November 2015

Agricultural Market Research

The Carbon Footprint of Sorghum

for

SORGHUM CHECKOFF

SGS North America (Société Générale de Surveillance)

November 2015

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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:

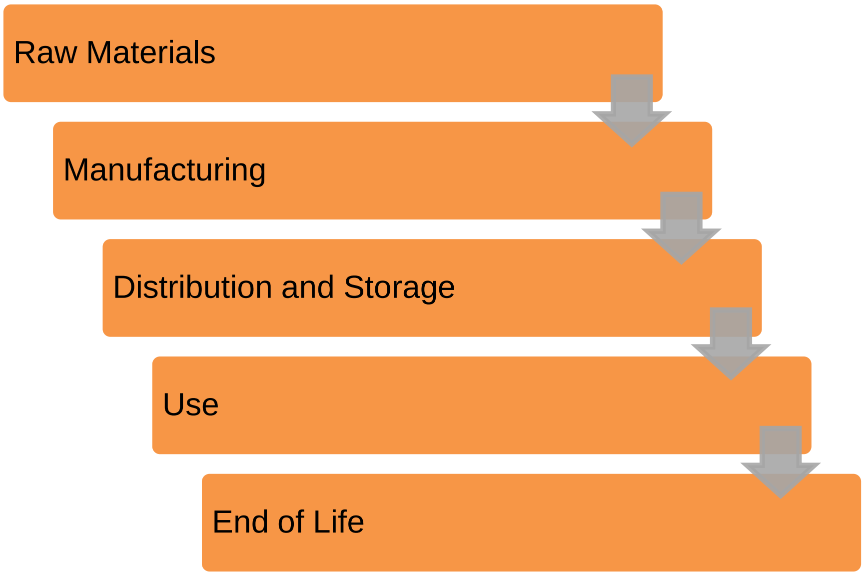


Figure 1. The stages of an LCA.

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:

