rainfed biomass yield of sorghum based on the DayCent model.
Source: Gautam et al., 2020.

Malins et al. (2020) concluded that the large reductions in iLUC emissions from CARB's 2015 updated GTAP-BIO modeling reflect subjective modeling decisions based on limited data and analysis that lacks the power to demonstrate causal relationships. Had modelers chosen different subjective parameters or chosen to develop different areas of the model, iLUC estimates may well have risen compared to earlier published values. Key points pertained to:

- Intensive Yield Change
- Cropping Intensity Responses
- Cropland-Pasture Role
- Model Emission Factors
- Extensive Yield Responses

Scully et al. (2021) contend that it is important to consider the time-component involved in GHG emissions accounting, and that LUC is a dynamic property which begins as a large source of emissions, and over time transitions to a net carbon sink, meaning that the initial carbon debt is repaid over time. They point out that the original analyses based upon a 'debt-dividend' framework suggested a payback period for corn ethanol of 48–167 years based upon a relatively small biofuel dividend. As previously discussed, their modeling indicates lower emissions values, based on an increased dividend result. They posit that the timescale for ethanol production is shorter than modeled in previous iLUC calculations, and recommend that analyses should be updated based on recent data on the carbon content of Midwest prairie lands and the net CI of corn ethanol farming and production relative to gasoline refined from petroleum.

6. Conclusions

Because sorghum and corn interact in the same food and biofuel markets, and exhibit similar price responses to market demand, they are effective substitutes for each other, and assessment of their iLUC values should be similar. Sorghum is primarily sold as animal feed, and secondarily as feedstock for ethanol. In contrast to corn, sorghum is more drought tolerant, and capable of growing on less fertile, marginal lands. As a result, sorghum yields are typically lower than those for corn. Such differences support a case for a lower YPE value for sorghum, which would effectively reduce the associated iLUC values estimated in models such as GTAP-BIO, which is used in the CA LCFS. In addition, because the majority of sorghum is cultivated using no-till or minimum-till, and common harvest practice is to leave substantial crop residue on the fields, current sorghum farming practices greatly contribute to soil carbon sequestration, and reduction of GHGs.

In addition to the market similarities and the farming practice benefits that sorghum provides, as summarized above, regardless of the year and model used, the iLUC of sorghum-based ethanol is shown to be comparable or slightly lower than that of corn-based ethanol (**Figure 4**). The most recent iLUC value modeled for corn from CCLUB is 3.9 g CO_2e/MJ (Scully et al., 2021). Other ongoing research[6] may soon provide updated iLUC values specific to sorghum. However, absent such data, given the strong similarities between corn and sorghum, and the close relationship between respective iLUC values, it is clear that a conservative approach to updating the iLUC for sorghum in any biofuel program, is to set it no higher than that for corn. In the case of the most recent CCLUB results, that would mean establishing a sorghum iLUC no greater than 3.9 g CO_2e /MJ.

[6] H. Kwon, personal communication, April 28, 2022.

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Agricultural Market Research

The Carbon Footprint of Sorghum

for

SORGHUM CHECKOFF

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Executive Summary

In California and across the United States, consumers are demanding agricultural products with lower carbon footprints from their supermarket chains, animal feed manufacturers and ethanol producers. This demand has sparked a growing number of protocols and methodologies that attempt to measure, report and verify the carbon intensity of agricultural products around the globe with varying levels of success.

This report develops a gap analysis of existing carbon intensity methodologies for agricultural products, identifies a methodology for calculating the carbon footprint of sorghum using best practices from the methodologies reviewed (including methodologies used for certification in European and other markets) then conducts the largest ever comprehensive survey of over 300 sorghum farms in 9 states representing over 80 percent of the industry to calculate the carbon intensity for sorghum. This study was completed by SGS in collaboration with a third party, Strategic Marketing Research & Planning, for the recruitment of farmers and for the survey.

The goal of this study was to obtain real data on the carbon footprint of sorghum (as raw material) from cradle to farm gate to the next user in the supply chain (e.g., elevator, ethanol plant, etc.) and to be able to compare these data with other crops like corn. The sample size for this study was designed to be large enough to examine information across regions/districts in 9 states that account for 80 percent of planted sorghum acres. To determine carbon usage a sample of over 300 sorghum growers were surveyed that created a margin of error of +/-5.6 percent at a 95 percent level of confidence.

All GHG emissions (mostly CO2 and N2O) were included for sorghum with enough data gathered to represent the entire U.S sorghum industry. The system boundary for the study was sorghum farmers primarily producing sorghum for ethanol. Because sorghum tolerates dry climates it is mostly grown in the southwestern and central portions of the U.S. The values and representative sample therefore comes from mostly southwestern and central plains farmers. A four-year Olympic average yield was used.

The study found that the total carbon footprint for sorghum is 0.25 kg CO2e per kg of sorghum or 6.4 kg CO2e per bushel of sorghum. This value is calculated based on the average reported inputs per farm. The footprint value is an average value but ranges are wide. With a standard deviation of 0.1 kg CO2e per kg of sorghum for all farmers that filled out the total questionnaire and a range from 0.05 kg CO2e up to 0.74 kg CO2e per kg of sorghum, we can observe differing practices across the sample of farmers. The ranges mostly depend on differences in fertilizer application and the other energy inputs.

The findings in this report are the most comprehensive farm data collected to date for sorghum not dependent on third party estimates of sorghum use.

1 Introduction

Within the last ten years, measuring the carbon footprint of any activity, industrial or agricultural, has become a core activity within the broader environmental and sustainability movement.
In the U.S., there is an increasing demand from supermarket chains, animal feed manufacturers and ethanol producers to provide verifiable and accurate data on the carbon footprint of agricultural products.

This has presented some problems for agricultural producers and the entire agricultural supply chain because:

- There is no unified standard of measurement and verification. Although there are some nascent schemes, they have developed in a disjointed way.

- Much of the data is based on third party information (such as government estimates of energy usage on different crops) rather than true verification which by nature must take place at the farm level.

- Some data does not take into account the specific attributes of a species but bundles data together. This is potentially particularly damaging to sorghum producers especially where cereal and corn data is substituted for unknown sorghum data.

- There is currently no definitive global standard for the measurement of the carbon footprint in agricultural crops. The International Organization for Standardization (ISO) is attempting to address this issue under ISO 14067, but this work has yet to be published. Even then, there are several competing protocols.

The solution to these issues is to create a gap analysis for sorghum which will demonstrate a carbon footprint measurement methodology that fits within the current main protocols (both in the U.S. and overseas). It includes devising a method of measurement that collects data and simulates activity on actual sorghum producers' farms. This was achieved by collaboration between two groups within SGS: the Climate Change Group (for the model development) and the Agricultural Market Research Group (for the statistical validation of the model) which also collaborated with a third party, Strategic Marketing Research & Planning for the recruitment of farmers and the online survey.

2 Goal, Scope and Methods

2.1 Goal and Scope

The goal of this study was to get real data on the carbon footprint of sorghum (as raw material) from cradle to farm gate to the next user in the supply chain (e.g., elevator, ethanol plant, etc.). These data can then be used to compare with other crops like corn. It will also offer information on the hot spots of greenhouse gas (GHG) emissions.

The functional unit was kg CO_2 (equivalent) per bushel of sorghum and kg CO_2 (equivalent) per kg of sorghum. All GHG emissions, mostly CO_2 and N_2O, were included.

Enough data was gathered to get a representative U.S sector value. The system boundary was sorghum farmers primarily producing for ethanol. Because sorghum tolerates dry climates it is mostly grown in the southwestern and central portions of the U.S. The values and representative sample therefore comes from mostly southwestern and central plains farmers.

A four-year Olympic average yield was used.

2.2 Methodology

A model was developed based on in-depth farm analysis and a desk study of existing schemes for gap analysis. Data were gathered within a representative group of sorghum farmers through the U.S. These data were used to populate the model, which gave an average GHG sector value for the carbon footprint. With data from a statistically significant sample size of over 300 farmers representing areas that in total account for over 80 percent of U.S. sorghum production we were also able to observe ranges.

3 In-depth Farm-level Analysis

A preliminary questionnaire was developed based on the expertise of the SGS team and tested against the most common standards as well as our knowledge. This questionnaire was used to carry out an in-depth farm-level analysis.

There were two major aims for the in-depth farm-level analysis:

1. To make sure that all input and waste streams were found to ensure nothing was missed in the footprint.
2. To test the draft questionnaire to make sure all farmers were able to fill in the data as completely and as accurately as possible. Farmers needed to be able to find the data within a reasonable period of time.

For this we visited five farmers across Texas, Oklahoma and Kansas. These farmers had a variety of farming methods (e.g., irrigated, non-irrigated, aerial spraying of herbicides, etc.) on different parts of each farm. These farmers gave us significant insight into the preliminary questionnaire and allowed us to revise and refine it to ensure the final questionnaire allowed us to capture the entire picture of U.S. sorghum production.

Each interview took on average 2.5 hours. The farmers received the draft questionnaire in advance. Some of them had taken the time to fill it out completely. Others had read it before our visit or read it during our visit.

During each visit we discussed the questionnaire, asked whether inputs were missed, asked whether the questions were clear and tested the conclusion we got from the visits. We found out solutions for one farmer were not necessarily consistent with another, but in the end we found overall consensus.

The main issues found and addressed in subsequent versions of the questionnaire were:

- Made sure all field operations performed from the end of harvesting of the previous crop were included, since they were all relevant to one crop year.
- Because of the planning of the questionnaire and the influence of seasons we decided to work with four-year average production. We found annual production per acre varied significantly. The crop inputs, however, did not change much from year to year and were influenced very little by weather.
- Seeds and seed coating, although a small GHG input, had to be taken into account.
- Since sorghum is never the only crop grown on a farm, it is hard or impossible for farmers to allocate their diesel use relating specifically to the sorghum crop. It was easier to work with the field operations (e.g., plowing, spraying, etc.) and calculate an average diesel

usage to find the total diesel use per acre of sorghum. Finally a question was asked relating to any other energy usage.

- Similarly, it was hard to allocate the energy use for the irrigated sorghum acres. After consulting with industry we decided to ask the average inches applied combined with the average well depth to calculate the fuel or energy use based on the given data.
- Farmers were able to calculate the actual nitrogen/phosphorus/potassium in fertilizers. For herbicides/insecticides/fungicides we decided to ask for the commercial product name and do the calculations based on active ingredients on the given data.
- There was no opportunity to give a ‘do not know’ answer on fertilizers and field operations since these would likely be associated with the highest emissions.
- We created a list of checks to make the questionnaire easier to use (e.g., minimum and maximum values, control calculations, drop down menus, etc.).
- There were some very small inputs like seed coating, use of propane in bird-scaring cannons and small elements that would have no material influence on the data but should officially be taken into account.

4 Desk Study of Existing Schemes for Gap Analysis

A gap analyses was undertaken of existing schemes to set up a standard of measurement, reporting and possible verification.

Therefore the following standards were studied:

- ADEME (Agence de l'Environnement et de la Maîtrise de l'Energie) 2009, Study for a simplified life cycle assessment (LCA) methodology adapted to bioproducts.
- PAS 2050:2011 Specification for the assessment of the life cycle greenhouse gas emissions of goods and services. British Standards Institution (BSI).
- PAS2050-1:2012 Assessment of life cycle GHG emissions from horticultural products. Supplementary requirements for the cradle to gate stages of GHG assessments of horticultural products undertaken in accordance with PAS 2050. British Standards Institution (BSI).
- ISCC 2011. ISCC 205 GHG Emissions Calculation Methodology and GHG Audit. International Sustainability & Carbon Certification (ISCC).
- RSB 2011. RSB GHG Calculation Methodology. (Version 2.0) Roundtable on Sustainable Biomaterials (RSB).
- Product Life Cycle Accounting and Reporting Standard. World Resources Institute and World Business Council for Sustainable Development 2011, Greenhouse Gas Protocol.
- Draft International Standard ISO/DIS 14067.2 (2012), Carbon Footprint of products – requirements and guidelines for quantification and communication.

In this report, all standards above and their purpose will be introduced. This introduction is made based on the date of publication and also demonstrates the development and relevance of the different standards and guidelines. Then, an overview of general consensus for reporting carbon footprints of products will be given. Lastly, a list of differences or issues will be discussed and the choices we made for this footprint.

4.1 Introduction of the Standards

4.1.1 ADEME 2009, Study for a Simplified LCA Methodology Adapted to Bioproducts

This study was done by the French Environment and Energy Management Agency and was designed to have the following purposes:

- Developing, if possible, a simplified and uniform method for assessing the environmental impacts of bioproducts.

- Consolidating this method by means of actual tests
- Proposing adaption(s) to an ADEME Product tool in line with this method.

The analysis lead to recommendations on the scope of the study, the functional unit, the sources of data and level of detail in input of data, allocation of emissions to coproducts, timescale and carbon sequestration, N_2O emissions and land use change. All these outcomes will be discussed in parts 4.2 and 4.3, including consensus and differences.

4.1.2 PAS 2050: 2011 and PAS2050-1:2012

The PAS 2050:2011 Specification for the assessment of the life cycle greenhouse gas emissions of goods and services is the second version (first developed in 2008) that was developed by the British Standard Institution in response to broad community and industry desire for a consistent method for assessing the life cycle GHG emissions of goods and services. PAS 2050 offers organizations a method to deliver improved understanding of the GHG emissions arising from their supply chains, but the primary objective of this PAS is to provide a common basis for GHG emission quantification that will inform and enable meaningful GHG emission reduction programs.

The PAS 2050 is the first standard that was recognized and is used in reporting and verifying product carbon footprints in the world, but mostly in the United Kingdom.

PAS2050-1:2012 Assessment of life cycle greenhouse gas emissions from horticultural products. Supplementary requirements for the the cradle to gate stages of GHG assessments of horticultural products undertaken in accordance with PAS 2050.

This standard was developed to provide supplementary requirements that when used in conjunction with PAS 2050, has the aim to enhance the effectiveness of the assessment of GHG emissions from any horticultural product. The standard was cosponsored by the Dutch Product Board for Horticulture and the Dutch Ministry of Economic Affairs, Agriculture and Innovations. In this standard the focus is on horticultural products in which open field cropping is included and therefore very relevant for our study. This standard makes provisional lists of all the life cycle inputs for the cradle to gate footprint for horticultural products and also provides a list of inputs that should be excluded.

4.1.3 ISCC 205 GHG Emissions Calculation Methodology and GHG Audit

In 2009, the European Union agreed on the Renewable Energy Directive (2009/28/EC) which sets sustainability requirements for all biofuels being traded on the European Market. One of the requirements is a minimum GHG emissions saving of 35 percent (rising to 50 percent in January 2017, and 60 percent in January 2018). The Directive contains a methodology for calculating this saving. The Directive requires certification of these sustainability requirements by approved schemes. One of the first of the approved schemes and the most recognized is the International Sustainability and Carbon Certification (ISCC). The ISCC 205 GHG Emissions Calculation

Methodology and GHG Audit are applying the GHG Calculation Methodology as prescribed in the directive for biomass producers, conversion units, and transport and distribution. The calculations for biomass producers can be perfectly adapted for use for the growing of sorghum. Furthermore, it also gives a prescriptive list of emission factors mostly based on Ecoinvent or the European Biograce Project.

4.1.4 The Roundtable on Sustainable Biomaterials (RSB) GHG Methodology

This standard is intended to define the GHG calculation methodology to be used by participating operators in the RSB certification scheme when calculating GHG emission for the scope of its operations. The Roundtable on Sustainable Biomaterials (RSB) is an international initiative coordinated by the Energy Center at EPFL in Lausanne, Switzerland, that brings together farmers, companies, nongovernmental organizations, experts, governments and intergovernmental agencies concerned with ensuring the sustainability of biofuel production and processing. Participation in the RSB is open to any organization working in a field relevant to biofuel sustainability. The RSB has developed a third-party certification system for biofuel sustainability standards, encompassing environmental, social and economic principles and criteria through an open, transparent and multi-stakeholder process. RSB certificates are also recognized by the European Union under the Renewable Energy Directive (2009/28/EC), although there are some differences. The system boundary is from cradle (biofuel feedstock production) up to, but not including, use of the fuel in an engine. Farm equipment is included (they are excluded in other schemes). The methodology also gives a large set of emission factors mostly based on Ecoinvent data. In Chapter 2 the calculation for agriculture is prescribed.

4.1.5 Product Life Cycle Accounting and Reporting Standard

The primary goal of this standard is to provide a general framework for companies to make informed choices to reduce GHG emissions from the products (goods or services) they design, manufacture, sell, purchase or use. In the context of this standard, public reporting refers to product GHG-related information reported publicly in accordance with the requirements specified in the standard. The standard has no special focus on agricultural products.

4.1.6 Draft International Standard ISO/DIS 14067.2 (2012), Carbon Footprint of Products

This draft carbon footprint (CFP) ISO standard with requirements and guidelines for quantification and communication is still in a comment and approval phase and has been developed and discussed for years. The draft standard specifies principles, requirements and guidelines for the quantification and communication of the carbon footprint or a carbon footprint of a product or, based on International Standards, on life cycle assessment (ISO 14040 and ISO 14044) and on environmental labels and declarations (ISO 14020, ISO 14024, and ISO 140125). It has no special focus on agricultural products.

4.2 Overlapping Consensus and Gap Analysis Issues

4.2.1 Accounting and Reporting Principles

The PAS 2050 standards, the ISO 14067 and the Product Life Cycle Accounting and Reporting Standard all list the following reporting principles:

- Relevance: Select data and methods appropriate to the assessment of the GHG emissions and removals arising from the product system being studied.
- Accuracy: Ensure that carbon footprint quantification and communication are accurate, verifiable, relevant and not misleading and bias and uncertainties are reduced as far as is practical.
- Completeness: Include all GHG emissions and removals that provide a significant contribution to the carbon footprint of the product system being studied.
- Consistency: Apply assumptions, methods and data in the same way throughout the carbon footprint study to arrive at conclusions in accordance with the goal and scope definition.
- Transparency: Address and document all relevant issues in an open, comprehensive and understandable presentation of information.

The draft ISO 14067 adds an extra list of principles of which some also come back in the texts of all the other standards. The principles of life cycle perspective, relative approach and functional unit will be discussed in the next paragraphs (boundaries). The principles' iterative approach and scientific approach describe the process of doing the assessment. The last principles the draft ISO 14067 describes are:

- Coherence: Select methodologies, standards and guidance documents already recognized and adopted for product categories to enhance comparability between CFPs within any specific product category.
- Avoidance of double counting: Avoid double counting of GHG emissions and removals within the studied product system and avoid the allocation of GHG emissions and removals that have already been taken into account within other product systems.
- Participation: Apply an open, participatory process with interested parties when developing and implementing CFP communication programs and undertake reasonable efforts to achieve a consensus throughout the process.
- Fairness: Make clear the CFP communication is based on a CFP study which assesses the single impact category of climate change and does not imply overall environmental superiority nor examine broader environmental implications. Avoid misconception by not confusing quantified GHG emissions with reductions in GHG emissions.

The ADEME methodology, ISCC 205 and RSB GHG methodology are more practical and do not name the principles as such. However, there are no discrepancies.

Conclusion for this Study

All above principles are relevant for our sorghum carbon footprint assessment.

4.2.2 Boundaries

4.2.2.1 Cradle to Gate Carbon Footprint

The establishment of the system boundary is in all standards and is of highest importance. To develop a carbon footprint, the start is life cycle assessment in which all stages are covered. Although the names of the stages differ slightly in the different standards, in general the full LCA 'cradle to grave' are the following:

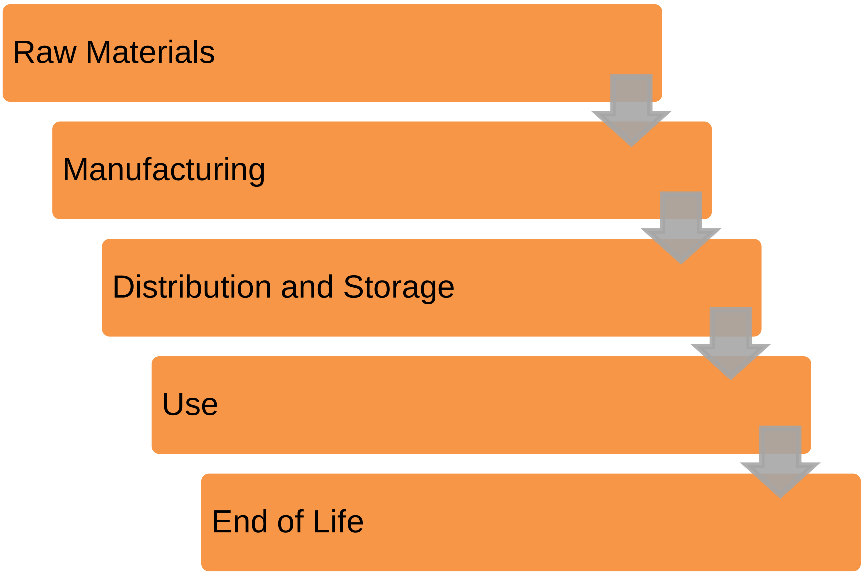


Figure 1. The stages of an LCA.

All standards offer the possibility to construct a carbon footprint model which can be named 'cradle to gate' and includes the emissions and removals identified that have occurred up to and including the point where the product leaves the organization undertaking the assessment for transfer to another party that is not the consumer (PAS 2050:2011) and excluding final product use and end-of-life (Product Life Cycle Accounting and Reporting Standard). The draft ISO 14067 does not differ.

As the more specific standards PAS 2050-1:2012, the ADEME methodology, ISCC 205 and RSB GHG methodology are designed for specific products (horticultural products or biofuels), and they more effectively describe what this means for the study of sorghum. So is PAS 2050-1:2012, which only describes a cradle to gate standard just for a horticultural product when it leaves the organization.

The ISCC 205 speaks about three kinds of processes in the chain:

- Biomass producers (the focus of this study)
- Conversion units (conversion of the solid biomass into liquid biomass or processing of liquid biomass)
- Transport and distribution

For the RSB GHG methodology the system boundary is similar, from cradle (biofuel feedstock production) up to but not including use of the fuel in an engine. Separate chapters are made for:

- Agriculture (the focus of this study)
- Fuel production and fuel refining
- Transport and storage

The ADEME methodology describes the full bioproduct life cycle but focuses on the following processes, which they term ‘cradle to factory gate:’

- Extraction and treatment of non-renewable resources
- Agricultural production and pretreatment of biomass
- Production of bioproduct
- Coproduct and waste management

Conclusion for this Study

A carbon footprint for the farming stage which includes all emissions and removals up to the next organization in the chain (elevator, ethanol plant, etc.) was made.

4.2.2.2 Inputs that are Included

With the defined boundary for the footprint of sorghum, one can start to select all inputs of the process that are relevant to the farming stages and on up to the next organization in the chain. The in-depth farm-level analysis gave a good overview of all inputs but the question of what was to be done with capital goods (farm equipment, on-site warehouses and roads, etc.) or minor inputs remained.

The Product Life Cycle Accounting and Reporting Standard, the draft ISO 14067 and the PAS 2050:2011 prescribe in the first instance to check when relevant Product Category Rules (PCR) exist and adopt them. This was not the case for this project. Furthermore, PAS 2050:2011 prescribes where supplementary requirements are available and are in accordance, those requirements should be used to support the application of PAS 2050 to the product sectors or categories for which they were developed.