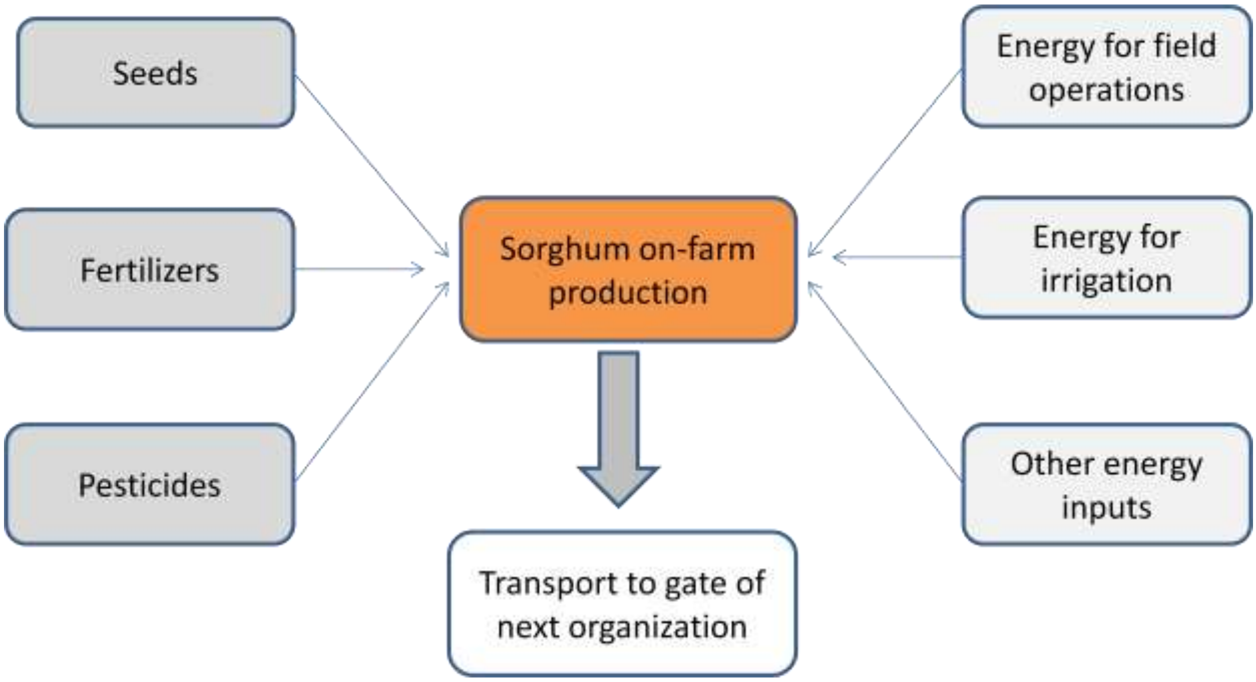


Figure 2. The sorghum LCA process map.

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

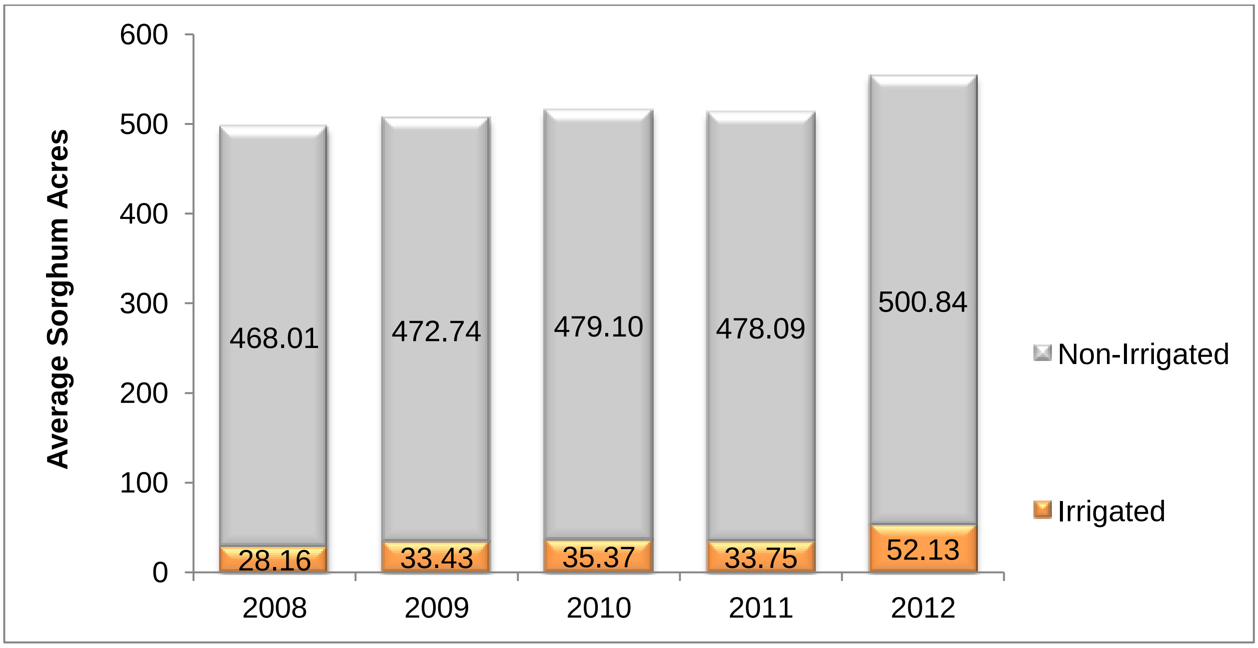
9.1 The Sample of Sorghum Acres by State (Irrigated and Non-Irrigated)