The PAS 2050-1:2012 gives an extended list of life cycle processes that shall be taken into consideration. Also the ISCC 205, the RSB GHG methodology and the ADEME methodology prescribe the inputs of the LCA. Below is a list of all inputs that are included (or excluded) for biomass or horticultural products. Only inputs that ‘exist’ for sorghum were taken into account (e.g. greenhouse construction is not reported as sorghum is a field crop).

What to do with Small and *de Minimis* Sources?

- Draft ISO 14067: Quantification shall include all GHG emissions and removals that have the potential to make a significant contribution. No exact threshold is given.
- Product Life Cycle Accounting and Reporting Standard: An insignificance threshold can be used but needs to be defined.
- PAS 2050: Emissions or sources lower than one percent are seen as non-material and do not need to be included (i.e., propane cannons).
- ADEME: maximum cut-off threshold of five percent.
- RSB methodology: no *de minimis* rules of materiality thresholds.
- ISCC 205: no *de minimis* rules of materiality thresholds.

Conclusion for this Study

The list of literature did not lead to any unexpected inputs, other than those we already encountered during the in-depth farm-level analysis. A small significance threshold of one percent helped to keep the non-material emissions (e.g., zinc as a micronutrient, propane cannons, etc.) out of the questionnaires.

For nitrogen field emissions, the use of fixed literature based values was seen as the most simple and transparent method for calculations, although the chosen method does not take into account soil type. The soil carbon change or carbon sequence, caused by changes in tilling techniques, crop types and other management actions is in most standards. This was not taken into account because of a lack of good data. The draft ISO 14067 does request it should be assessed but we did not take into account LUC (land use change). However we made a note that ‘there is on-going research to develop methodology and models for the inclusion of soil carbon change in GHG reporting.' For this study, information on tilling was collected but with the knowledge that only the differences in diesel use on the fields produced usable data.

Carbon emissions from LUC for sorghum were not an issue since the soil in most cases had been used as farmland for extensive periods (often over 200 years) and in many cases was previously open prairie.

4.2.2.3 Time Boundary

Another issue was to set the time boundary for data which is defined as the time period for which the quantified figure for the CFP is representative.

The Draft ISO 14067 does not prescribe a fixed period but that the time period shall be specified and justified.

The Product Life Cycle Accounting and Reporting Standard states that companies shall report the time period that is in inventory. For nondurable goods like perishable foods or fuels, a time period of one year or less is typically taken according to the standard.

The PAS 2050:2011 discusses in paragraph over-variability in emissions and removals associated with the product life cycle that is where the GHG emissions or removals associated with the life cycle of a product vary over time. Data shall be collected over a period of time sufficient to establish the average GHG emissions and removals associated with the life cycle of the product.

The PAS 2050-1:2012 specifies this for horticultural products and prescribes an assessment period of three years (or at least three recent consecutive cycles) on the basis of a three year, rolling average of emissions. The three year requirement is to offset differences in crop yields related to fluctuations in growing conditions over the period (e.g., weather variation, pests, diseases, etc.).

For the RSB methodology and the ISCC 205 the basis for the calculation should always be the previous year's data.

The ADEME methodology has used for its study a 4 years average, but gives no conclusion on the total data period.

Conclusion for this Study

The most important conclusion is that the time period used for reporting is representative. As we learned from the in-depth farm-level analysis, the input amounts do not differ very much annually and are very little influenced by seasonal conditions. The production output however does differ, so we decided to calculate an Olympic Average production value based on the last 4 year's production.

4.2.3 Data Requirements

4.2.3.1 Primary, Secondary and Site-specific Information

The draft ISO 14067, the PAS 2050 standards and the Product Life Cycle Accounting and Reporting Standard make a difference between the origins of the gathered data.

Primary data is a quantified value of an activity obtained form a direct measurement or a calculation based on direct measurements at its original source.

Secondary data is data obtained from sources other than direct measurement or a calculation based on direct measurements at the original source within the product system.

The standards agree with each other that site-specific primary data shall be collected for all individual processes under the financial or operational control of the organization undertaking the carbon footprint study. Secondary data and primary data that are not site-specific shall only be used for inputs where the collection of site-specific data is not possible or practicable or for processes of minor importance and may include data from literature, calculated data, estimates or other representative data.

All standards agree that the following data quality indicators should be addressed to support the data quality:

a) Time-related coverage: Age of data and the minimum length of time over which data should be collected.

b) Geographical coverage: Geographical area from which data for unit processes should be collected to satisfy the goal of the CFP study.

c) Technology coverage: Specific technology or technology mix.

d) Precision: Measure of the variability of the data values for each data expressed (i.e., variance).

e) Completeness: Percentage of flow measured or estimated.

f) Representativeness: Qualitative assessment of the degree to which the dataset reflects the true population of interest (e.g., geographical coverage, time period and technology coverage).

g) Consistency: Qualitative assessment of whether or not the study methodology is applied uniformly to the various components of the sensitivity analysis.

h) Reproducibility: Qualitative assessment of the extent to which information about the methodology and data values would allow an independent practitioner to reproduce the results reported in the CFP study.

i) Sources of the data.

j) Uncertainty of the information.

k) Reliability: The degree to which the sources, data collection methods and verification procedures used to obtain the data are dependable.

The Product Life Cycle Accounting and Reporting Standard only flags the indicators that are underlined, and it defines a score of either poor, fair, good or very good.

Conclusion for this Study

We took the data quality rules into account when collecting the data.

4.2.3.2 Data Sampling

Almost all standards focus on the carbon footprint from a chain of organizations with specific sites for the collection of primary data. However, this study had the purpose of getting a sector footprint for sorghum. The PAS 2050:2011 and the PAS2050-1:2012 gives directions for data sampling. They state that if horticultural products are sourced from a large number of growers (>10) a representative sample may be used that represents the group for the purpose of calculating the average GHG emissions. For a population of 5,000 or more farmers, two percent (100) is considered representative.

Conclusion for this Study

With a sample of over 300 farmers the number we collected was representative based on the PAS 2050:2011 and the PAS2050-1:2012, which prescribe a sample size of at least two percent or 100 farmers when the population is 5,000 or more.

4.2.4 Emissions Factors

For the emission factors, the amount of greenhouse gases emitted, expressed as CO_2 (equivalent) and relative to a unit or activity, mostly secondary literature based data was used. The general standards (draft ISO 14067, PAS 2050, the Product Life Cycle Accounting and Reporting Standard) refer to the data quality indicators listed in the paragraph above. The RSB methodology, ISCC 205, and ADEME methodology list their own emission factors. They are mostly based on Ecoinvent or IPCC data.

Conclusion for this Study

We took the data quality rules into account when collecting the data. We used, if appropriate and as much as possible, the generally accepted values used in biofuel/biomass calculations in relation to the specific standards.

4.2.5 Reporting

The PAS 2050 standards do prescribe how the product carbon footprint needs to be calculated, and that data sources need to be explained, but does not prescribe the format in which this should be reported.

This ISCC 205 prescribes a GHG calculation but does not require a reporting format.

The RSB GHG and ADEME methodologies were created to develop a personal tool for calculation and reporting but were not used in this study.

The draft ISO 14067 does prescribe in chapter 7 a CFP study report with 25 items that need to be covered in the report.

Similarly the Product Life Cycle Accounting and Reporting Standard lists in Chapter 13 the information that needs to be reported.

Conclusion for this Study

The lists from the draft ISO 14067 and the Product Life Cycle Accounting and Reporting Standard were used as a checklist for writing and reviewing this report. Information that was, or could not be reported was provided in our conclusions.

4.2.6 Allocation of Emissions to Coproducts

Most standards place a lot of attention on the topic of allocation in emissions to coproducts. The preference is to divide the inputs and allocate them directly to the main product. Otherwise, choices have to be made about allocation of emissions based on economic values, energy values or mass.

Conclusions for this Study

For this study this might have been a relevant topic since all farms also grow other crops other than sorghum. However, we set and tested the questions on input per acre of sorghum. The only ‘common’ inputs are the other energy inputs (residual energy). We asked the farmers to allocate this energy directly only to sorghum. Allocation is therefore not an issue for this study.

5 Model

Following the inputs that came out of the literature desk study and the in-depth farm-level analysis, the 'cradle to gate' LCA process map for sorghum is as follows:

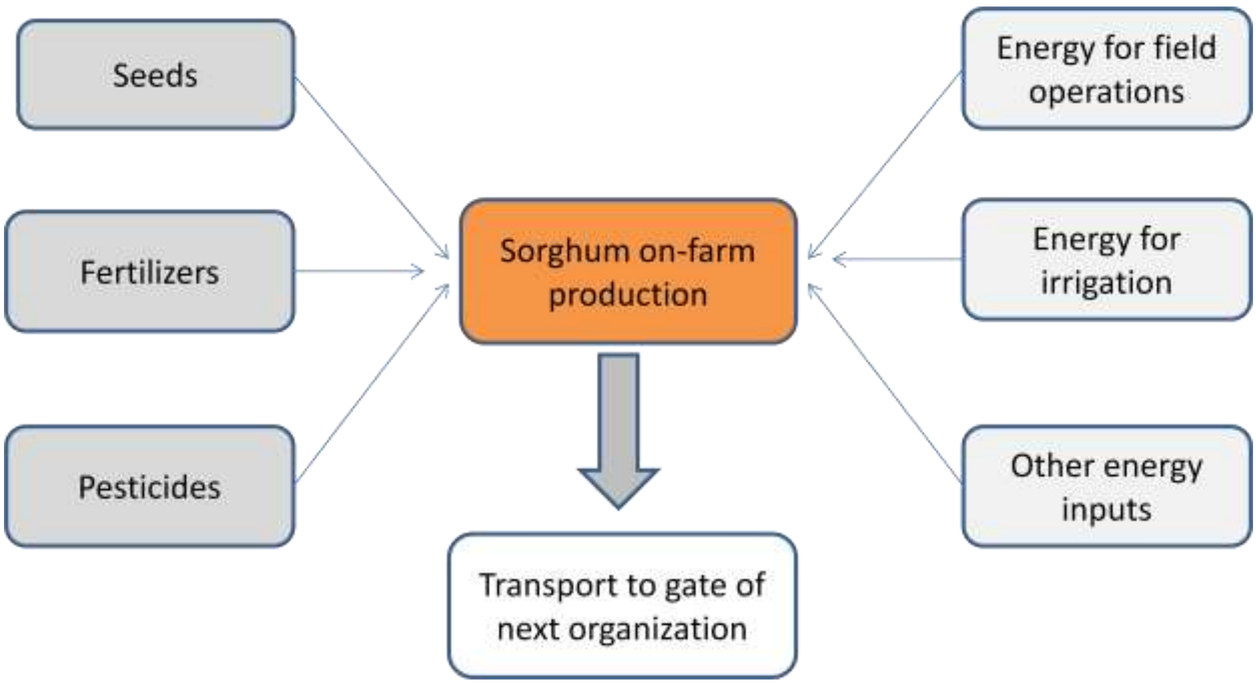


Figure 2. The sorghum LCA process map.

For all inputs, questions were designed (see below paragraph 6.4) and tested to provide data as accurately as possible.

6 Statistical Background on Data Collection

6.1 Recruitment

To complete the objectives of this study, sorghum farmers were screened via telephone interviews and invited to participate in a series of three online surveys. The Sorghum Checkoff Program was identified as the sponsor of the study.

To participate in this study, farmers had to meet the following criteria:

- Be a key sorghum production decision-maker and have access to all the operational information needed to complete the survey.
- Not be affiliated with the Sorghum Checkoff.
- Not be affiliated with any advertising, sales promotion, market research, or public relations organization.
- Not be affiliated with any chemical, fertilizer or energy manufacturing company, distributor or dealership.
- Plant 50 or more acres of sorghum.

Qualified farmers were sent a letter to confirm their participation in the study. The letter also briefly described the purpose of the study and the types of information farmers were asked to provide during the online surveys.

6.2 Data Collection

Data was collected via three online surveys from July 30, 2012 to January 16, 2013.

Farmers completed the surveys in the following sequential order:

- Wave 1 – Sorghum acres (last five years), sorghum yields (last five years), other crop acres, field operations (including type of operation and sorghum acres covered) and fertilizer use.
- Wave 2 – Herbicide, insecticide, fungicide and seed treatment use (including number of applications, method of application and number of sorghum acres treated).
- Wave 3 – Energy use for sorghum production, grain storage and the costs associated with sorghum production.

Farmers were required to refer to their records to provide accurate information.

Information collected during Wave 1 and 2 were critical to the model. Thus participants who completed these two waves were included in the sample even though they may not have completed Wave 3. For the missing data an average of the other farmers was used (corrected for earlier data reported).

6.3 Sample Plan

6.3.1 Sample Size

Sample size for this study was designed to be large enough to examine information across regions/districts that account for 80 percent of planted sorghum acres. To determine carbon usage a sample of over 300 sorghum growers were surveyed. A sample size of 300 yields a margin of error of +/-5.6 percent at a 95 percent level of confidence.

6.3.2 Sample Design

Based on a stratified cluster sample designed to ensure a representative sample and minimize potential list bias, participants for this study were selected randomly from targeted growers having 50 or more sorghum acres. Participants were required to be the *primary* decision-maker related to inputs used on their farm.

6.3.3 Geography

Based on the need for a national representation of sorghum growers, the sample of farmer interviews covers the following states that represent more than 80 percent of sorghum acres;

	# Farmers Waves 1 & 2	% Farmers Waves 1 & 2	# Farmers Wave 3	% Farmers Wave 3
Colorado	7	2%	6	2%
Kansas	176	57%	143	56%
Louisiana	1	0%	1	0%
Missouri	3	1%	2	1%
Nebraska	16	5%	12	5%
New Mexico	2	1%	2	1%
Oklahoma	13	4%	11	4%
South Dakota	3	1%	3	1%
Texas (excludes SE region)	51	16%	43	17%
SE Texas only	38	12%	32	13%
Total	**310**	**100%**	**255**	**100%**

Table 1. Home state of collected farmers.

6.4 Data collection

6.4.1 Questionnaire Items for Farmers

For the input values in our model the following values were asked for in the questionnaires:

Seeds	***Unit***
Seeding rate (coated and not coated)	lbs/acre
Fertilizer and minerals	
Nitrogen Use	lbs/ac
Type of Nitrogen Used - NH3, UAN, Urea	Type
Phosphorus Use	lbs/ac
Type of Phosphorus Used - MAP, DAP, 10-34-0	type
Potassium Use	lbs/ac
Type of Potassium Used - Muriate, Other	type
Lime Use	tons/ac
Sulfur Use	lbs/ac
Zinc Use	lbs/ac
Pesticides	
Herbicide Use	gal/ac
Type of Herbicide Used - atrazine, metolachlor, acetochlor, cyanazine, others	type
Insecticide Use	gal/ac
Type of Pesticide Used - fungicide, pyrethroid, others	type
Energy for field operations	
Diesel Use	gal/ac
Energy for irrigation	
Inches of water applied	in
Average depth to water (lift)	ft
Energy source for irrigation	gal/ac, kWh, mcf
Other energy input	
Gasoline Use (including overhead or fixed minimum gasoline usage - excluding transportation from farm to elevator)	gal/ac
Diesel Use (including overhead or fixed minimum diesel usage - excluding transportation from farm to elevator and field operations)	gal/ac
Electricity Use (including overhead or fixed minimum electricity usage)	kWh
Energy for drying (there was no energy used for drying)	

Transport to gate of next organization	
Bushels delivered and miles to first handler - largest three for sorghum	bu, mi
Other information	
Yield	bu/ac
Total acres of sorghum	ac
Irrigated sorghum acres	ac
Non-irrigated sorghum acres	ac
List of other crops	other crops
Acres of other crops	ac
Irrigated other acres	ac
Non-irrigated other acres	ac
Number of employees	employees
On-farm storage capacity	bu
Tillage practice on sorghum - (no-till, min-till, conventional)	percent
Tillage practice on other crops - (no-till, min-till, conventional)	percent

Table 2. Input values in the questionnaire.

6.4.2 Data Transformation for Calculations and Sources of Emissions Factors

After the data listed above in Table 2 was collected, we recalculated the values to SI units and fuel amounts and multiplied this with using the most appropriate emission factor (as determined by our desk study). This led to the following list of inputs and factors:

Input value	Activity data (if recalculated)	Emission factor	Literature source
Seeds (not treated)	Lbs/acre to kg/acre	0.555 kg CO_2e/kg	Bos et al., 2007
Seeds treated	Lbs/acre to kg/acre	0.575 kg CO_2e/kg	Extra CO_2 calculated on typical dressings
N-fertilizer	Lbs/acre to kg/acre	5.88 kg CO_2e/kg N	ISCC 205, Biograce
N-fertilizer field emissions N_2O	Lbs/acre to kg/acre	4.87 kg CO_2e /kg N	IPCC methodology for field emissions of N2O
Phosphorus	Lbs/acre to kg/acre	1.01 kg CO_2e /kg N	ISCC 205, Biograce
Potassium	Lbs/acre to kg/acre	0.57 kg CO_2e /kg K^2O	ISCC 205, Biograce
Sulfur	Lbs/acre to kg/acre	0.57 kg CO_2e /kg	Assumption
Lime	Tons/acre	.59 kg CO_2e/kg	Ohio State University
Pesticides (Herbicides, Insecticides, Fungicides)	Gal/acre to kg ai/acre	9.9 kg CO_2e /kg	Ohio State University
All field operations	From activity per acre to gallons/ acre		Virginia tech study
Diesel use	Gal/acre to liters / acre	2.68 kg CO_2e /liter diesel	US EIA
Aerial spraying	Assumption 42.5 kg Avgas per acre needed for spraying	3.16888 kg CO_2e/ kg Avgas	Revised1996 IPCC
Inches of application (irrigation) Average depth to water lift	With a pump efficiency of 60% the amount of energy needed was calculated.		
Energy source for irrigation	From MJ to m3 gas, liter diesel or kWh electricity	LHV gas: 34 MJ/m3 LHV diesel: 36.12 MJ/l	
Natural gas		1.93 kg CO_2e /m3 gas	US EIA
Diesel		2.68 kg CO_2e /liter diesel	US EIA
Electricity		0.68 kg CO_2e / kWh	US EIA (2004 US average)

Table 3. Data transformation and used emission factors.

6.5 Outliers and/or Obviously Incorrect Data as well as Data Not Provided

For all values parameters were set. Data that was obviously incorrect or not reported was replaced with an average value from the other farmers (corrected for the situation, irrigation practice and number of acres on that specific farm).

7 Results

7.1 Total Carbon Footprint for Sorghum Production

The total carbon footprint for sorghum is **0.25 kg CO_2e per kg** sorghum or **6.4 kg CO_2e per bushel** sorghum. This value is calculated based on the average reported inputs per farm.

The footprint value is an average value but ranges are wide. With a standard deviation of 0.1 kg CO_2e per kg sorghum for all farmers that filled out the total questionnaire and a range from 0.05 kg CO_2e up to 0.74 kg CO_2e per kg sorghum, we can observe differing practices across the sample of farmers.

The ranges mostly depend on differences in fertilizer application and the other energy inputs.

8 Limitations, Uncertainties and Assurance

8.1 Limitations

The results presented in this report need to be read in combination with the assumptions made in the calculation model. The results only give information about the carbon footprint of sorghum for the U.S. It gives no information about the subsequent steps in the chain of custody or about other environmental aspects other than the GHG potential associated with crop production.

8.2 Uncertainties

All activity data was gathered by questionnaires from more than 300 farmers. There is no assurance on the validity of the data as reported, since no verifications are performed on site at the farmers' premises. The questionnaires took time and effort and farmers were required to consult field and other records for reporting. The provided data was checked for evidence of obvious incorrect submissions, and we have no reason to assume farmers gave unconsidered answers since there was no individual gain for doing so. Farmers also have extensive experience with this type of data collection, as the U.S. Department of Agriculture National Agricultural Statistics Service collects data in the same manner without verification.

We used emission factors we considered the most appropriate, the most consistent (also based on the criteria named in paragraph 4.2.3.1) and also the most robust. Higher accuracy could be achieved by using more complex models (for example, models which account for soil type affects on field nitrogen emissions) or electricity grid factors by state.

8.3 Assurance

No third party verification was undertaken and no verification of supplied farmer data was carried out (see also 8.2). The calculations were internally reviewed by a second SGS expert who was not part of this project.

9 Reporting on Results and Extra Questions added by the Sorghum Checkoff

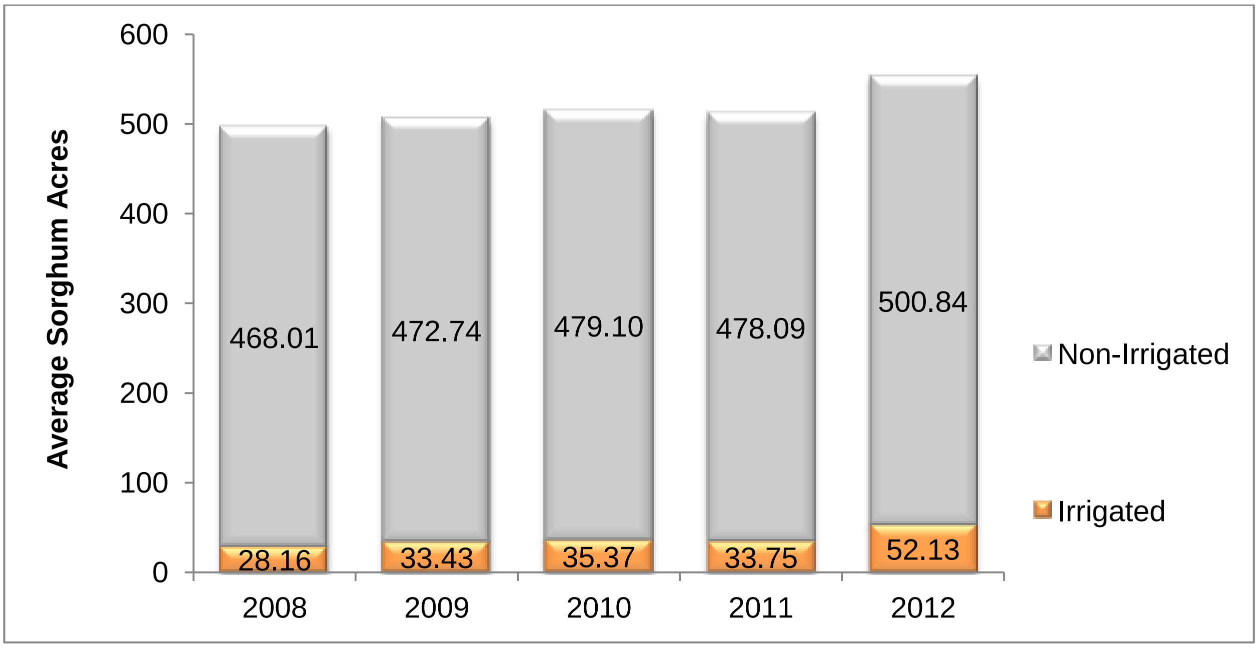
9.1 The Sample of Sorghum Acres by State (Irrigated and Non-Irrigated)

	# Acres Represented Waves 1 & 2	% Acres Represented Waves 1 & 2	% Irrigated Waves 1 & 2	# Acres Represented Waves 3	% Acres Represented Waves 3	% Irrigated Wave 3
Colorado	7,184	4%	2%	6,372	4%	2%
Kansas	78,767	46%	2%	65,036	44%	2%
Louisiana	130	0%	0%	130	0%	0%
Missouri	947	1%	21%	767	1%	26%
Nebraska	3,605	2%	3%	2,836	2%	4%
New Mexico	1,768	1%	3%	1,768	1%	3%
Oklahoma	4,527	3%	18%	3,757	3%	13%
South Dakota	3,410	2%	0%	3,410	2%	0%
Texas (exclude southeast region)	35,379	21%	32%	32,475	22%	33%
Southeast Texas only	35,705	21%	5%	30,695	21%	4%
Total	**171,422**	**100%**	**9%**	**147,246**	**100%**	**9%**

Table 4. Sorghum acres per state.

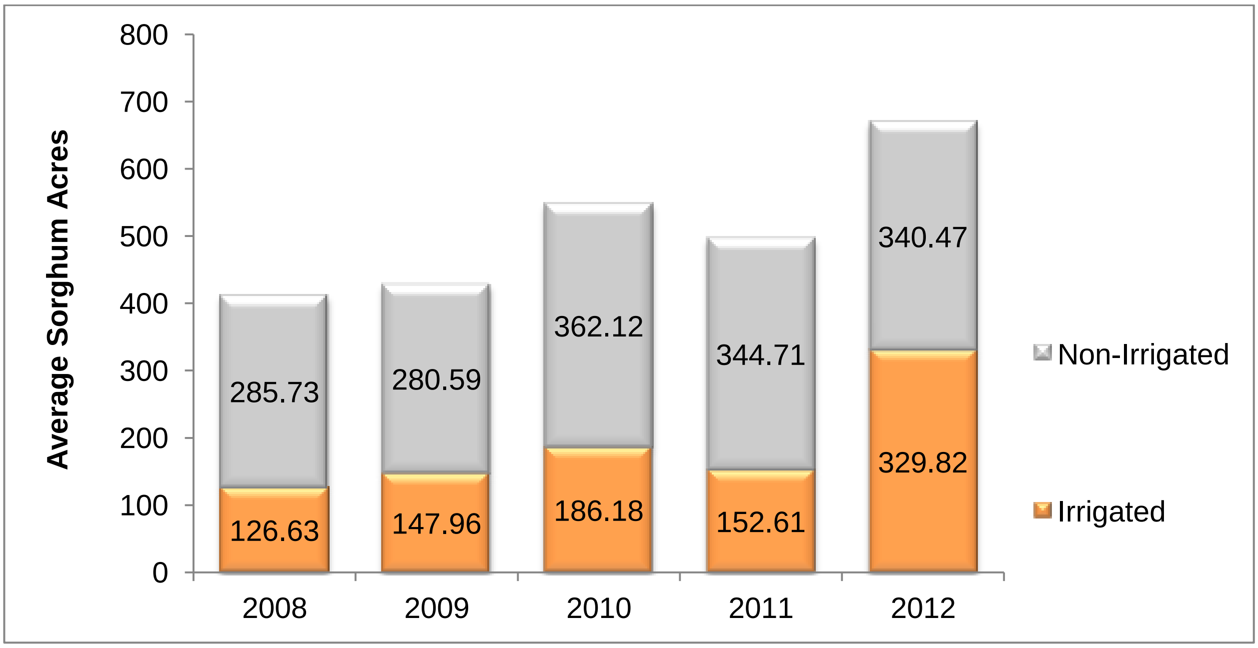
9.2 Average Sorghum Acres (All farmers)

Thinking only about your sorghum for grain over the past years, how many acres of irrigated and/or non-irrigated (dry land) sorghum for grain did you plant in the following years?



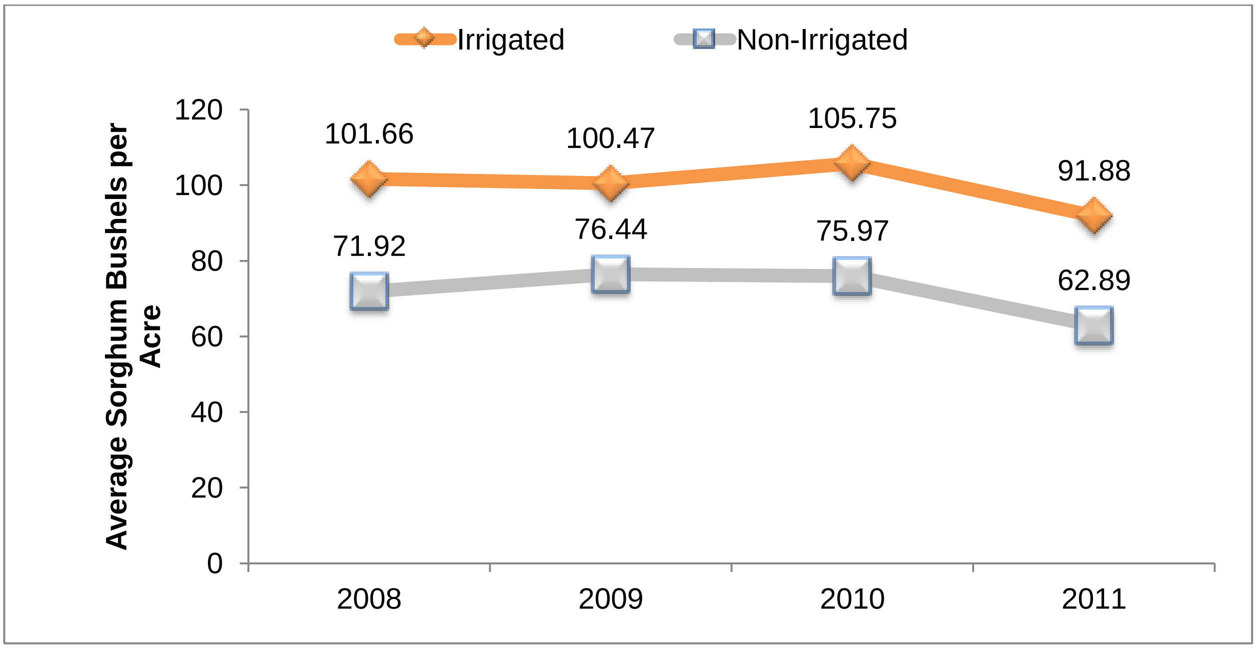
9.3 Average Sorghum Acres (Farmers with Irrigated Sorghum only)

Thinking only about your sorghum for grain over the past years, how many acres of irrigated and/or non-irrigated (dry land) sorghum for grain did you plant in the following years?



9.4 Average Sorghum Yields (Bushels per Acre[1])

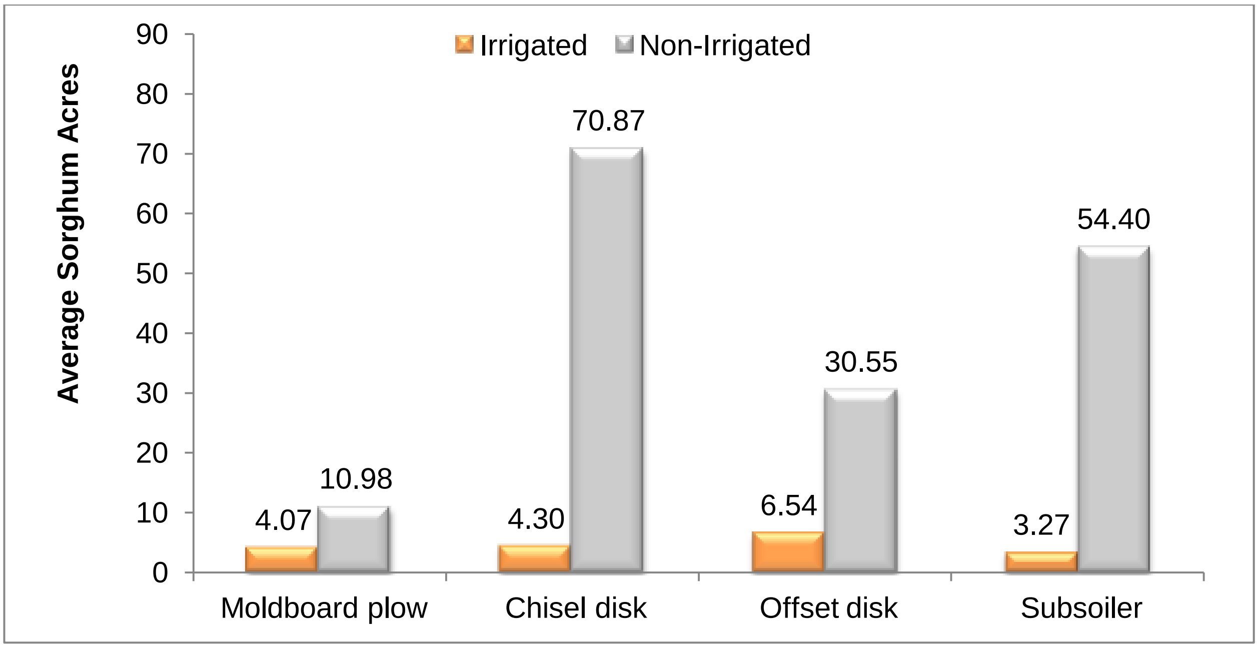
What was your average sorghum yield in bushels per acre or pounds per acre for your irrigated/non-irrigated sorghum in the following years?



[1] Some farmers reported in lbs/acre. The conversion to bushels used is lbs/56.

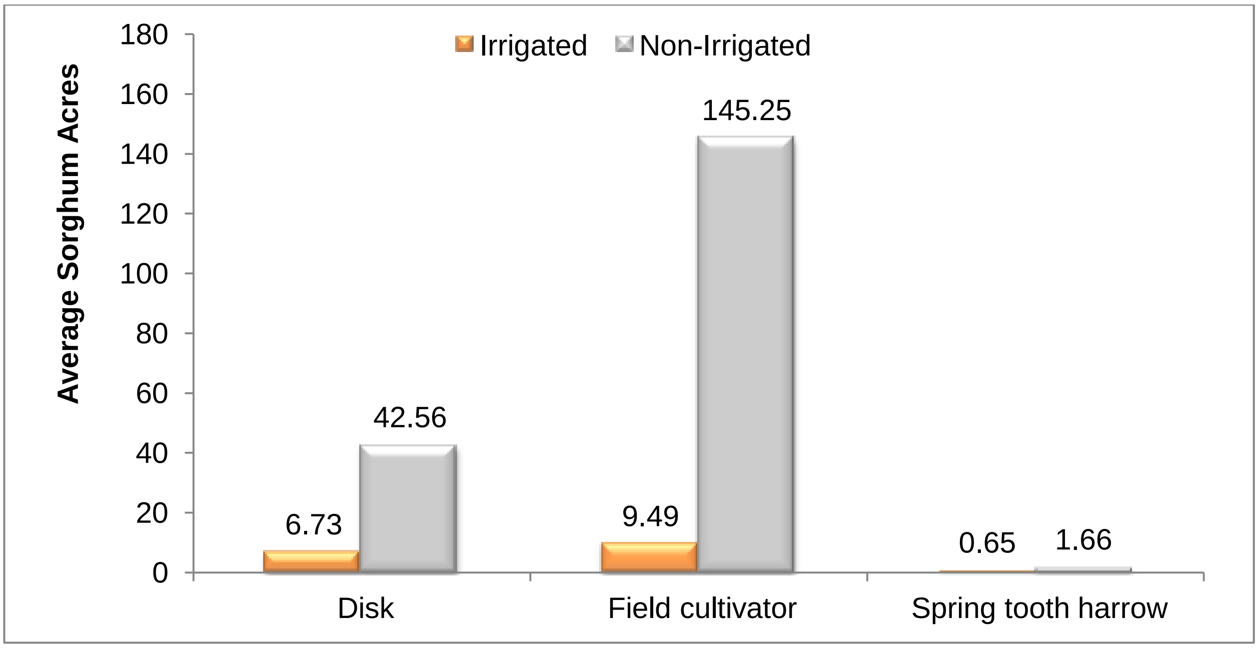
9.5 Average Acres Covered by Indicated Primary Tillage Practices

Please enter all acres covered during the following PRIMARY TILLAGE field operations.



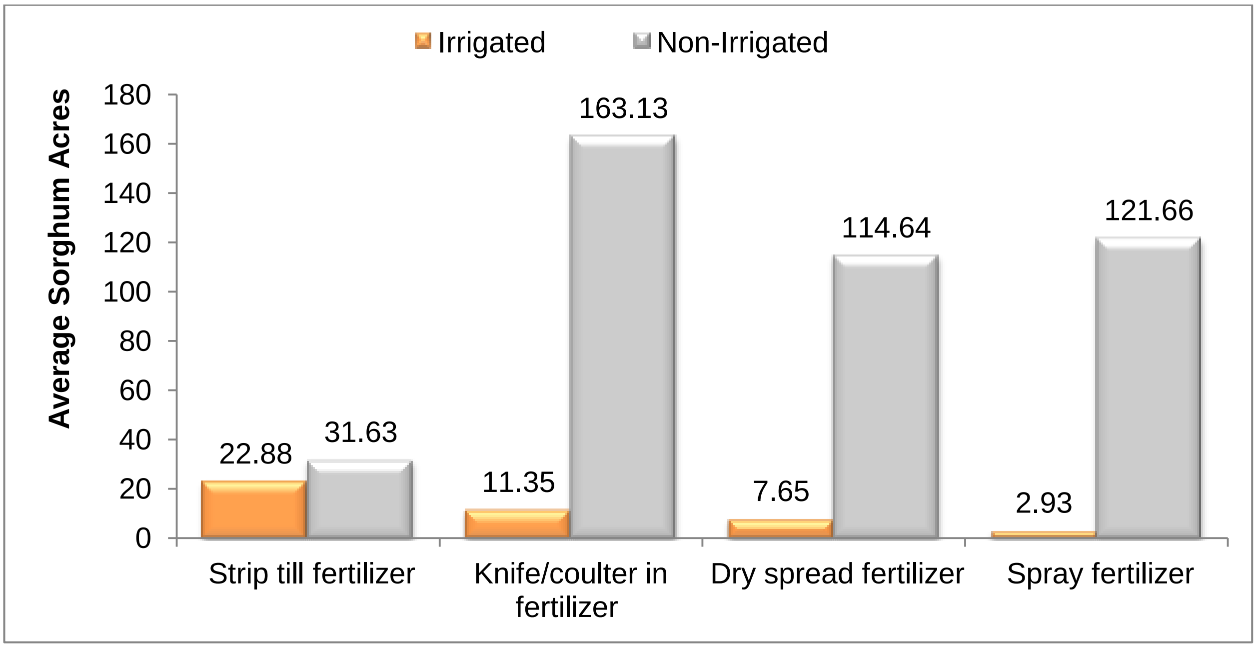
9.6 Average Acres Covered by Indicated Secondary Tillage Practices

Please enter all acres covered during the following SECONDARY TILLAGE field operations.



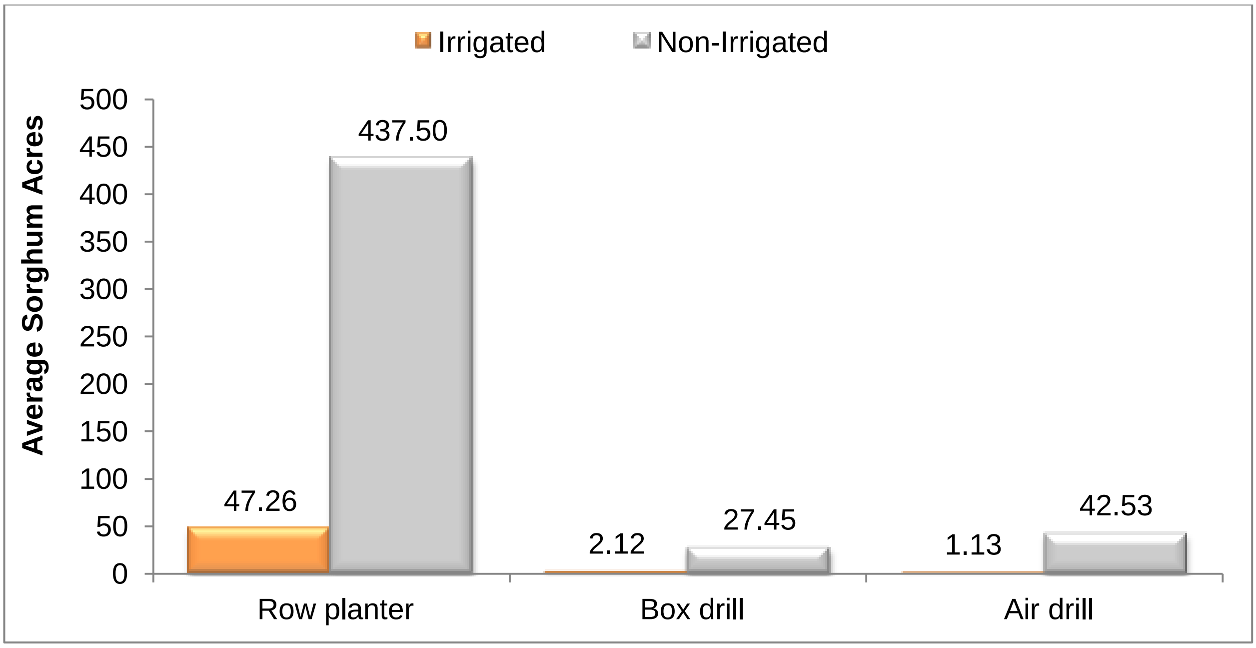
9.7 Average Acres Covered by Indicated Fertilizer Applications

Please enter all acres covered during the following FERTILIZER APPLICATION field operations. (Do NOT include operations that were done with herbicide/pesticide or planting operations).



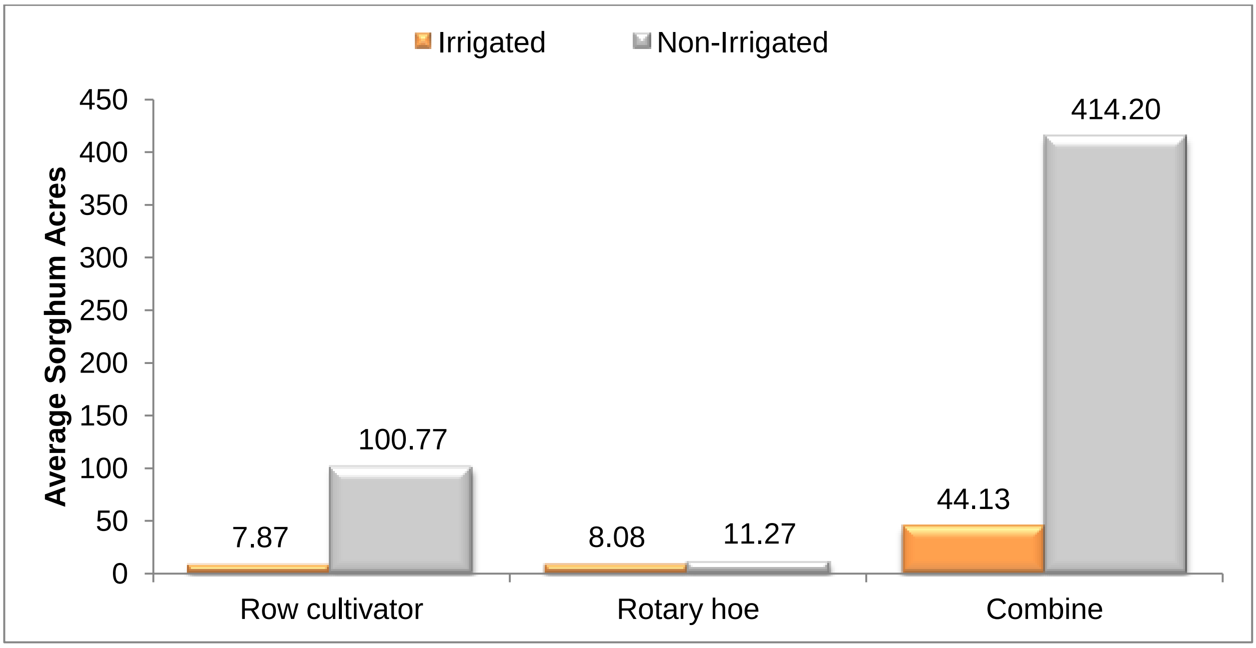
9.8 Average Acres Covered by Indicated Planting Operations

Please enter all acres covered during the following PLANTING field operations.



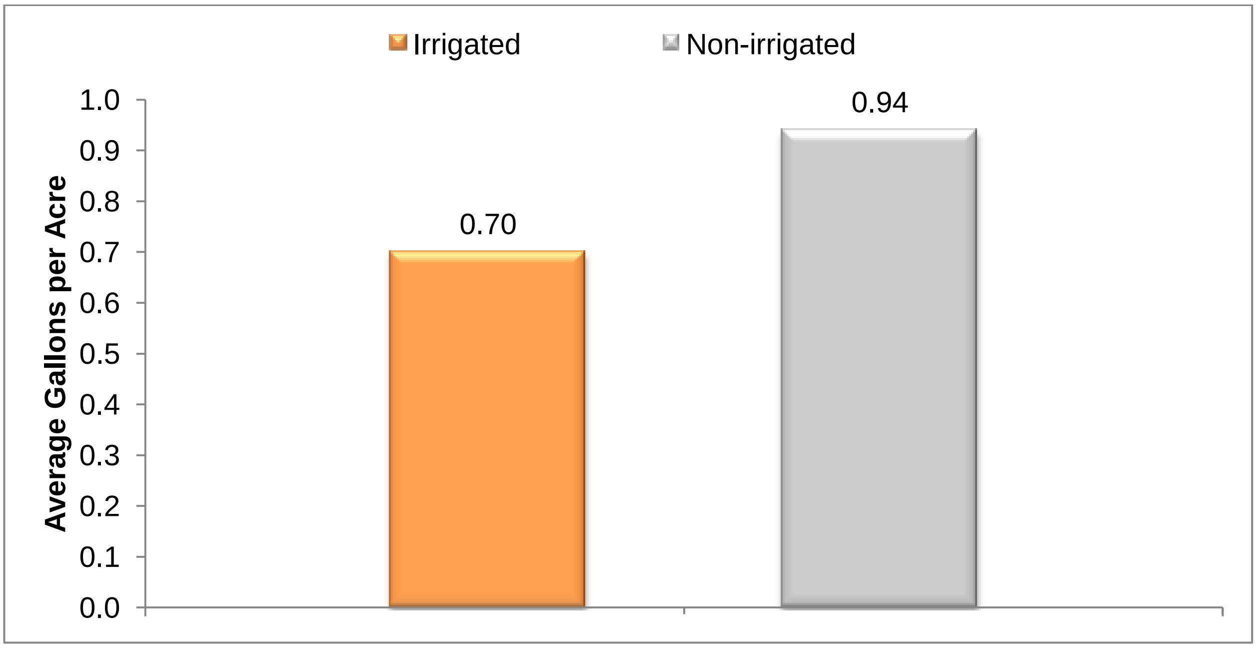
9.9 Average Acres Covered by Indicated Cultivation and Harvest Operations

Please enter all acres covered during the following CULTIVATION/HARVEST WITH COMBINE field operations.