	# 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.

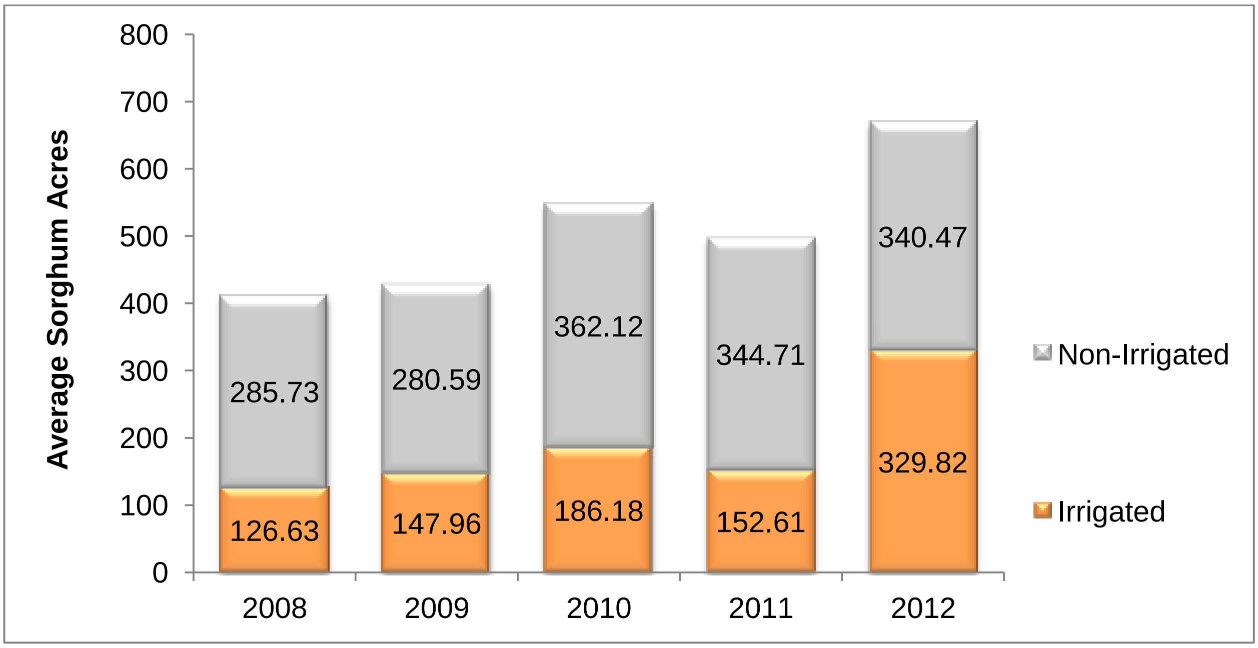
9.2 Average Sorghum Acres (All farmers)

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?



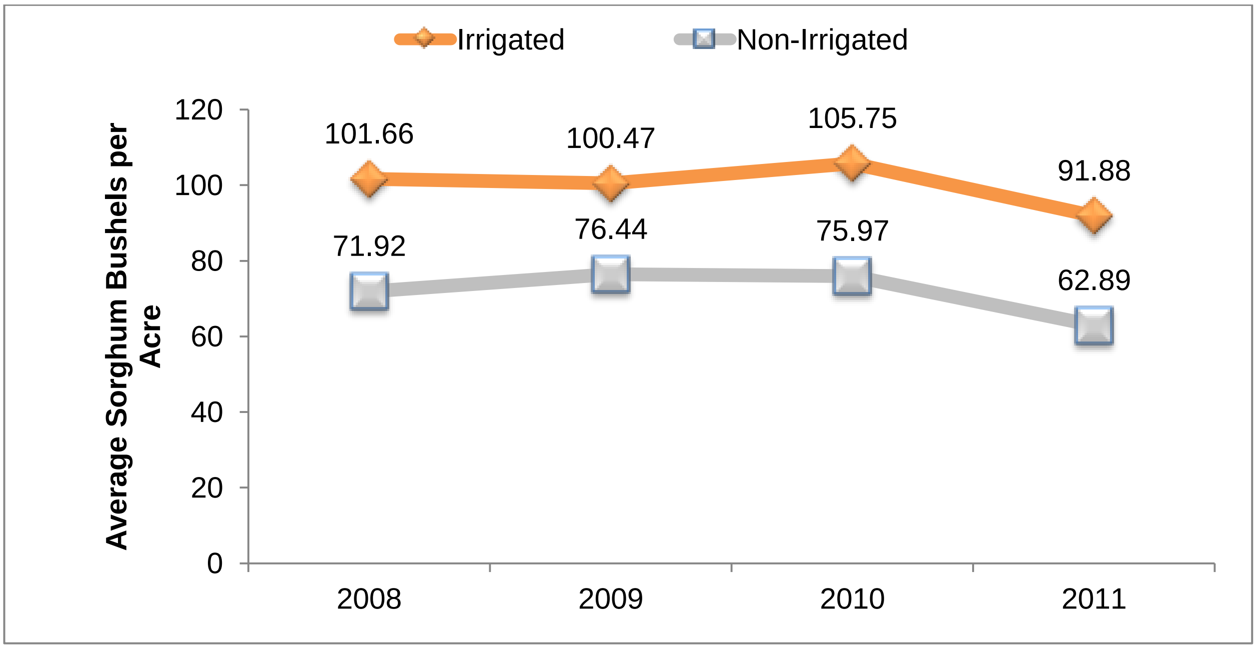
9.3 Average Sorghum Acres (Farmers with Irrigated Sorghum only)