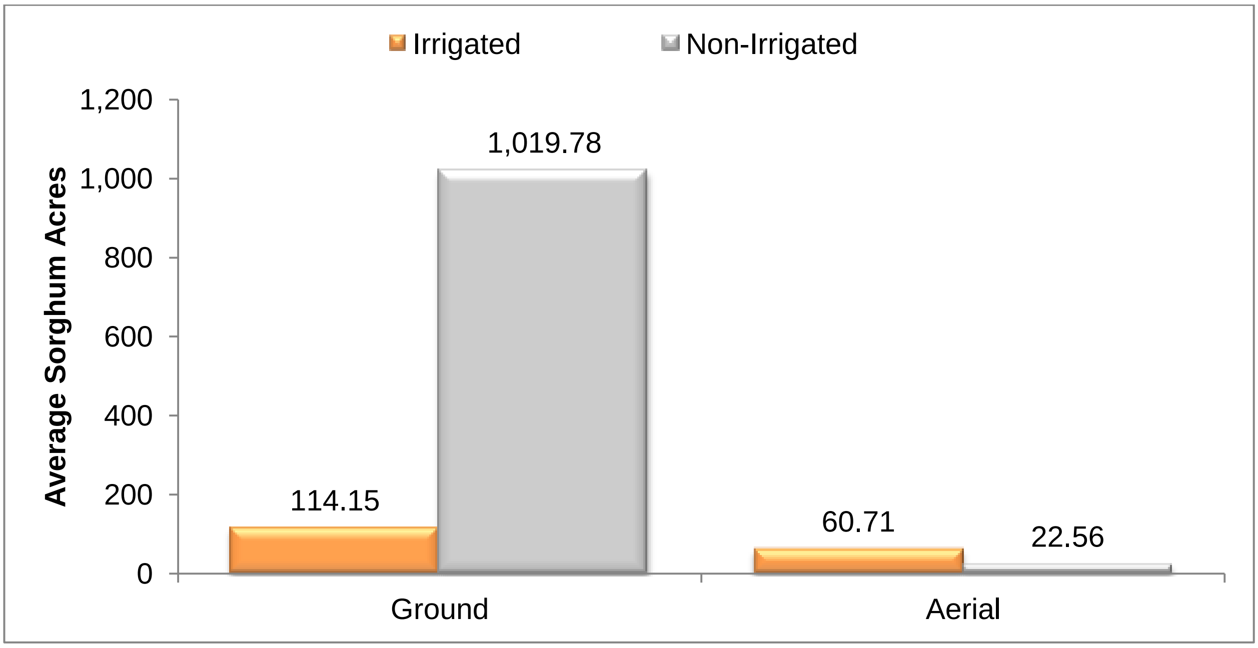
9.10 Average Gallons of Herbicide Applied

What herbicide did you apply on the [NUMBER] application to your grain sorghum? Please specify whether this application was in ounces, pounds or quarts.



9.11 Average Acres by Method of Chemical Application

How many total acres did you treat not combined with any other operation with [HERBICIDE] (TANK MIX) on that {1st, 2nd, 3rd, 4th, 5th…} application?



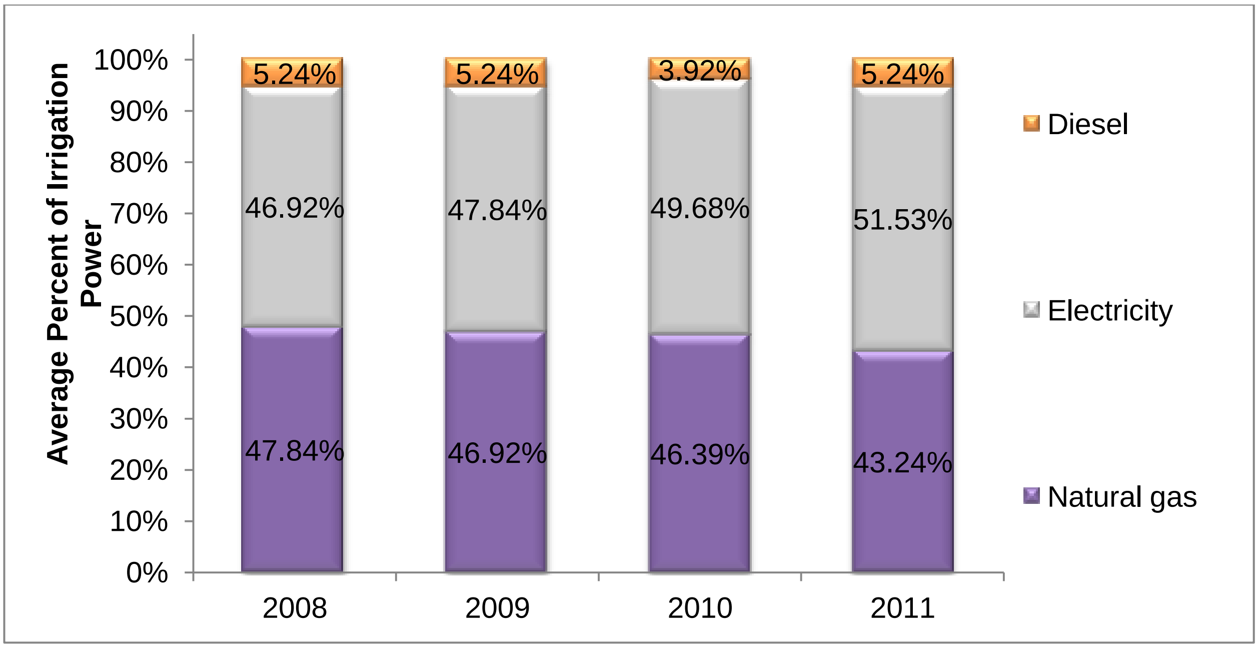
9.12 Average Irrigation Water Application and Lift Distance

How many acre-inches on average were applied to your sorghum crop?
What was your average depth to water (lift) in feet?

	2008	**2009**	**2010**	**2011**
Acre-Inches	*8.29*	*9.24*	*10.38*	*12.29*
Lift (feet)	*218.82*	*220.92*	*228.56*	*233.46*

9.13 Average Percent of Sorghum Irrigation Powered by Indicated Fuel Sources

What percentage of your sorghum irrigation was powered by…?



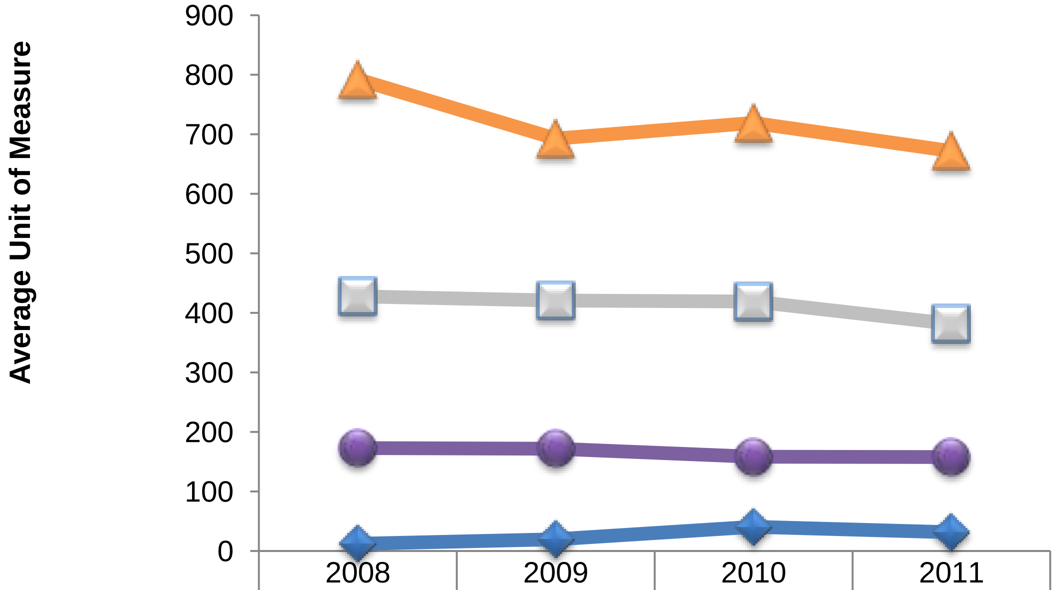
9.14 Fertilizer Applications (Irrigated - IR and Non-Irrigated – NI Sorghum Acres)

What was the average application rate of actual [insert fertilizer] on your sorghum acres? Please use the elemental rate for the actual rate.

Fertilizer	***Average Application Rate (IR)***	***% of Sorghum Acres (IR)***	***Average Application Rate (NI)***	***% of Sorghum Acres (NI)***
Nitrogen in lbs per acre (elemental rate)	*113.11*	*77%*	*79.73*	*82%*
Phosphorus in lbs per acre (elemental rate)	*38.14*	*66%*	*26.80*	*58%*
Potassium in lbs per acre (elemental rate)	*25.43*	*7%*	*23.83*	*14%*
Sulfur in lbs per acre (elemental rate)	*13.79*	*18%*	*10.32*	*24%*
Lime in tons per acre	*-*	*-*	*2.25*	*1%*

9.15 Average Residual Energy Use – All Farmers

Please allocate for grain sorghum all other residual energy uses you have on your farm. Make a best estimation for the residual energy used for your grain sorghum crop. Please take into account energy uses such as for pickup trucks, heating, and lights. For example, if your pickup truck uses approximately 2,000 gallons per year of diesel, and grain sorghum makes up 25 percent of your crop mix, then assign 500 gallons to diesel.



	2008	2009	2010	2011
Natural Gas (cubic metric feet)	12.39	19.61	40.53	31.55
Electricity (kilowatt/hour)	427.83	421.06	419.13	381.67
Diesel (gallons)	792.29	692.73	719.04	672.04
Gasoline (gallons)	173.17	172.04	158.39	157.93

10 References

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Carbon Footprint Study

Final Report

April 2020

•SMR&P•
Strategic Marketing Research & Planning

SORGHUM CHECKOFF

Carbon Footprint Study

Study Background

April 2020

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Study Background & Purpose

- In 2012, The United Sorghum Checkoff Program developed a model to analyze the carbon footprint of sorghum used for ethanol production based on information obtained from sorghum growers. This information was collected in an extensive study over time and included the following:
  - Sorghum acres – including both irrigated and non-irrigated acres in past five years; seeding rate; crop acres preceding 2012 sorghum.
  - Sorghum inputs (brands and acres treated) - including fertilizer, herbicide, insecticides, fungicides, seed treatments.
  - Sorghum outputs - including yields, sorghum stubble for grazing and bale.
  - Field operations (type of operation and sorghum acres covered) – including specific tillage practices; fertilizer, herbicide, insecticide and fungicide application methods; planting methods, cultivation methods, and harvest methods.
  - Energy use (type and quantity) – including energy for drying; energy for irrigation; residual energy; energy for delivery .

- The Sorghum Checkoff Program is now interested in redocumenting and confirming the model estimates using some of the primary predictors from the 2012 Sorghum Carbon Footprint Study. Thus, the current study will gather information from growers, with the purpose of confirming estimates and verifying near future estimates or sorghum's carbon footprint.

- Specifically, this study will gather the following information about sorghum production for both non-irrigated and irrigated acres for the years 2017, 2018 and 2019:
  - Sorghum production acres (seeding rates and crop acres)
  - Yields
  - Tillage practices (no till, minimum/strip till and conventional till acres)
  - Crop inputs (nitrogen fertilizers, phosphorus, potassium, sulfur and lime application rates and acres treated)
  - Organic matter percentage
  - Soil type

Methodology & Sample

- To gather information used in this study, phone interviews were conducted with 101 sorghum growers in Kansas in April 2020. Kansas was selected due to its high concentration of sorghum growers and high sorghum output. Kansas produces nearly half (48%) of all sorghum acres grown in the U.S. To participate in this study, growers had to meet the following criteria:
  - Have input into decisions about sorghum for their farming operation.
  - Not employed by or affiliated with advertising, sales promotion, market research or public relations organizations/companies.
  - Not employed by or affiliated with energy manufacturing company, distributor, or dealership.
  - Planted at minimum of 50 sorghum acres in 2019.

- To get a representative sample of sorghum growers across Kansas, counties were divided into three regions: Central, East and West (see appendix for a list of counties in each region). Soft quotas were imposed on each region. Below is the number of interviews completed in each region versus the quota.

	Sampled Growers		Acres Represented		
	Desired	Completed	# of Acres Represented	% of Acres Represented	% of Acres Irrigated
Central	62	62	26,532	56%	3%
East	5	6	2,580	5%	0%
West	33	33	18,455	39%	8%
Total	100	101	47,567	100%	5%

Carbon Footprint Study

Sorghum Production

April 2020

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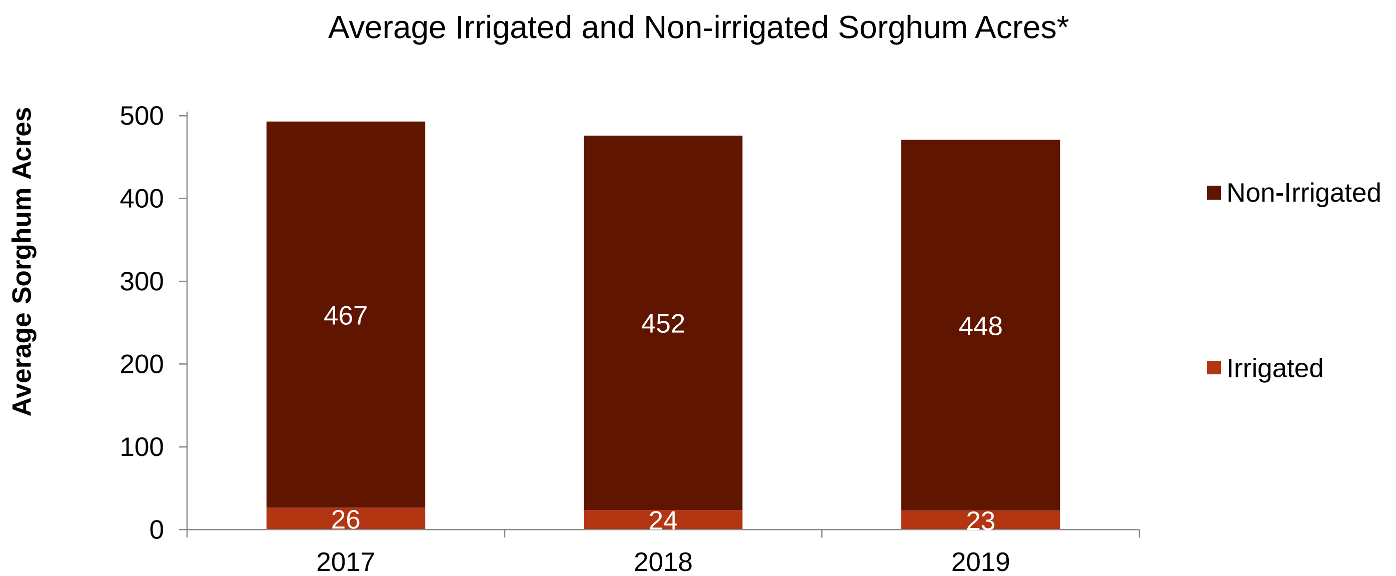
Sorghum Acres Planted

- About 5% of sorghum acres are irrigated. Growers in this study planted on average 471 sorghum acres in 2019. Sorghum acres increased from 2017 and 2018 by about 8%.

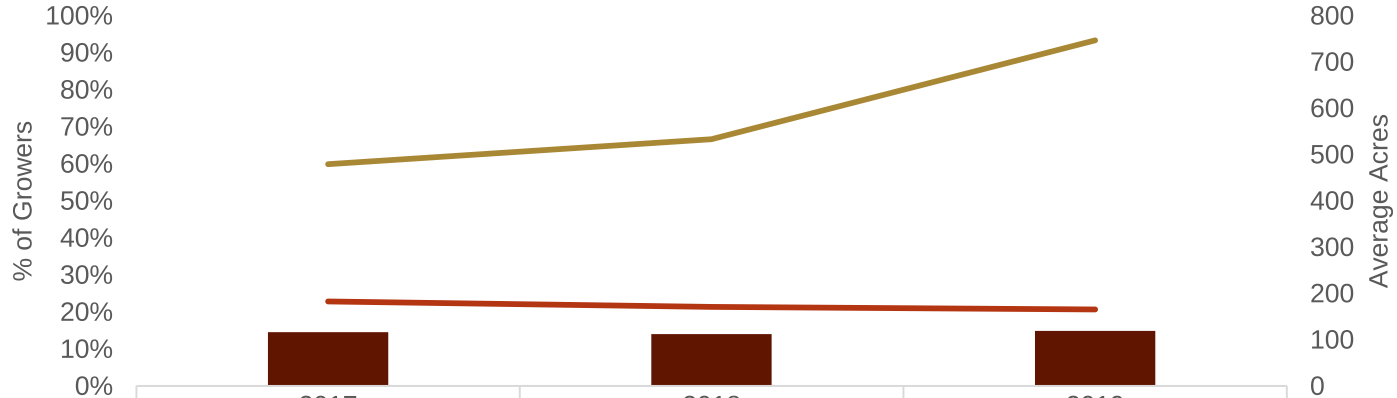


	2017	2018	2019
Average Sorghum Acres	439	438	471
% of All Sorghum Acres that are Irrigated	5%	5%	5%
Base	*101*	*101*	*101*

*Source: How many [irrigated/non-irrigated] sorghum acres did you plant in the following years? *Includes 0. Base=101.*

Irrigation in Sorghum

Average Acres Among Growers with Irrigated Sorghum Acres *

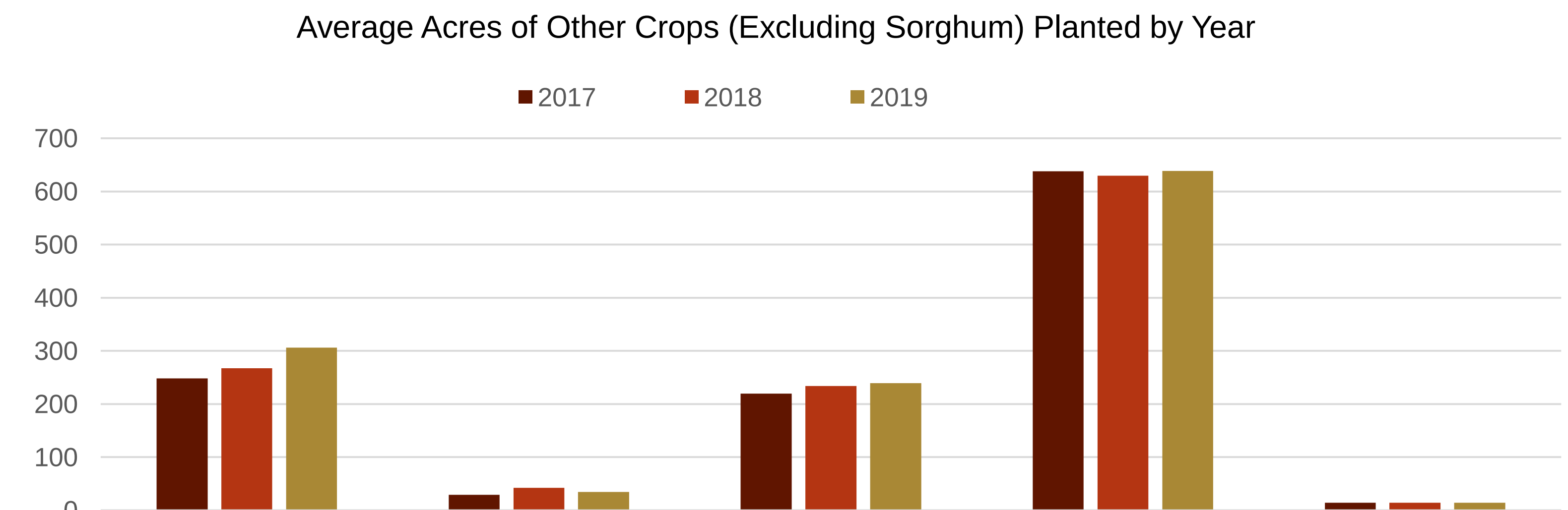


	2017	2018	2019
% Growers With Irrigated Sorghum	14%	14%	15%
Average Acres Irrigated	182	170	165
Average Acres Non-Irrigated	479	533	747
% of Growers	*101*	*101*	*101*
Average Irrigated	*13*	*13*	*14*
Average non0-irrigated	*10*	*10*	*12*

Source: Were any of your sorghum acres irrigated in [insert year]? How many [irrigated/non-irrigated] sorghum acres did you plant in the following years?
**Caution due to small sample sizes.*

Other Crops Planted

- Winter wheat is the next most planted crop among sorghum growers.

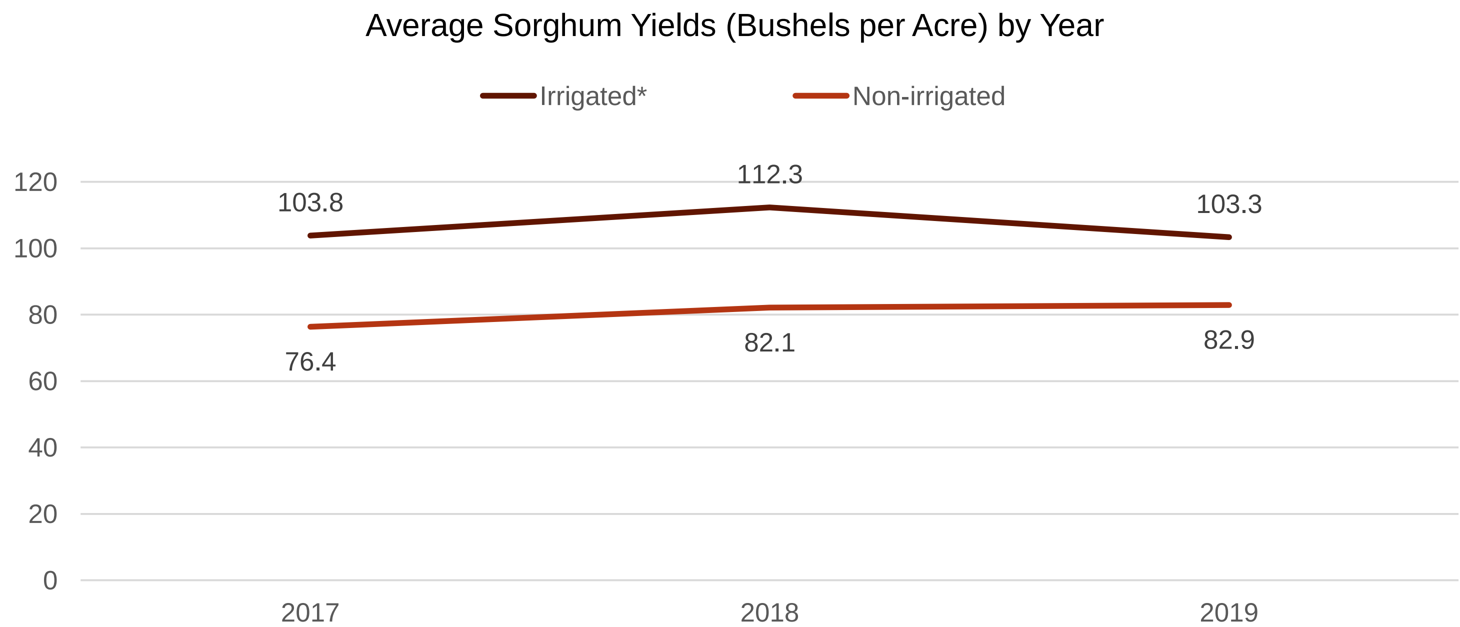


	Corn	Cotton	Soybeans	Winter Wheat	Other
2017	248	29	219	638	14
2018	267	42	234	630	14
2019	306	34	239	639	14

Source: How many acres of the following other crops did you plant in the following years? If none, enter 0. 0's included in average.

Sorghum Yields

- Sorghum yields have remained consistent over the past year at about 82 bushels per acre. Irrigated sorghum acres yield about 20% to 25% more bushels per acre than non-irrigated sorghum.

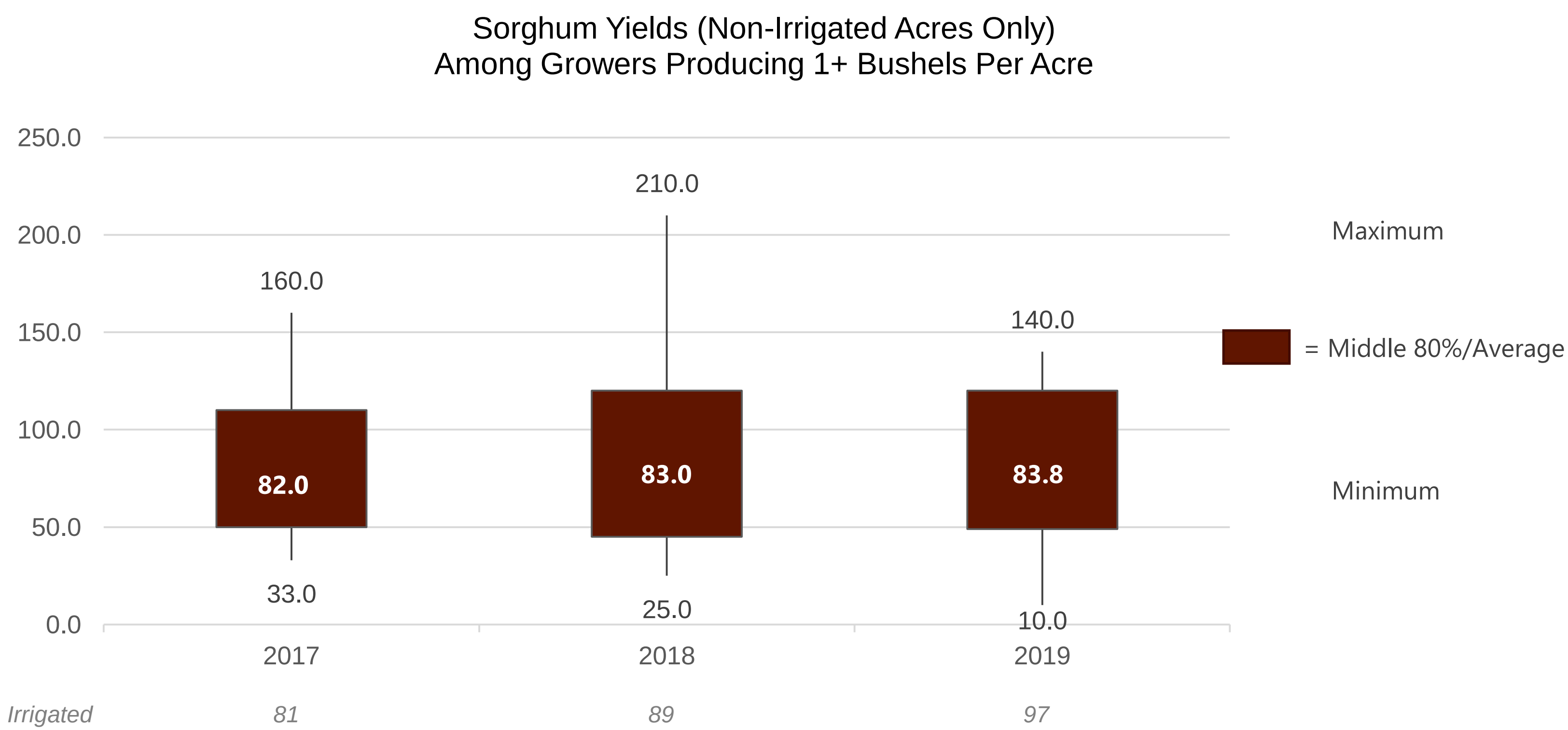


	2017	2018	2019
Base Irrigated	*13*	*13*	*15*
Base Non-irrigated	*87*	*90*	*98*

Source: What was your average sorghum yield in bushels per acre or pounds per acre for your [irrigated/non-irrigated] sorghum in the following years? Sorghum yields include 0's (i.e., growers who reported planting sorghum, cut said they had 0 yields.
** Caution due to small sample size..*

Sorghum Yields (Non-Irrigated Acres Only)

- Growers over the past three years have produced about 83 bushels per acre of sorghum on non-irrigated land. However, yields vary widely with most growers (80%) reporting yields between 50 and 120 bushels per acre.



Source: What was your average sorghum yield in bushels per acre or pounds per acre for your [non-irrigated] sorghum in the following years?

Carbon Footprint Study

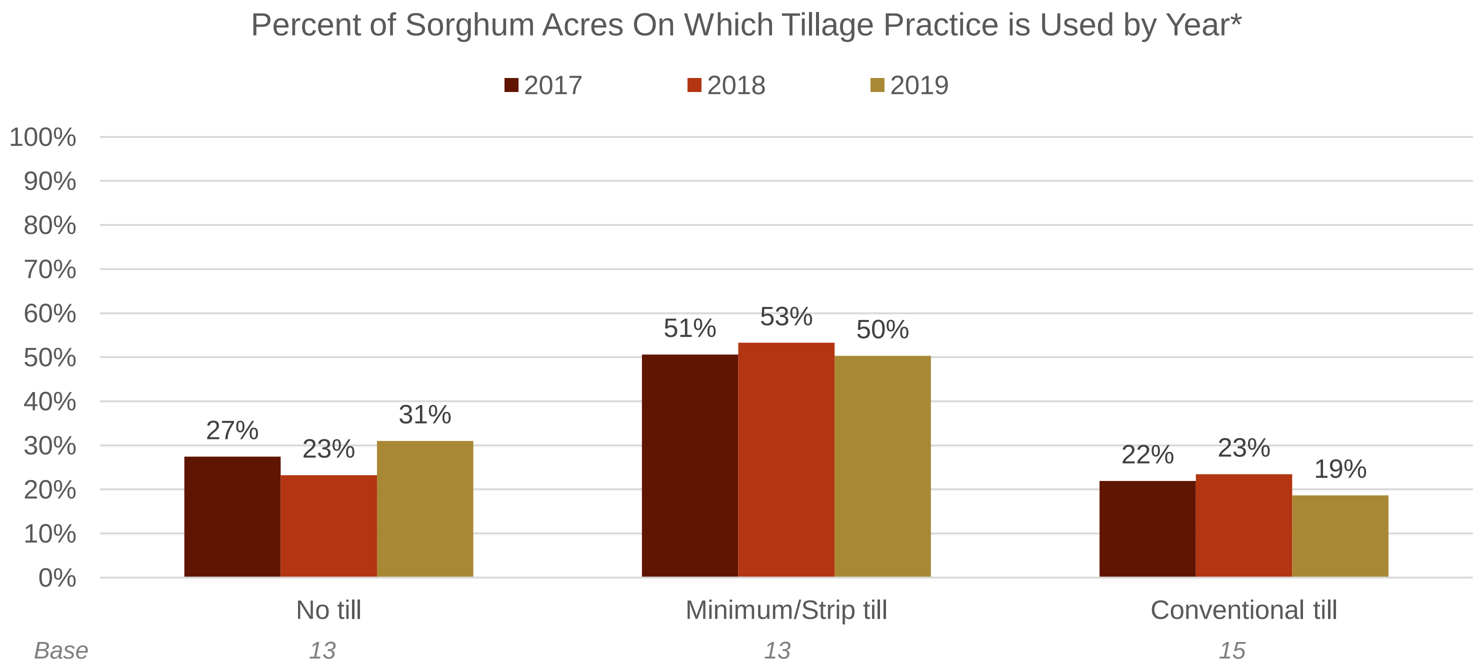
Tillage Practices

April 2020

Strategic Marketing Research & Planning

Tillage Practices on Irrigated Acres

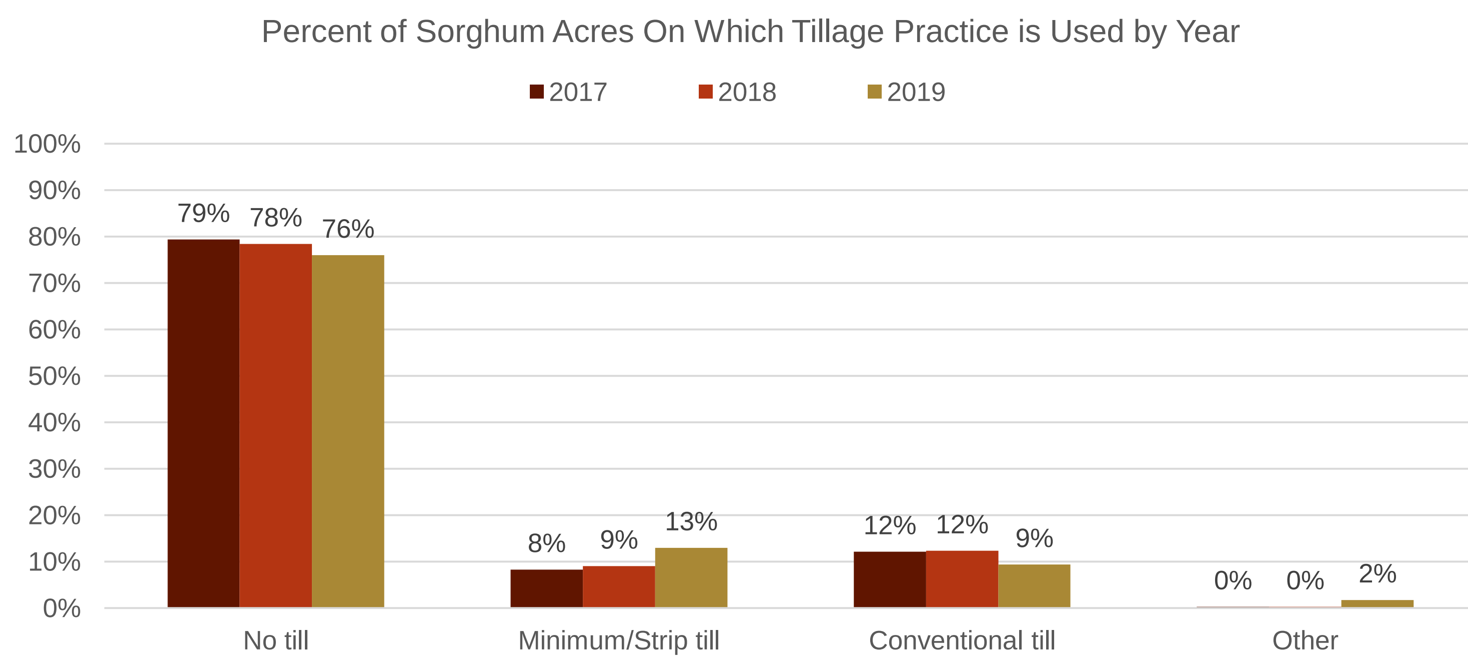
- Roughly half of grower use strip till on their irrigated sorghum acres (50%). This was also true in 2017 and 2018.



Source: How many of your sorghum acres were no till, minimum/strip till or conventional tillage in [year[?
** Caution due to small sample.*

Tillage Practices on Non-Irrigated Acres

- Most all growers practice no till on their non-irrigated sorghum acres (76%). This was true in 2017 (79%) and 2018 (78%).
- Directionally, the practice of no till appears to be declining slightly and minimum till increasing.



Base 2017 *87*
Base 2018 *90*
Base 2019 *98*

Source: How many of your sorghum acres were no till, minimum/strip till or conventional tillage in [READ YEAR[?

Carbon Footprint Study

Carbon Inputs

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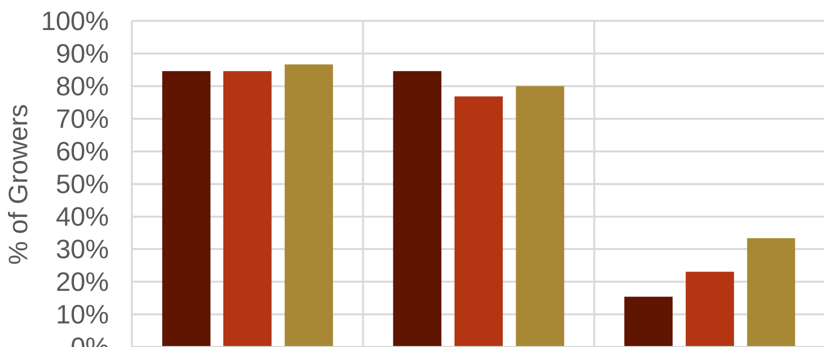
Nutrient Use

- Roughly 85% of growers apply nitrogen to their irrigated sorghum acres and 90% of growers apply nitrogen to the non-irrigated sorghum acres.
- Most all growers (irrigated and non-irrigated sorghum) apply phosphate to their acres. A higher portion of growers with irrigated acres apply this nutrient than growers with non-irrigated sorghum acres.
- The portion of growers with irrigated sorghum acres who applied potash increased year over year from 2017 to 2019. Few growers with non-irrigated sorghum apply potash (10%)*.

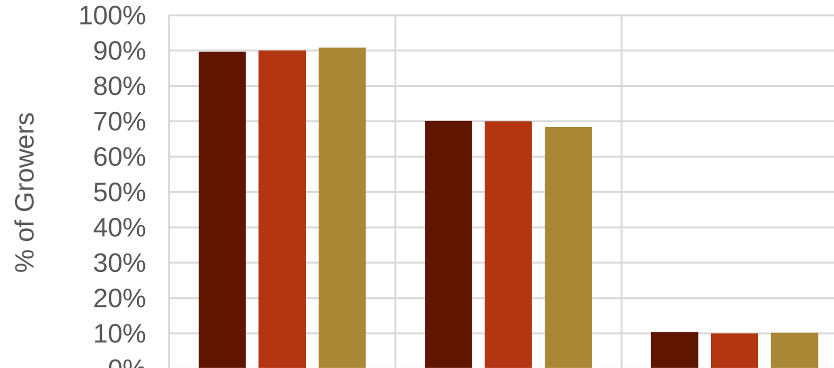
Nutrient Use Among Growers who Plant Sorghum in Indicated Years

Irrigated Sorghum Acres*



	Nitrogen	Phosphate	Potash
2017	85%	85%	15%
2018	85%	77%	23%
2019	87%	80%	33%
Base:	*13*	*13*	*14*

Non-Irrigated Sorghum Acres



	Nitrogen	Phosphate	Potash
2017	90%	70%	10%
2018	90%	70%	10%
2019	91%	68%	10%
Base:	*87*	*90*	*98*

Source: What was your nitrogen fertilizer target [lbs/acre] in [year] for your [irrigated/non-irrigated] sorghum acres? Please tell me the application rate for [phosphate/potash] to your [irrigated/non[irrigated] sorghum acres in [year]?
**Caution due to small sample.*

Nitrogen Use

- Growers with irrigated sorghum acres generally apply nitrogen at a rate of 108 lbs. per acre, compared to a target rate of 77 lbs. per acre for growers with non-irrigated sorghum acres. Over the past three years, growers with non-irrigated sorghum apply 30 lbs. to 35 lbs. less per acre to their sorghum than growers with irrigated acres. Growers target rate for nitrogen has not changed significantly over the past three years.
- Most growers (with or without irrigated acres) treat the majority of their sorghum acres with nitrogen.

Nitrogen Target Application Rates and Acres Treated at Target Rate

Irrigated*	2017	2018	2019	*Base*
Average Target Rate (lbs./acre)	113.6	112.3	107.7	*11,11,13*
% of Sorghum Acres Treated	87%	93%	87%	*13,13,15*
Average Sorghum Acres Treated (among users only)	169.1	169.1	137.3	*11,11,13*

Non-Irrigated	2017	2018	2019	*Base*
Average Target Rate (lbs./acre)	77.9	78.0	77.4	*78,81,89*
% of Sorghum Acres Treated	92%	92%	93%	*87,90,98*
Average Sorghum Acres Treated (among users only)	417.7	402.1	396.4	*78,81,89*

Source: What was your nitrogen fertilizer target rate in lbs. per acre in [year] for your [irrigated/non-irrigated] sorghum acres? For context, a recent study found a target rate of 0.91 pounds per bushel. How many acres were treated at that rate in [year]?
**Caution due to small sample.*

Phosphate Use

- Growers generally apply phosphate at a slightly higher rate on their irrigated acres (35 lbs./acre) than non-irrigated acres (29 lbs./acre). Over the past three years, phosphate is applied to 70% to 75% of both irrigated and non-irrigated sorghum acres.

Phosphate Application Rates and Acres Treated at Application Rate

Irrigated*	2017	2018	2019	*Base*
Average Rate (lbs./acre)	32.3	31.5	35.0	*11,10,12*
% of Irrigated Sorghum Acres Treated	76%	69%	77%	*13,13,14*
Average Sorghum Acres Treated (among users only)	162.7	152.0	147.1	*11,10,12*

Non-Irrigated	2017	2018	2019	*Base*
Average Rate (lbs./acre)	29.0	29.4	29.2	*61,63,67*
% of Sorghum Acres Treated	74%	75%	70%	*87,90,98*
Average Sorghum Acres Treated (among users only)	508.3	502.7	469.6	*61,63,67*

Source: Please tell me the application rate for [phosphate] to your [irrigated/non[irrigated] sorghum acres in [year]? How many acres were treated at that rate?
** Caution due to small sample.*

Potash Use

- Potash is applied to about 10 percent of sorghum acres (irrigated and non-irrigated) at a rate of about 30 lbs. to 35 lbs. per acre.

Potash Application Rates and Acres Treated at Application Rate

Irrigated*	2017	2018	2019	*Base*
Average Rate (lbs./acre)	45.0	30.7	40.0	*2,3,5*
% of Sorghum Acres Treated	7%	10%	20%	*13,13,15*
Average Sorghum Acres Treated (among users only)	85.0	77.7	91.0	*2,3,5*

Non-Irrigated*	2017	2018	2019	*Base*
Average Rate (lbs./acre)	30.8	33.6	31.5	*9,9,10*
% of Sorghum Acres Treated	11%	9%	10%	*87,90,98*
Average Sorghum Acres Treated (among users only)	505.6	418.3	444.0	*9,9,10*

Source: Please tell me the application rate for [potash] to your [irrigated/non[irrigated] sorghum acres in [year]? How many acres were treated at that rate?
** Caution due to small sample.*

SORGHUM CHECKOFF

Other Farm Information

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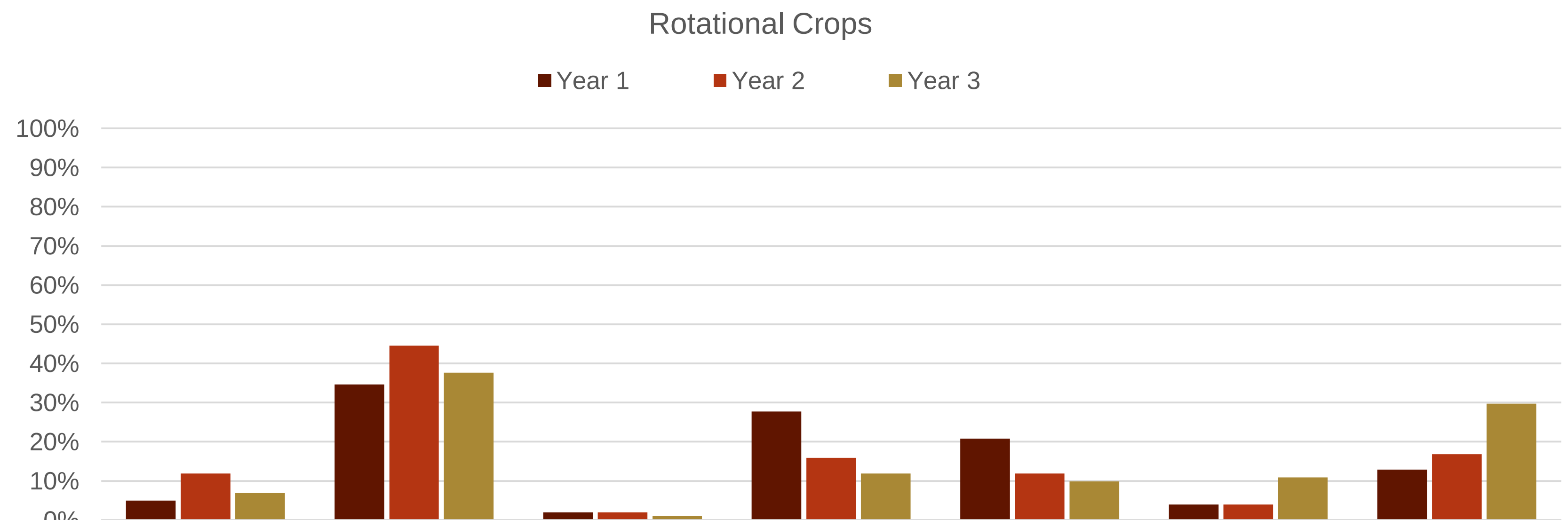
Crop Rotation

- Wheat is the crop that typically follows sorghum for the single largest portion of growers (38%).



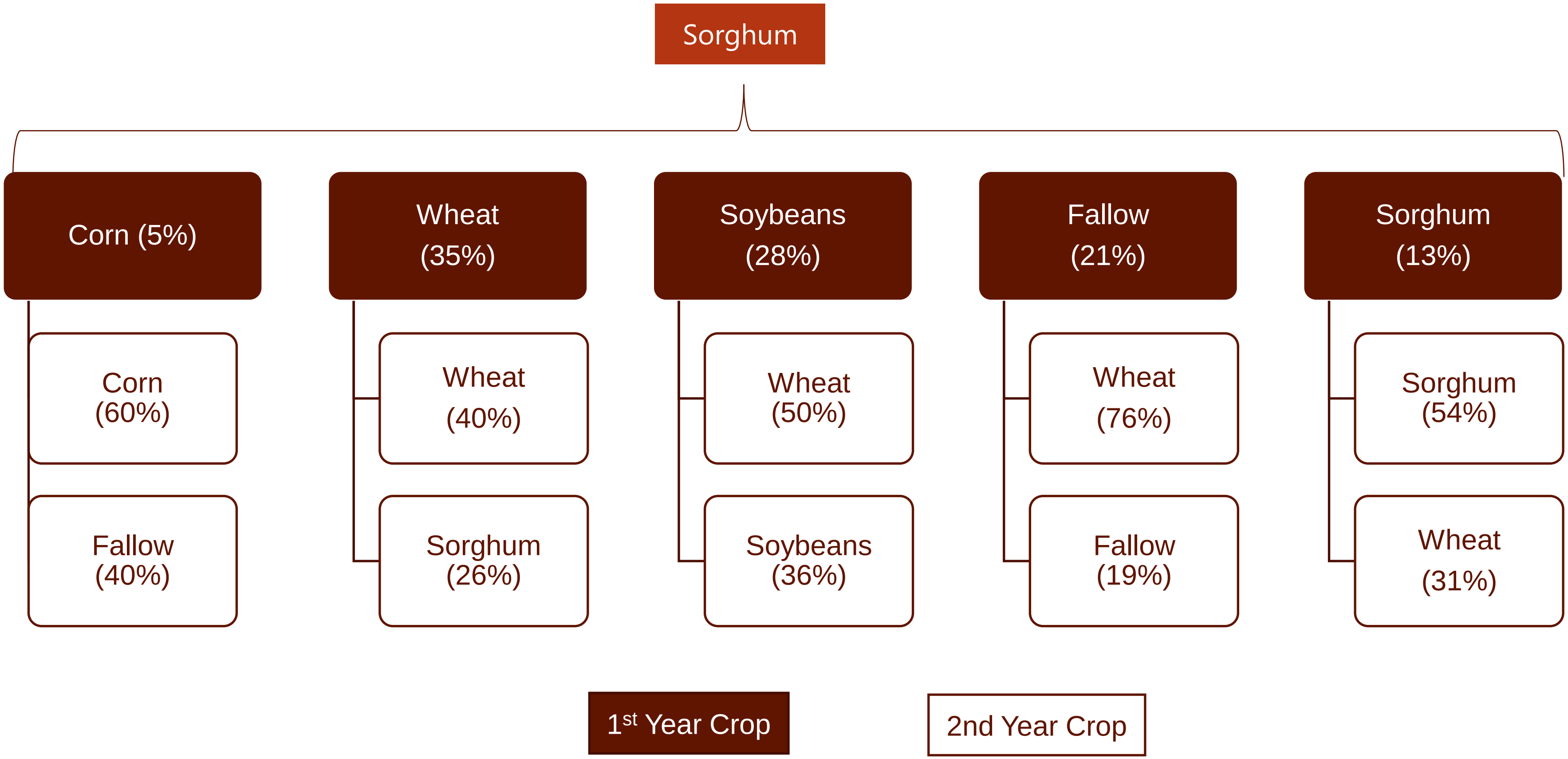
	Corn	Wheat	Cotton	Soybeans	Fallow	Other	Sorghum
Year 1	5%	35%	2%	28%	21%	4%	13%
Year 2	12%	45%	2%	16%	12%	4%	17%
Year 3	7%	38%	1%	12%	10%	11%	30%

Base =101.

Source: Common Kansas rotational systems include sorghum-wheat and sorghum-soybeans. What is your typical sorghum rotation?

1st and 2nd Year Crop Rotations

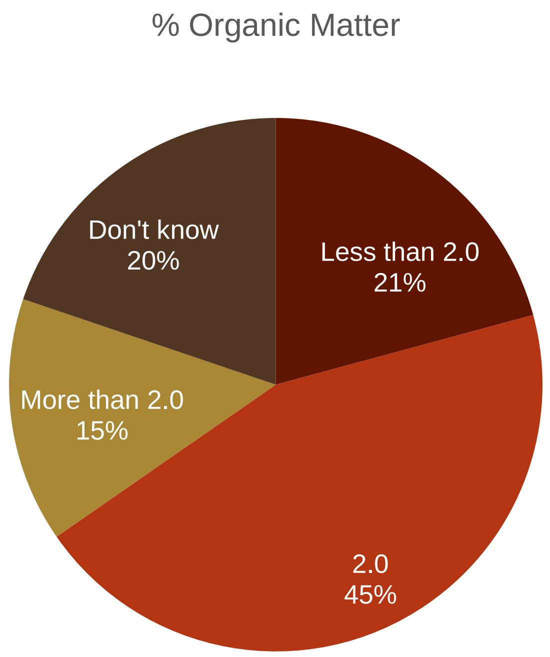
- The diagram below shows crops following sorghum in the first year followed by the two most mentioned second year crops. The highest portion of growers plant wheat (35%) or soybeans (28%) following sorghum in the first year. Half of growers who plant soybeans following sorghum plant wheat in the second year following sorghum.



Source: Common Kansas rotational systems include sorghum-wheat and sorghum-soybeans. What is your typical sorghum rotation?

Organic Matter

- Growers report an average of 2% organic matter. About 20% of growers did not know the percent of organic matter.



Base =101.

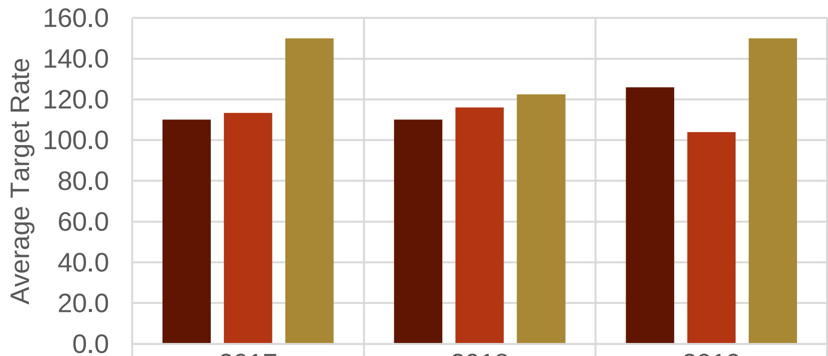
Source: What is your typical organic matter percentage? For context, typical Kansas soils have organic matter between 0% and 3%.

Nitrogen Use by Organic Matter

- Among growers with non-irrigated sorghum acres, growers with higher percentages of organic matter report having a higher target rate for nitrogen on average.

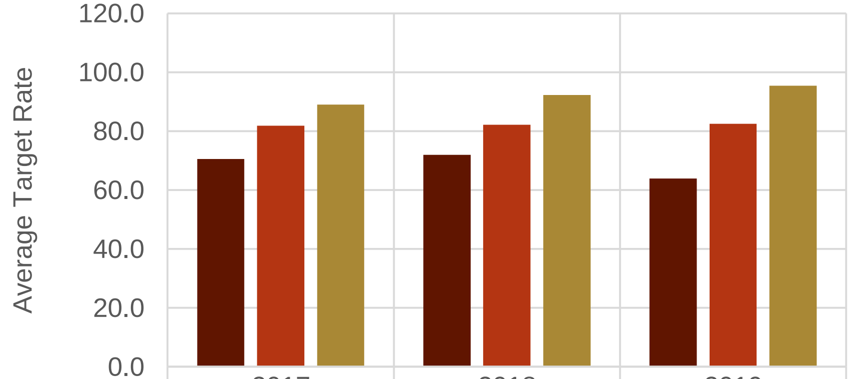
Average Target Nitrogen Rate by Percent Organic Matter

Irrigated Sorghum Acres*



	2017	2018	2019
< 2%	110.0	110.0	126.0
2%	113.3	116.0	104.0
>2%	150.0	122.5	150.0
<2%. Base:	*3*	*3*	*5*
2% Base:	*6*	*5*	*5*
>2% Base:	*1*	*2*	*1*

Non-Irrigated Sorghum Acres*

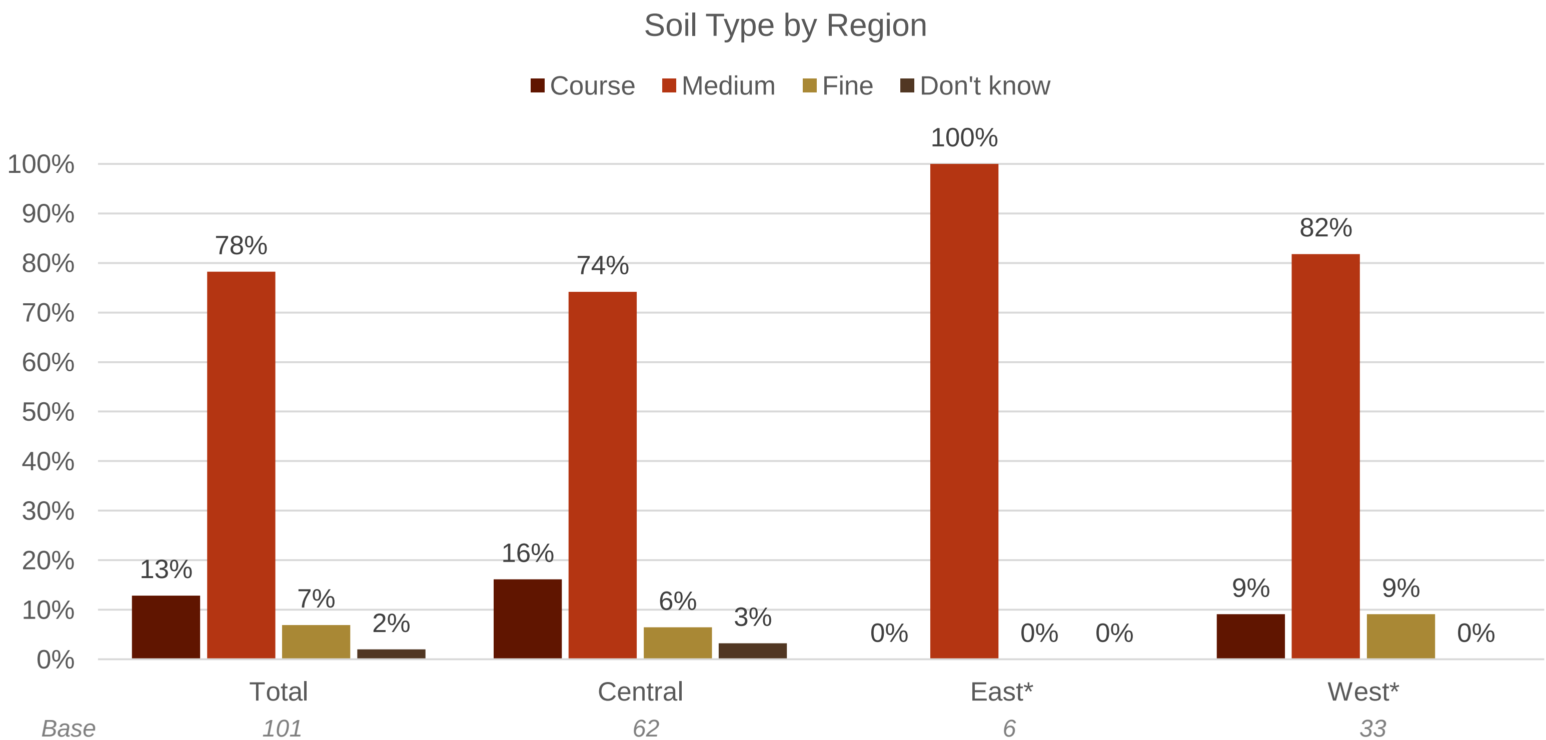


	2017	2018	2019
< 2%	70.5	71.9	63.9
2%	81.8	82.1	82.5
>2%	89.0	92.3	95.4
<2%. Base:	*15*	*14*	*17*
2% Base:	*38*	*38*	*40*
>2% Base:	*10*	*11*	*13*

Source: What was your nitrogen fertilizer target [lbs/acre] in [year] for your [irrigated/non-irrigated] sorghum acres? Please tell me the application rate for [phosphate/potash] to your [irrigated/non[irrigated] sorghum acres in [year]? What is your typical organic matter percentage? For context, typical Kansas soils have organic matter between 0% and 3%.
**Caution due to small sample.*

Soil Type

- Most growers, regardless of region, describe their soil type as medium.



Source: How would you define your typical soil type---course, medium or fine?
**Caution due to small bases.*

SORGHUM CHECKOFF

Carbon Footprint Study

Appendix

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Counties in Regions

County	Region	County	Region	County	Region
Barber	Central	Cheyenne	West	Coffey	East
Barton	Central	Clark	West	Douglas	East
Butler	Central	Decatur	West	Johnson	East
Clay	Central	Finney	West	Labette	East
Cloud	Central	Ford	West	Marshall	East
Comanche	Central	Gove	West	Morris	East
Cowley	Central	Graham	West	Nemaha	East
Dickinson	Central	Grant	West	Riley	East
Edwards	Central	Gray	West	Shawnee	East
Ellis	Central	Greeley	West		
Ellsworth	Central	Hamilton	West	Saline	Central
Harper	Central	Haskell	West	Sedgwick	Central
Harvey	Central	Hodgeman	West	Smith	Central
Jewell	Central	Kearny	West	Stafford	Central
Kingman	Central	Lane	West	Sumner	Central
Kiowa	Central	Logan	West	Washington	Central
Lincoln	Central	Meade	West		
Marion	Central	Morton	West		
McPherson	Central	Ness	West		
Mitchell	Central	Norton	West		
Osborne	Central	Rawlins	West		
Ottawa	Central	Scott	West		
Pawnee	Central	Seward	West		
Phillips	Central	Sheridan	West		
Pratt	Central	Sherman	West		
Reno	Central	Stanton	West		
Republic	Central	Stevens	West		
Rice	Central	Thomas	West		
Rooks	Central	Trego	West		
Rush	Central	Wallace	West		
Russell	Central	Wichita	West		

Sorghum Sustains

Findings from the KansCAT Database

Project Summary

Few farmers have the information or ability to quantify the effectiveness of various farm practices in improving soil health and water quality. This project, titled "Community and Market Partnerships to leverage the creation and application of a technology platform, KansCAT, for conservation of soil and water systems in Kansas," consists of three objectives aimed at addressing this problem. These objectives include 1) deploying a database for storing and assessing practice information, 2) increasing literacy of farmers and conservation Partners using this information and 3) leveraging conservation practices for value in carbon-focused ethanol markets.

Partners in this project include National Sorghum Producers, Natural Resources Conservation Service, United Sorghum Checkoff Program, Kansas Sorghum, Kansas Department of Agriculture, Kansas State University, Conestoga Energy Partners, Western Plains Energy, and Field to Market. In addition to Partners, the project surveyed numerous farmers growing crops on approximately 80,000 acres covering 79 percent of the U.S. sorghum ethanol demand shed and 100 percent of the Kansas ethanol demand shed.

The project saw dozens of educational pieces disseminated to various stakeholder groups including and especially farmers. Young and beginning farmers in particular were targeted for education that would drive positive natural resource outcomes. In keeping with this, social media and podcasts were the centerpiece of the project's outreach effort. To learn more, visit https://sorghumgrowers.com/kanscat/.

Findings

In addition to the need to understand current practices to improve environmental outcomes in the future, it is important to know farmers' footprints given their growing importance in environmental services markets. For example, nitrogen application and energy usage are just two of many important variables under the California Low Carbon Fuel Standard, the framework under which most sorghum ethanol is marketed.

Key findings from the project include a weighted average nitrogen application rate (for irrigated and dryland acres) of **0.75 pounds per bushel,** a minimum tillage adoption rate of **89.6 percent** and a dryland farming practice adoption rate of **93.6 percent.** These values make Kansas sorghum farmers among the best in the U.S. in terms of conservation and sustainability practice adoption and environmental stewardship. In particular, few farmers till less than those in Kansas, and this adds to air quality, water quality and soil carbon sequestration in Kansas.

Exposure for Young Conservationists

In addition to targeting young farmers for education that would drive positive natural resource outcomes, this project featured a landmark partnership between National Sorghum Producers, Kansas Sorghum, and Kansas State University. The partnership created the Conservation and Sustainability Fellowship which saw two outstanding young conservationists work directly with participating farmers to collect information for the KansCAT database. These fellows were managed day-to-day by Kansas Sorghum and upon completing their fellowship took an active role in mentoring other young conservationists at Kansas State University.

Kansas Natural Resources Conservation Service

nrcs.usda.gov/

SORGHUM THE SMART CHOICE™

Updated Carbon Footprint Study

Topline Information

May 2022

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SORGHUM THE SMART CHOICE

Updated Carbon Footprint Study

Study Background

May 2022

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Study Background & Purpose

- In 2012, The United Sorghum Checkoff Program developed a model to analyze the carbon footprint of sorghum used for ethanol production based on information obtained from sorghum growers. This information was collected in an extensive study over time and included the following:
  - Sorghum acres – including both irrigated and non-irrigated acres in past five years; seeding rate; crop acres preceding 2012 sorghum.
  - Sorghum inputs (brands and acres treated) - including fertilizer, herbicide, insecticides, fungicides, seed treatments.
  - Sorghum outputs - including yields, sorghum stubble for grazing and bale.
  - Field operations (type of operation and sorghum acres covered) – including specific tillage practices; fertilizer, herbicide, insecticide and fungicide application methods; planting methods, cultivation methods, and harvest methods.
  - Energy use (type and quantity) – including energy for drying; energy for irrigation; residual energy; energy for delivery .

- In 2020, the United Sorghum Checkoff Program confirmed the model estimates using some of the primary predictors from the 2012 Sorghum Carbon Footprint Study. Now the United Sorghum Checkoff Program is interested in obtaining updated information for 2022. Thus, the current study will gather information from growers, with the purpose of confirming estimates and verifying near future estimates or sorghum's carbon footprint.

- Specifically, this study will gather the following information about sorghum production for both non-irrigated and irrigated acres for the years 2019, 2020 and 2021:
  - Sorghum production acres (seeding rates and crop acres)
  - Yields
  - Tillage practices (no till, minimum/strip till and conventional till acres)
  - Crop inputs (nitrogen fertilizers, phosphorus, potassium, sulfur and lime application rates and acres treated)
  - Organic matter percentage
  - Soil type

Methodology & Sample

- To gather information used in this study, phone interviews were conducted with 101 sorghum growers in Kansas in May 2022. Kansas was selected due to its high concentration of sorghum growers and high sorghum output. Kansas produces nearly half (48%) of all sorghum acres grown in the U.S. To participate in this study, growers had to meet the following criteria:
  - Have input into decisions about sorghum for their farming operation.
  - Not employed by or affiliated with advertising, sales promotion, market research or public relations organizations/companies.
  - Not employed by or affiliated with energy manufacturing company, distributor, or dealership.
  - Planted at minimum of 50 sorghum acres in 2021.

- To get a representative sample of sorghum growers across Kansas, counties were divided into three regions: Central, East and West (see appendix for a list of counties in each region). Soft quotas were imposed on each region. Below is the number of interviews completed in each region versus the quota.

- Note, one grower in the West reported producing 18,000 sorghum acres in 2021. Some results in this report exclude this grower from the analysis due to his disproportionate influence on stated results.

	Sampled Growers*		Acres Represented		
	Desired	Completed	# of Acres Represented*	% of Acres Represented	% of Acres Irrigated
Central	63	70	32,688	41%	1%
East/Others	2	4	1,255	2%	0%
West*	36	27	45,100	57%	7%
Total	101	101	79,043	100%	4%

** One sorghum producer reported 18,000 sorghum acres.*

SORGHUM™ THE SMART CHOICE

Updated Carbon Footprint Study

Sorghum Production

May 2022

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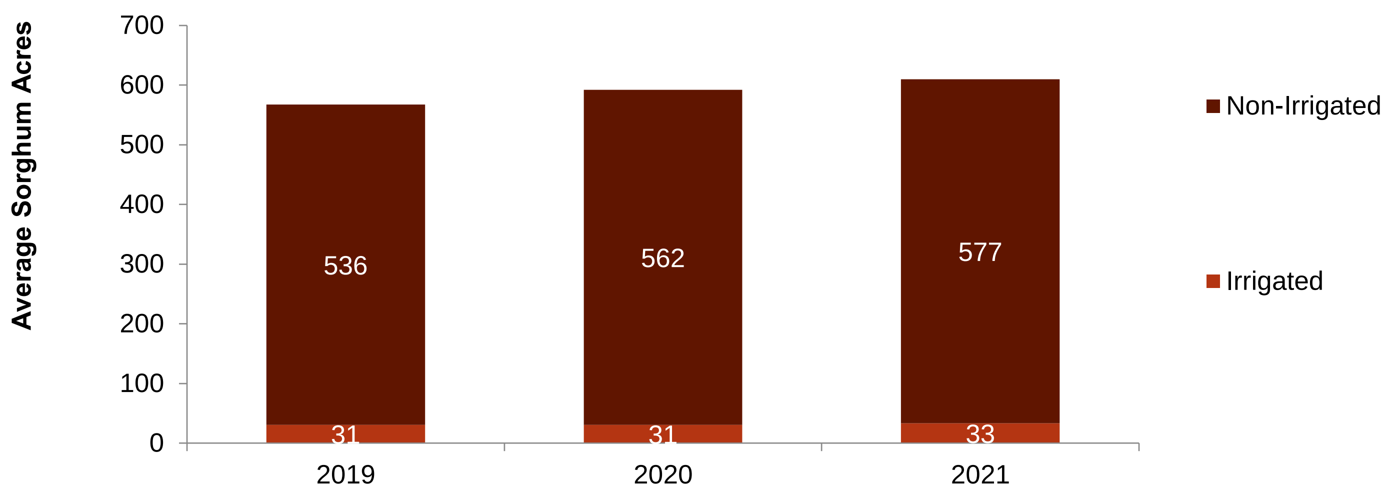
Sorghum Acres Planted

- Growers in this study planted on average 577 sorghum acres in 2021. Year over year, sorghum acres increased by about 4% each year from 2019 and 2021. Consistently, about 5% to 6% of sorghum acres are irrigated year over year. The latter result was similarly observed in the 2020 study.

Average Irrigated and Non-irrigated Sorghum Acres*



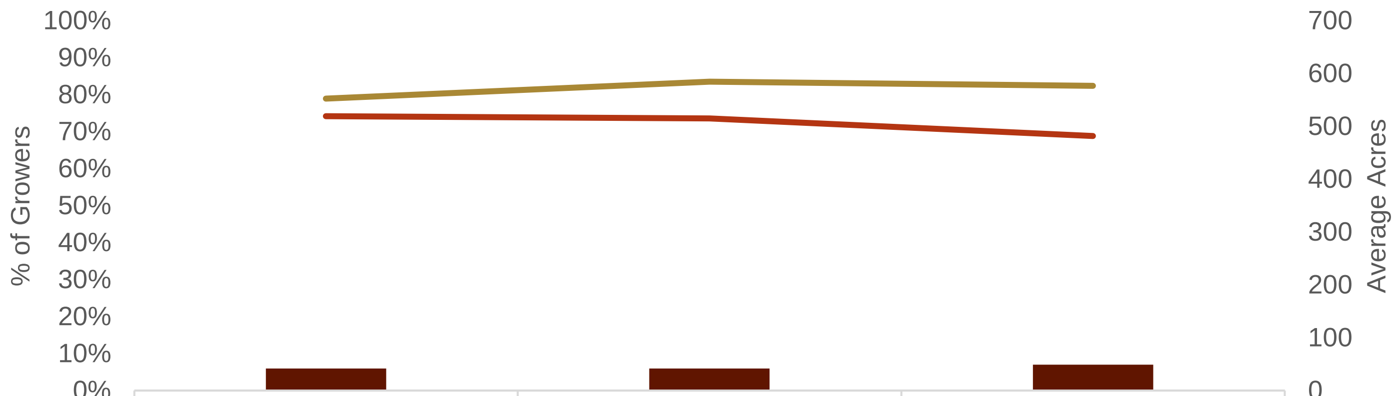
	2019	2020	2021
Average Sorghum Acres	568	593	610
% of All Sorghum Acres that are Irrigated	5%	5%	6%
*Base**	*100*	*100*	*100*

*Source: How many [irrigated/non-irrigated] sorghum acres did you plant in the following years? *Includes 0*
**One grower eliminated due to disproportionate influence on averages.*

Irrigation in Sorghum

- About 7% of growers had irrigated sorghum in 2021, similar to the previous two years.

Average Acres Among Growers with Irrigated Sorghum Acres *



	2019	2020	2021
% Growers With Irrigated Sorghum	6%	6%	7%
Average Acres Irrigated	519	516	482
Average Acres Non-Irrigated	553	585	577

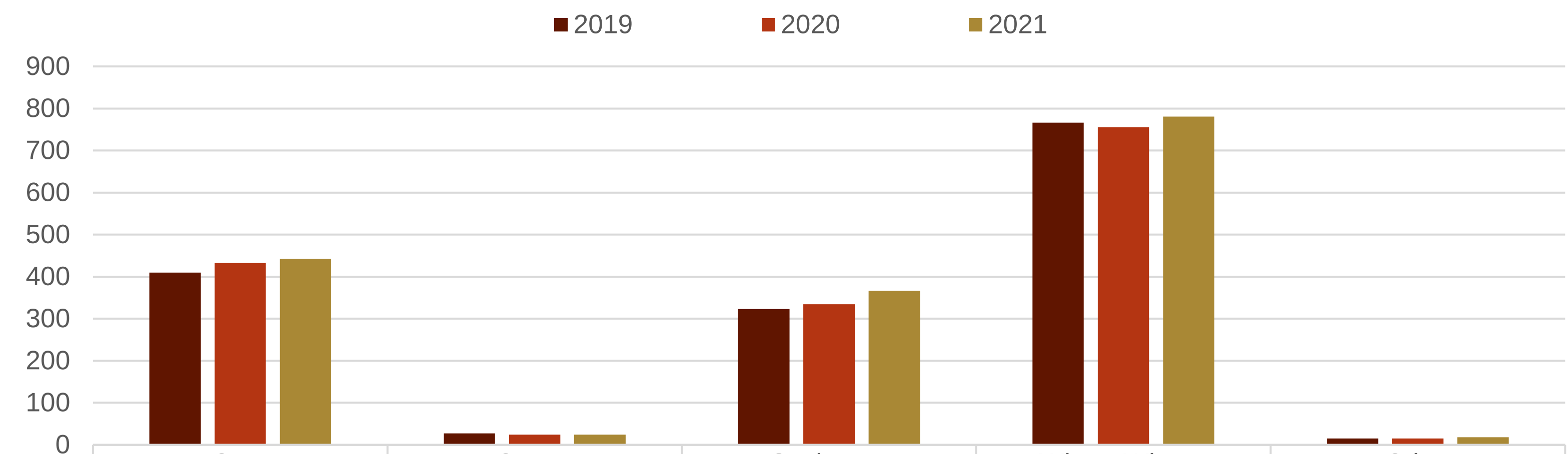
% of Growers	*100*	*100*	*100*
Average Irrigated	*6*	*6*	*7*
Average non-irrigated	*97*	*96*	*100*

Source: Were any of your sorghum acres irrigated in [insert year]? How many [irrigated/non-irrigated] sorghum acres did you plant in the following years?
**Caution due to small sample sizes. Excludes 0's. One grower eliminated due to disproportionate influence on averages.*

Other Crops Planted

- Year over year, winter wheat is the other crop planted most among sorghum growers. This result is consistent with the 2020 study results.

Average Acres of Other Crops (Excluding Sorghum) Planted by Year

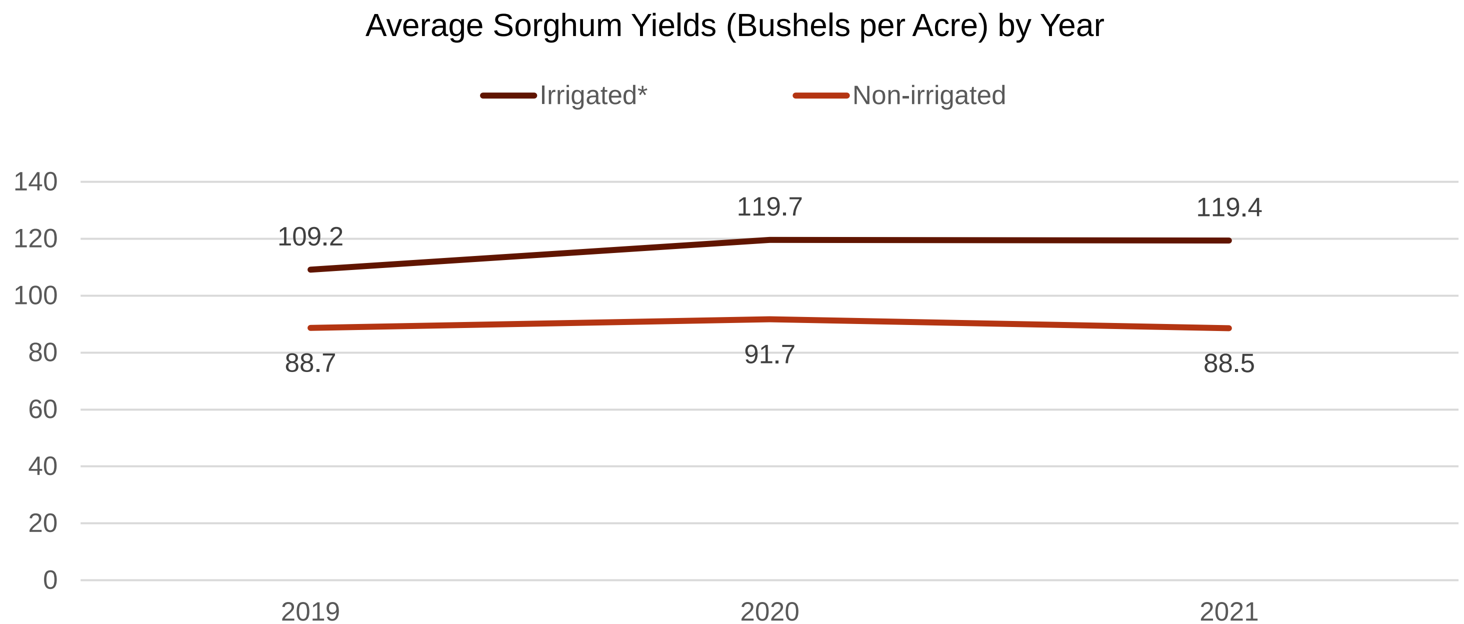


	Corn	Cotton	Soybeans	Winter Wheat	Other
2019	410	27	323	766	15
2020	432	25	335	756	15
2021	442	24	366	780	18

Source: How many acres of the following other crops did you plant in the following years? If none, enter 0. 0's included in average.

Sorghum Yields

- Non-irrigated sorghum yields have remained consistent over the past year at about 89 bushels per acre. Compared to the 2020 study, non-irrigated sorghum yields have increased by about 9%. Irrigated sorghum acres yield about 20% to 25% more bushels per acre than non-irrigated sorghum. This trend is consistent with the 2020 study.

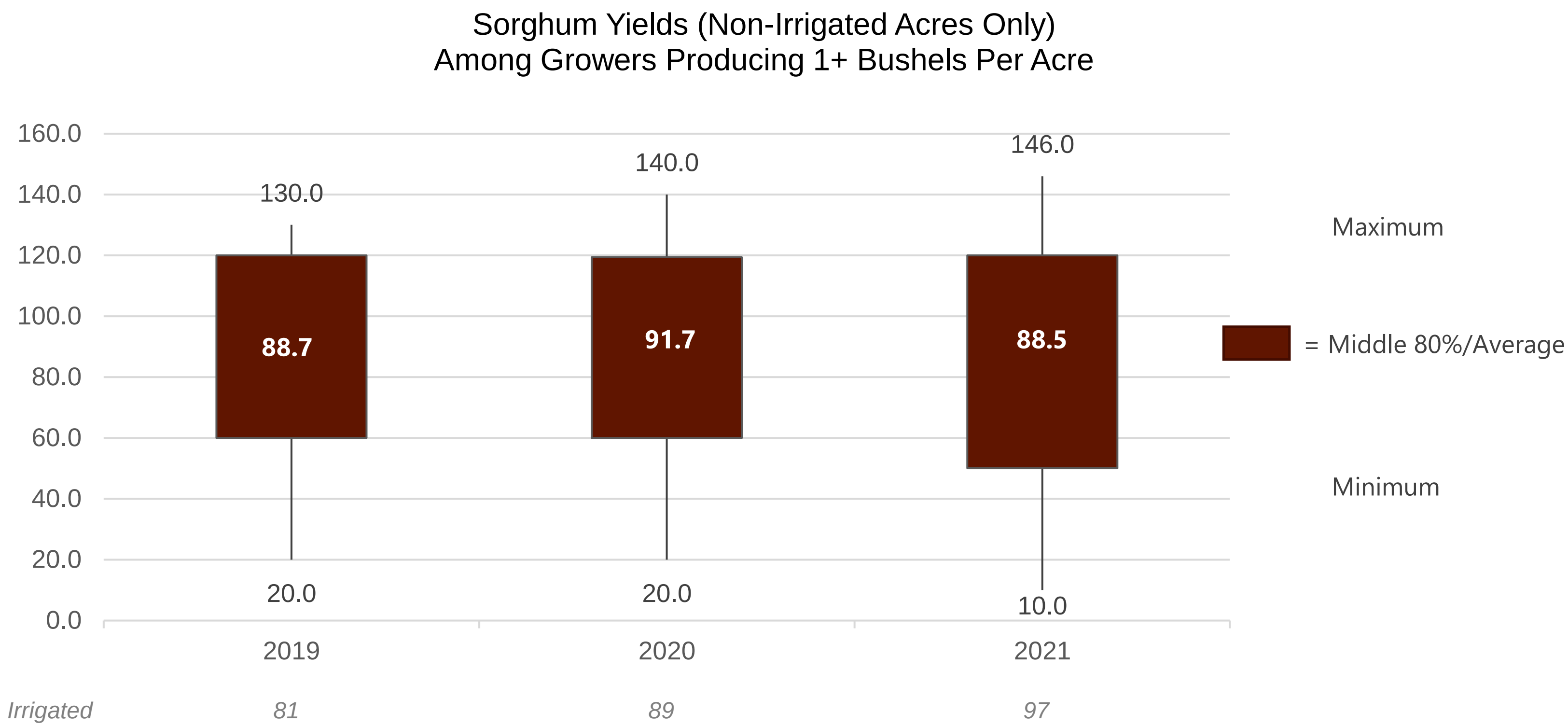


	2019	2020	2021
Base Irrigated	*6*	*6*	*7*
Base Non-irrigated	*96*	*95*	*99*

Source: What was your average sorghum yield in bushels per acre or pounds per acre for your [irrigated/non-irrigated] sorghum in the following years? Sorghum yields include 0's (i.e., growers who reported planting sorghum, cut said they had 0 yields.
** Caution due to small sample size..*

Sorghum Yields (Non-Irrigated Acres Only)

- Growers over the past three years have produced on average about 89 bushels per acre of sorghum on non-irrigated land. However, yields vary widely with most growers (80%) reporting yields between 50 and 120 bushels per acre.



Source: What was your average sorghum yield in bushels per acre or pounds per acre for your [non-irrigated] sorghum in the following years?

Updated Carbon Footprint Study

Tillage Practices

May 2022

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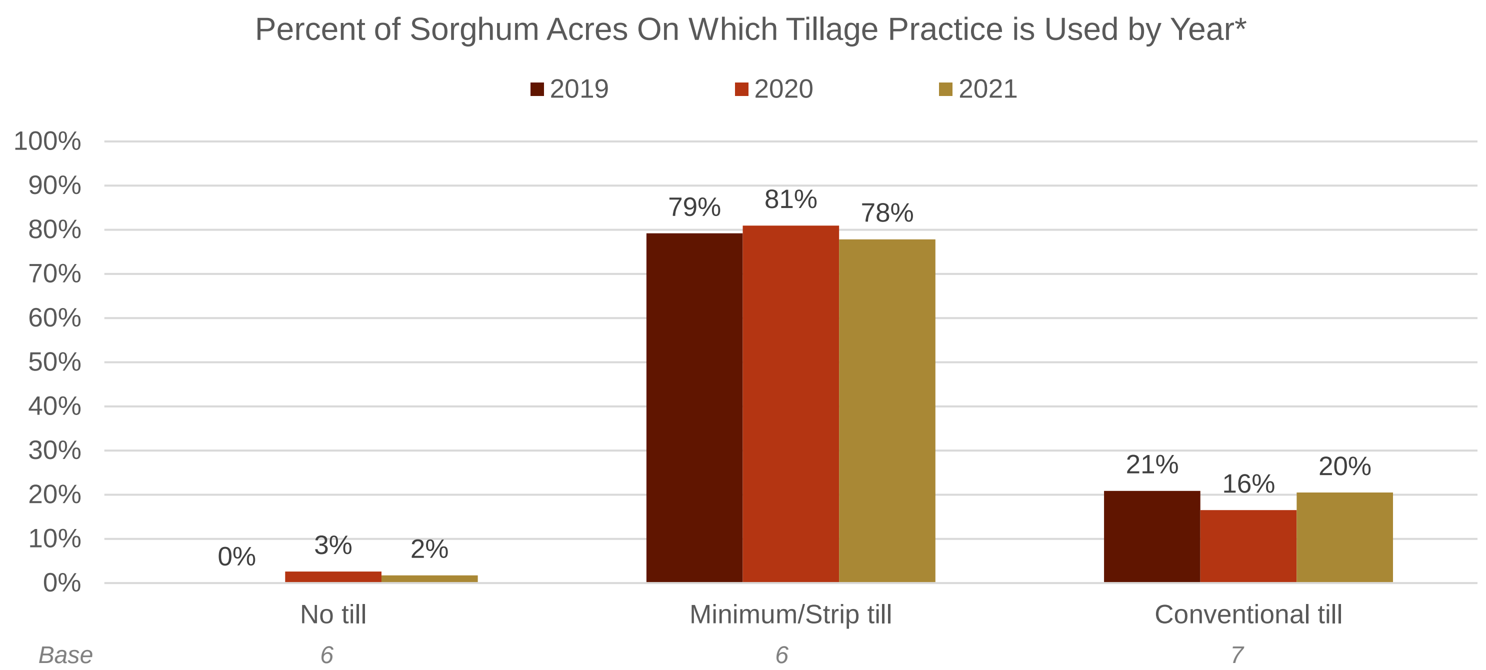
Tillage Practices on Irrigated Acres

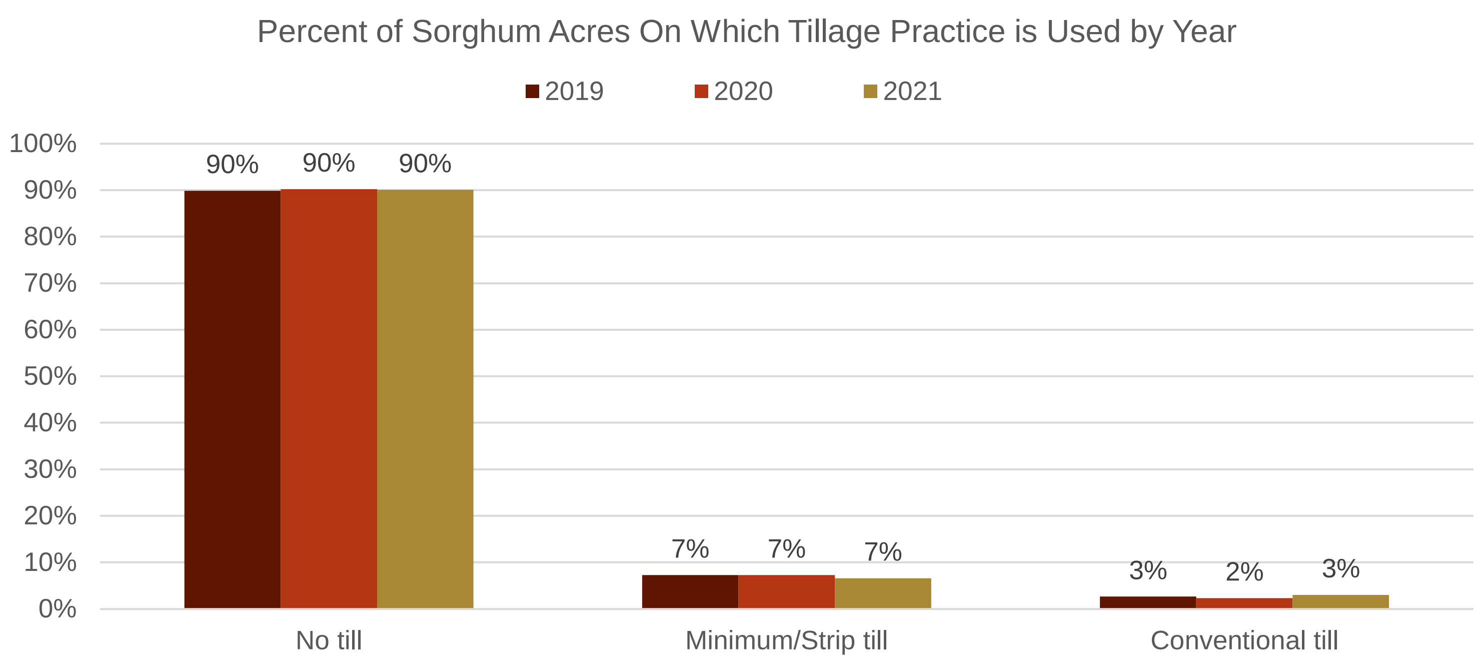
- Year over year, minimum/strip till is used on most all sorghum acres and conventional till is used on another 20% of sorghum acres. Few growers use no till.



Source: How many of your sorghum acres were no till, minimum/strip till or conventional tillage in [year]?
** Caution due to small sample.*

Tillage Practices on Non-Irrigated Acres

- Similar to the 2020 study, no till is used on most all sorghum acres. It is worth noting that the portion of no till sorghum acres increased in the current study by about 15% to 20% compared to the 2020 study, primarily at the expense of conventional till.



Base 2017	*101*
Base 2018	*101*
Base 2019	*101*

Source: How many of your sorghum acres were no till, minimum/strip till or conventional tillage in [READ YEAR[?

Updated Carbon Footprint Study

Carbon Inputs

May 2022

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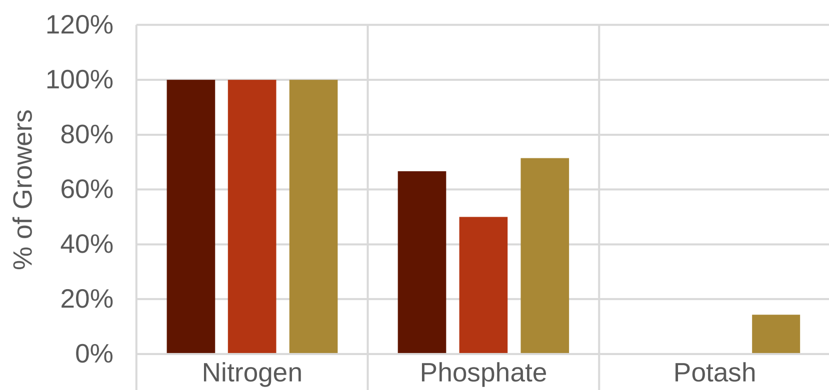
Nutrient Use

- Nearly all growers apply nitrogen to the non-irrigated sorghum acres (96% in 2021).
- Most all growers also apply phosphate to their non-irrigated acres.
- Few growers with non-irrigated sorghum apply potash (13% in 2021)*.
- For non-irrigated sorghum acres, these trends were also observed in the 2020 study.

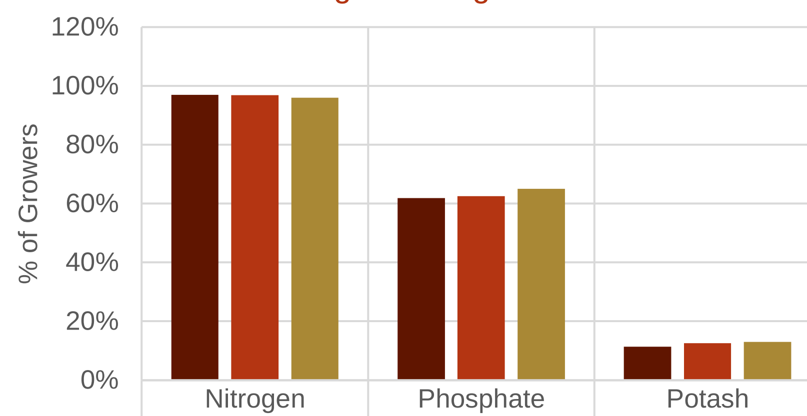
Nutrient Use Among Growers who Plant Sorghum in Indicated Years

Irrigated Sorghum Acres*



	Nitrogen	Phosphate	Potash
2019	100%	67%	0%
2020	100%	50%	0%
2021	100%	71%	14%
Base:	*6*	*6*	*7*

Non-Irrigated Sorghum Acres



	Nitrogen	Phosphate	Potash
2019	97%	62%	11%
2020	97%	63%	13%
2021	96%	65%	13%
Base:	*97*	*96*	*100*

Source: What was your nitrogen fertilizer target [lbs/acre] in [year] for your [irrigated/non-irrigated] sorghum acres? Please tell me the application rate for [phosphate/potash] to your [irrigated/non[irrigated] sorghum acres in [year]?
**Caution due to small sample.*

Nitrogen Use

- Growers with irrigated sorghum acres generally apply nitrogen at a rate of 115 lbs. per acre, compared to a target rate of 87 lbs. per acre for growers with non-irrigated sorghum acres. Compared to the same information gathered in 2020, results suggest growers increased their target rate for nitrogen over the past few years for both irrigated and non-irrigated sorghum acres.
- Most growers (with or without irrigated acres) treat the majority of their sorghum acres with nitrogen.

Nitrogen Target Application Rates and Acres Treated at Target Rate

Irrigated*	2019	2020	2021	*Base*
Average Target Rate (lbs./acre)	120.8	114.2	115.0	*6,6,7*
% of Sorghum Acres Treated	100%	100%	100%	*6,6,7*
Average Sorghum Acres Treated (among users only)	519.3	515.5	482.0	*6,6,7*

Non-Irrigated	2019	2020	2021	*Base*
Average Target Rate (lbs./acre)	85.6	85.7	87.3	*83,81,84*
% of Sorghum Acres Treated	99%	95%	91%	*97,96,100*
Average Sorghum Acres Treated (among users only)	819.7	902.1	717.5	*94,93,96*

Source: What was your nitrogen fertilizer target rate in lbs. per acre in [year] for your [irrigated/non-irrigated] sorghum acres? For context, a recent study found a target rate of 0.91 pounds per bushel. How many acres were treated at that rate in [year]?
**Caution due to small sample.*

Phosphate Use

- Growers generally apply phosphate at a rate of roughly 32 lbs./ acre on non-irrigated sorghum acres. Over the past three years, phosphate is applied to 70% to 75% of non-irrigated sorghum acres. Compared to the 2020 study, the phosphate rate increased slightly on non-irrigated sorghum acres from about 29 lbs./acre.

Phosphate Application Rates and Acres Treated at Application Rate

Irrigated*	2019	2020	2021	*Base*
Average Rate (lbs./acre)	32.5	30.0	44.0	*4,3,5*
% of Irrigated Sorghum Acres Treated	19%	20%	25%	*6,6,7*
Average Sorghum Acres Treated (among users only)	146.5	207.7	168.8	*4,3,5*

Non-Irrigated	2019	2020	2021	*Base*
Average Rate (lbs./acre)	32.6	32.4	32.8	*62,62,66*
% of Sorghum Acres Treated	71%	75%	72%	*97,96,100*
Average Sorghum Acres Treated (among users only)	922.9	1107.6	838.1	*60,60,65*

Source: Please tell me the application rate for [phosphate] to your [irrigated/non[irrigated] sorghum acres in [year]? How many acres were treated at that rate?
** Caution due to small sample.*

Potash Use

- Potash is applied to about 7% of sorghum acres at a rate of about 30 lbs. to 35 lbs. per acre. Rate results are consistent with results observed in 2020, although acres treated may have decreased slightly.

Potash Application Rates and Acres Treated at Application Rate

Irrigated*	2019	2020	2021	*Base*
Average Rate (lbs./acre)	-	-	80.0	*0,0,1*
% of Sorghum Acres Treated	-	-	8%	*6,6,7*
Average Sorghum Acres Treated (among users only)	-	-	260.0	*0,0,1*

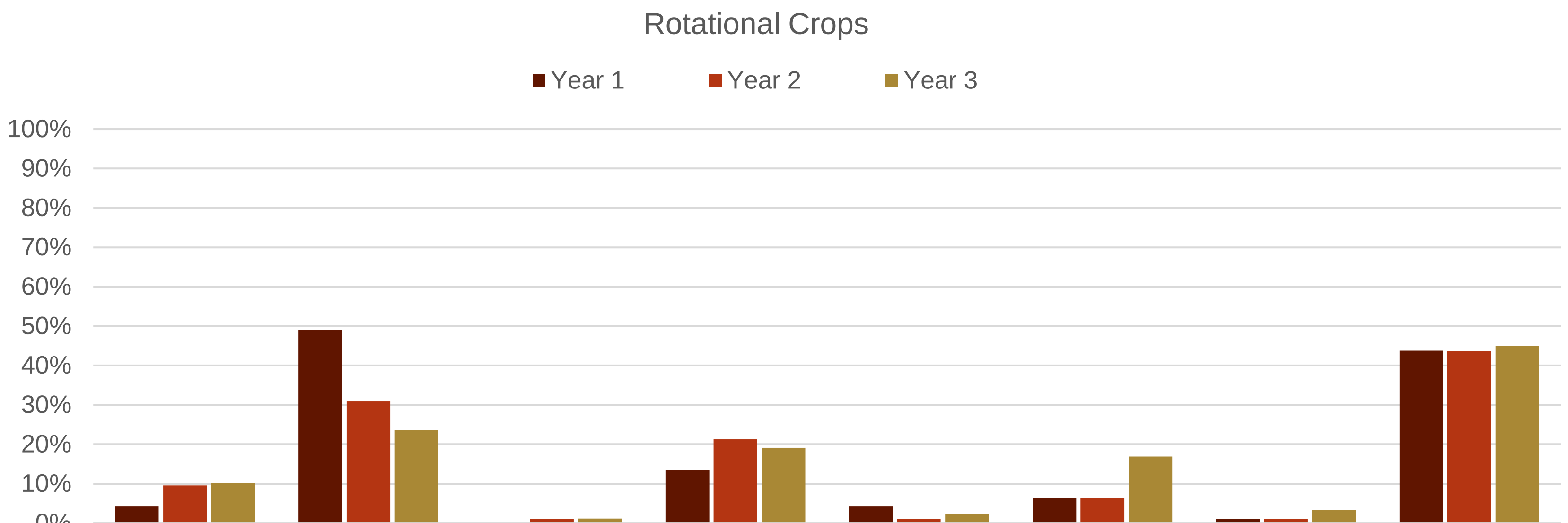
Non-Irrigated*	2019	2020	2021	*Base*
Average Rate (lbs./acre)	29.7	36.4	35.2	*11,12,13*
% of Sorghum Acres Treated	6%	5%	7%	*97,96,100*
Average Sorghum Acres Treated (among users only)	394.5	382.5	401.5	*11,12,13*

Source: Please tell me the application rate for [potash] to your [irrigated/non[irrigated] sorghum acres in [year]? How many acres were treated at that rate?
** Caution due to small sample.*

Other Farm Information

Crop Rotation

- Wheat is the crop that typically follows sorghum for the single largest portion of growers. Similar results were observed in the 2020 study.



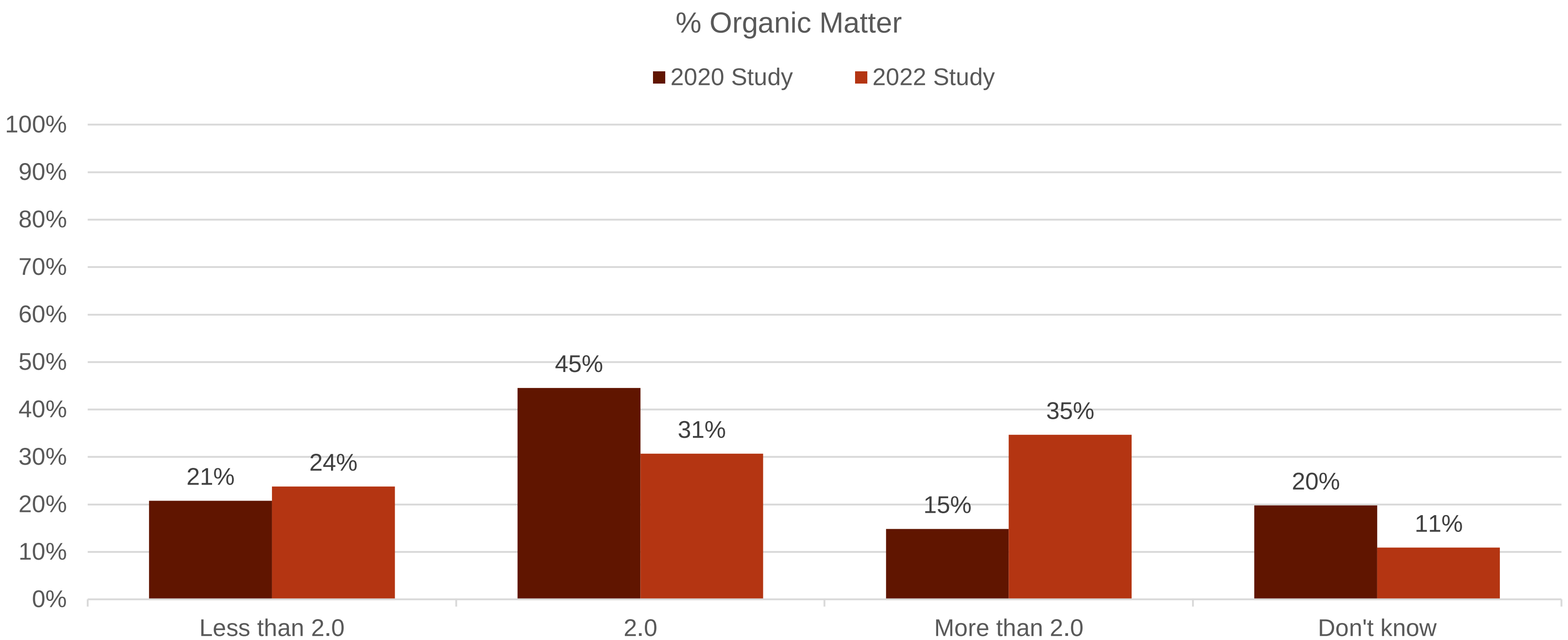
	Corn	Wheat	Cotton	Soybeans	Cover crop to control erosion	Fallow	Other	Sorghum
Year 1	4%	49%	0%	14%	4%	6%	1%	44%
Year 2	10%	31%	1%	21%	1%	6%	1%	44%
Year 3	10%	24%	1%	19%	2%	17%	3%	45%

Base =101.

Source: Common Kansas rotational systems include sorghum-wheat and sorghum-soybeans. What is your typical sorghum rotation?

Organic Matter

- Growers report an average of 2% organic matter in both 2020 and 2022.



Base =101.

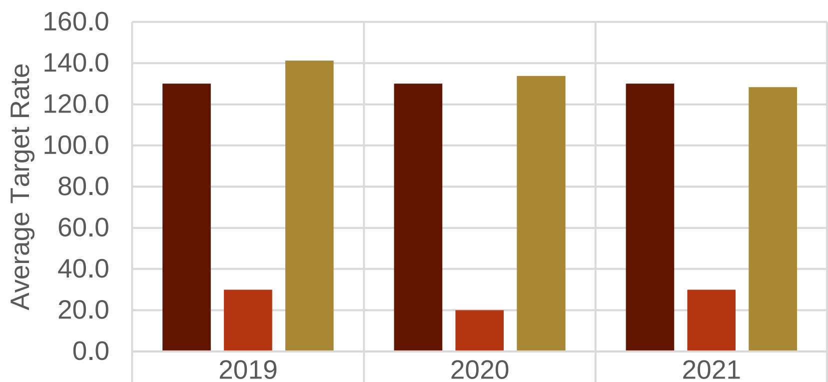
Source: What is your typical organic matter percentage? For context, typical Kansas soils have organic matter between 0% and 3%.

Nitrogen Use by Organic Matter

- Among growers with non-irrigated sorghum acres, growers with higher percentages of organic matter (>2%) report having a higher target rate for nitrogen on average.

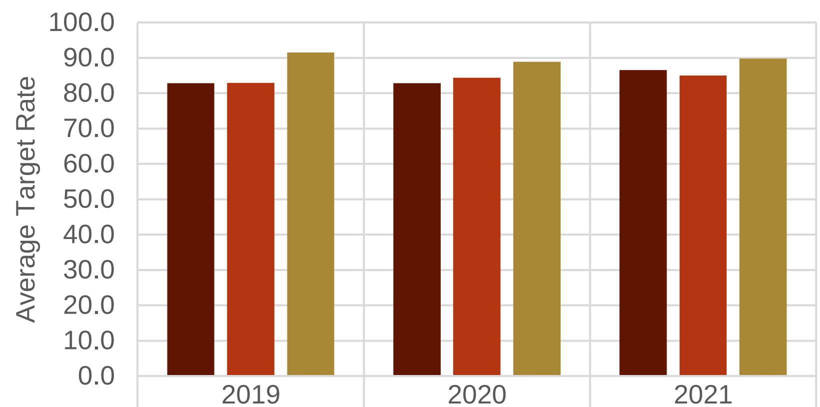
Average Target Nitrogen Rate by Percent Organic Matter

Irrigated Sorghum Acres*



	2019	2020	2021
< 2%	130.0	130.0	130.0
2%	30.0	20.0	30.0
>2%	141.3	133.8	128.3
<2%. Base:	*1*	*1*	*3*
2% Base:	*1*	*1*	*1*
>2% Base:	*4*	*4*	*3*

Non-Irrigated Sorghum Acres*

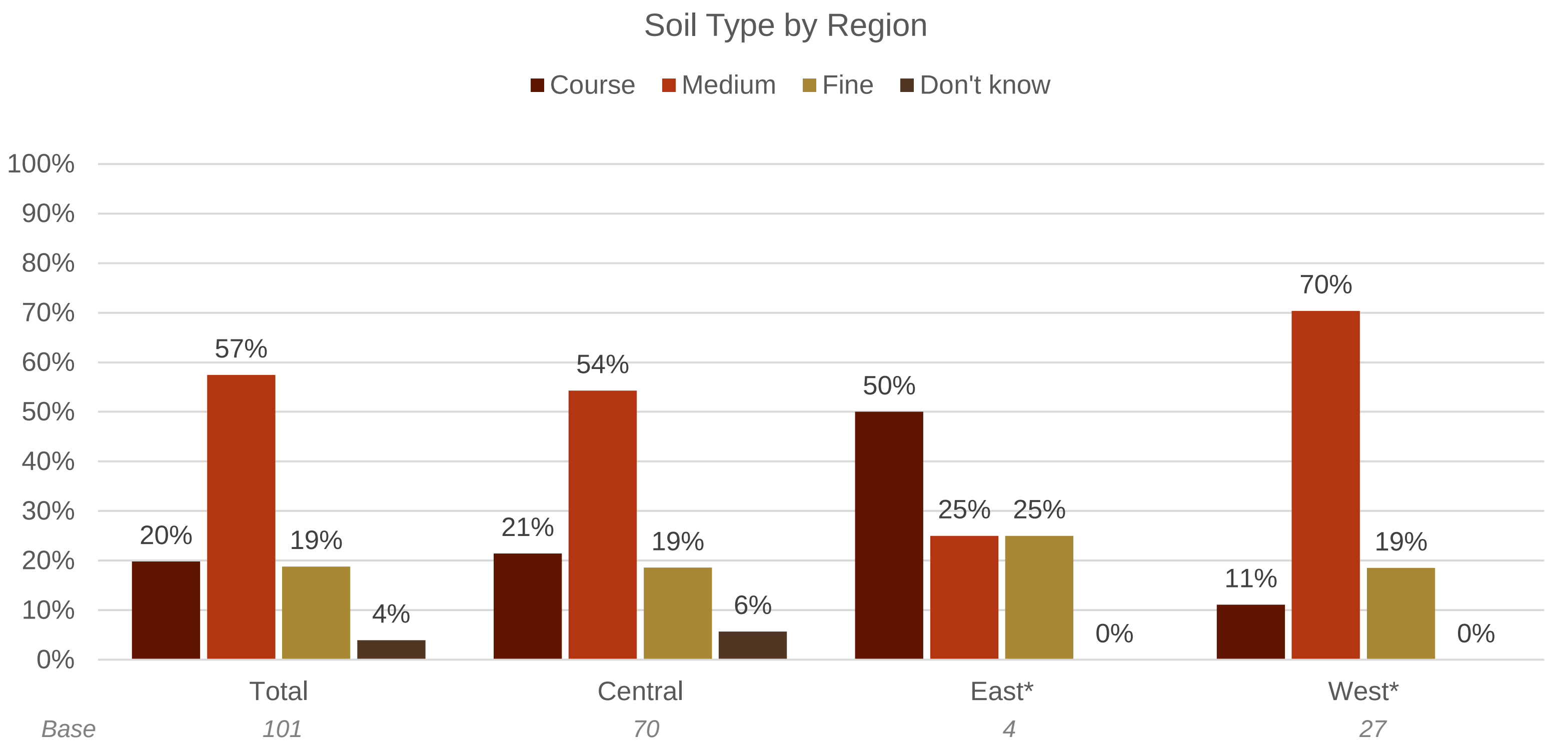


	2019	2020	2021
< 2%	82.8	82.8	86.6
2%	82.9	84.4	85.0
>2%	91.5	88.9	89.8
<2%. Base:	*22*	*22*	*21*
2% Base:	*26*	*26*	*27*
>2% Base:	*26*	*26*	*27*

Source: What was your nitrogen fertilizer target [lbs/acre] in [year] for your [irrigated/non-irrigated] sorghum acres? Please tell me the application rate for [phosphate/potash] to your [irrigated/non[irrigated] sorghum acres in [year]? What is your typical organic matter percentage? For context, typical Kansas soils have organic matter between 0% and 3%.
**Caution due to small sample.*

Soil Type

- Most growers describe their soil type as medium. This is especially true in the Western counties.



Source: How would you define your typical soil type---course, medium or fine?
**Caution due to small bases.*

SUSTAINABILITY ANALYSIS

2020 ON-FARM PRACTICES REPORT

EXECUTIVE SUMMARY

About the Project

United Sorghum Checkoff supports growers that are implementing conservation practices, in-field and edge-of-field, on their farms. They have partnered with Pheasants Forever to bring a unique program to assist with expertise and incentives to implement these types of practices. Sorghum is one of the top five cereal crops in the world. The growers in the program participated from across the state of Kansas. Kansas is the largest sorghum producer in the United States (Kansas Grain Sorghum Commission, 2019).

About Sorghum Checkoff

The Sorghum Checkoff commits to reveal the potential and versatility of sorghum through increased shared value.

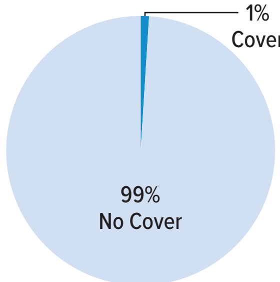
Quantifying the Impact of Actual Farm Practices

The benefits were determined through EcoPractices' unique process that is able to pinpoint the influence of specific agricultural practices. While agricultural practices have progressed to better care for natural resources, the ability to quantify the influence these practices have on sustainability has not kept pace. Having such data brings more depth to on-farm decision-making while reducing supply chain sustainability risk.

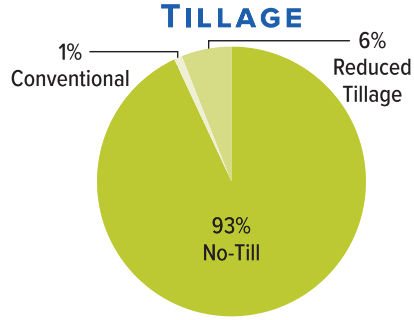
Conservation Practice	Fields	Acres
Buffer	1	5
Grassed Waterway	2	12

7 **farms** with **9,167** **acres** from **65** **fields**

Cover Crops



Tillage



According to the 2017 US Ag Census, the national average is **4% cover crop** adoption, **37% no-till** adoption, and **35% reduced till** adoption.

MANURE APPLICATION

7,505 **tons of natural manure** were applied. **13%** **of acres** received solid manure fertilizer at an average rate of **6.4** **tons/acre.**

MANURE ECONOMIC VALUE

The average **cost savings** from manure applied to **1,164** acres was estimated to be **$35.35** per acre based on a reduced need for commercial N, P & K resulting in **a total savings** of **$41,138.**

IRRIGATION EFFICIENCIES

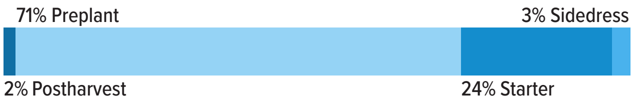
Pivots have nozzles which drop down closer to the ground to avoid much water loss.

7% **of fields are irrigated** at an average rate of **9.4** **acre-in per acre.**

One of the biggest benefits of growing sorghum is its drought tolerance. It originated in northeastern Africa and therefore is greatly adapted to arid-semiarid regions. It also requires less inputs, such as nitrogen fertilizer, compared to other grain crops. Sorghum is in the top 5 cereal grains by production and acreage internationally.**

FERTILIZER TIMING

Application timing is an important strategy to minimize fertilizer loss and increase efficiency.



AVERAGE APPLICATION RATE

An average rate of **66 lbs/acre of nitrogen** applied on **92% of acres.**

Weather, Soils, and In-Field Management Practices influence the following environmental metrics

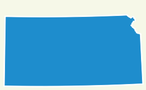
IN-FIELD ENVIRONMENTAL OUTCOMES

The data is reflective of weather and soils influence in addition to implemented in-field management practices for the project year.†

	OVERALL FARM
Net GHG Emissions	**-0.30 T CO_2e/ac**
Soil Carbon Sequestered	**0.18 T C/ac**
Soil Erosion Rate	**0.82 T/ac**

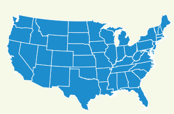
EROSION AVERAGE

*The USDA National Resources Inventory provides estimates on average erosion for different systems across the US.**



KS Cropland

5.0 T/ac



National Average

4.6 T/ac

CROP	% ACRES	YIELD
Sorghum Grain	98%	66 bu/ac
Soybean	2%	43 bu/ac

SOIL CONDITIONING INDEX (SCI)

Soil Conditioning Index (SCI) is a tool from NRCS that shows the trajectory of soil health. A positive SCI means a positive trajectory of soil health and vice versa.

The fields in the project are an overall **+ trajectory** for **SCI.**

CROPLAND

100%

IN-FIELD PRACTICE COMPARISON IMPACTS

When compared to conventional practices (i.e. conventional tillage, no cover crop scenario), in-field farm practices generated:‡

2,948 fewer tons of CO_2e, *which is the same as*

572 average passenger cars off the road for a year

or **15 rail cars of coal** saved from being burned

804 tons of soil carbon sequestered

10,249 tons of soil saved instead of being lost to erosion, *which is the same as*

641 dump trucks of soil

2 lbs/acre of nitrogen saved instead of being lost through leaching and runoff.

<1 lb/acre of phosphorus saved instead of being lost through runoff.

ECOPRACTICES

Data provided by 7 sorghum growers for the 2020 growing season and calendar year.

†‡EcoPractices estimates an environmental impact value for reducing greenhouse gas emissions, reducing soil erosion, and reducing nutrient loss due to reduced leaching. These estimates adhere to processes that are documented by the NRCS Technical Guides and publications from the EPA. These values are tailored to a specific location and participant's operation. Models used are supported by USDA, NRCS, other government agencies, and major universities. Modeled results include input data from public resources for weather, soils, and historical crop rotation. Greenhouse gas simulations were produced from the Greenhouse Gas Inventory (GGIT) tool developed by Soil Metrics, LLC (2021) https://soilmetrics.eco. The GGIT tool implements the USDA-sanctioned greenhouse gas inventory methods described in Eve et al. (2014) 'Quantifying Greenhouse Gas Fluxes in Agriculture and Forestry: Methods for Entity-Scale Inventory". The GGIT tool utilizes greenhouse gas modeling technology developed for the COMET-Farm tool, licensed by Colorado State University to Soil Metrics, LLC.

*USDA, NRCS 2017 National Resource Inventory | **Kansas State University, Department of Agronomy

This summary must not be edited or altered in any way without the involvement and consent of EcoPractices.

SORGHUM
THE RESOURCE CONSERVING CROP™

National Sorghum Producers

Climate Smart Agriculture And Forestry Partnership Initiative

COMMITTEE BRIEFING

Overview

Sorghum is a climate-smart commodity lacking only a framework for compensating sorghum farmers accordingly, and this project will build such a framework based on the existing California fuel market, the longest-running and most stable ecosystem services market in the U.S., and longer-term opportunities in the food space. In addition to being the best established, the California market also provides more compensation than other ecosystem services markets because it values all emissions reductions rather than just carbon emissions. For bushels already flowing into the California market, significant value from this market could accrue directly to sorghum farmers to incentivize climate-smart practices if a framework existed for ethanol plants to track these practices as attributes of their fuel and monetize them when selling into the very large California market. This fact makes the California fuel market a nearer-term opportunity to bridge the gap to longer-term and potentially equally valuable climate-smart markets tied to food. California has the most rigorous standards for measurement and verification, so basing our framework on its requirements will ensure a framework that can be used in these other potentially even higher value markets and for other crops, as well.

Target Geography

We will be recruiting farmers and landowners to take part in a pilot that will span a target geography that includes portions of five states. These five states cover 67 percent of the sorghum industry or approximately 4.4 million acres per year and will be a significant undertaking and one of the most important components of the program. The area includes approximately 20,000 farmers who are vitally important to U.S. agriculture.

Payment Mechanism

Farmers will have the option to choose up to three practices from a menu. These practices will be valued based on their estimated value in California and to our food company partners. A partial list is included below. The full list we are considering includes resource-conserving crop rotations; cover crops; manure management; row crop head usage; buffers, wetland and grassland management (edge of field practices); food plots; pollinator habitat; planting for a high carbon sequestration rate; soil amendments and biologicals.

Practice	CI Savings (g/bu)	Payment ($/ac)
No Till	2,152	$40.32
Precision N	2,350	$44.03
No Till + Precision N	2,904	$54.41
Reduced Irrigation	2,341	$58.03
Reduced Irrigation + No Till	2,895	$71.77
Reduced Irrigation + Precision N	3,093	$76.67
Reduced Irrigation + No Till + Precision N	3,647	$90.41