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])

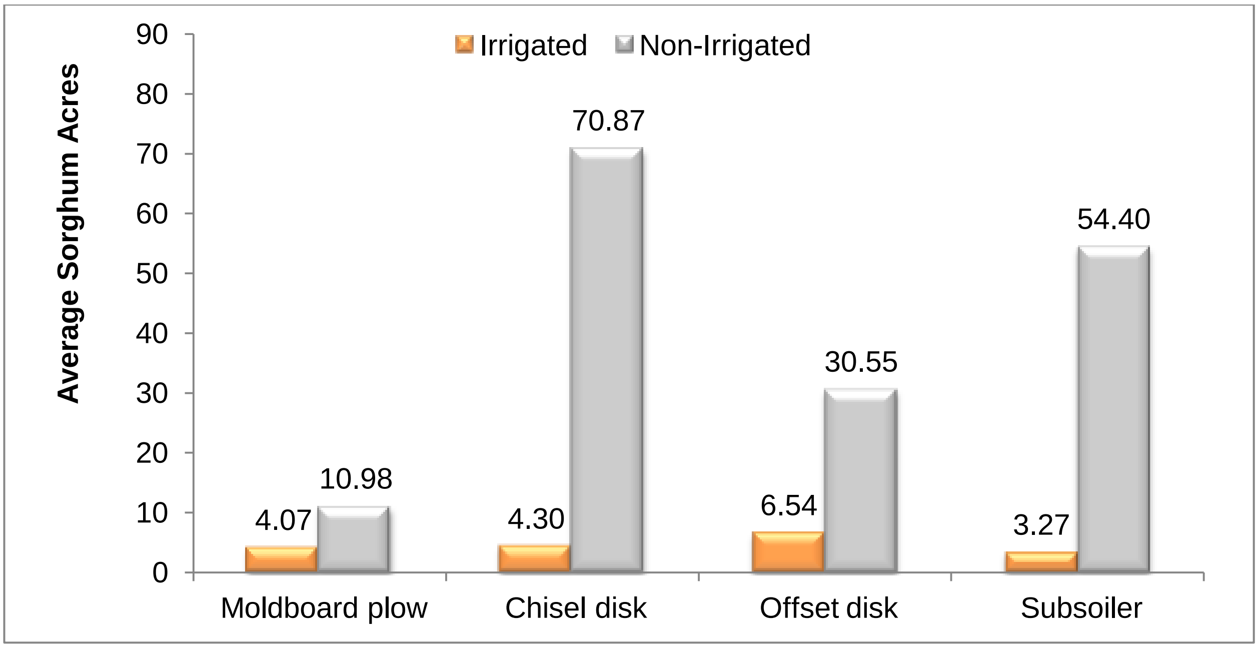
What was your average sorghum yield in bushels per acre or pounds per acre for your irrigated/non-irrigated sorghum in the following years?



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

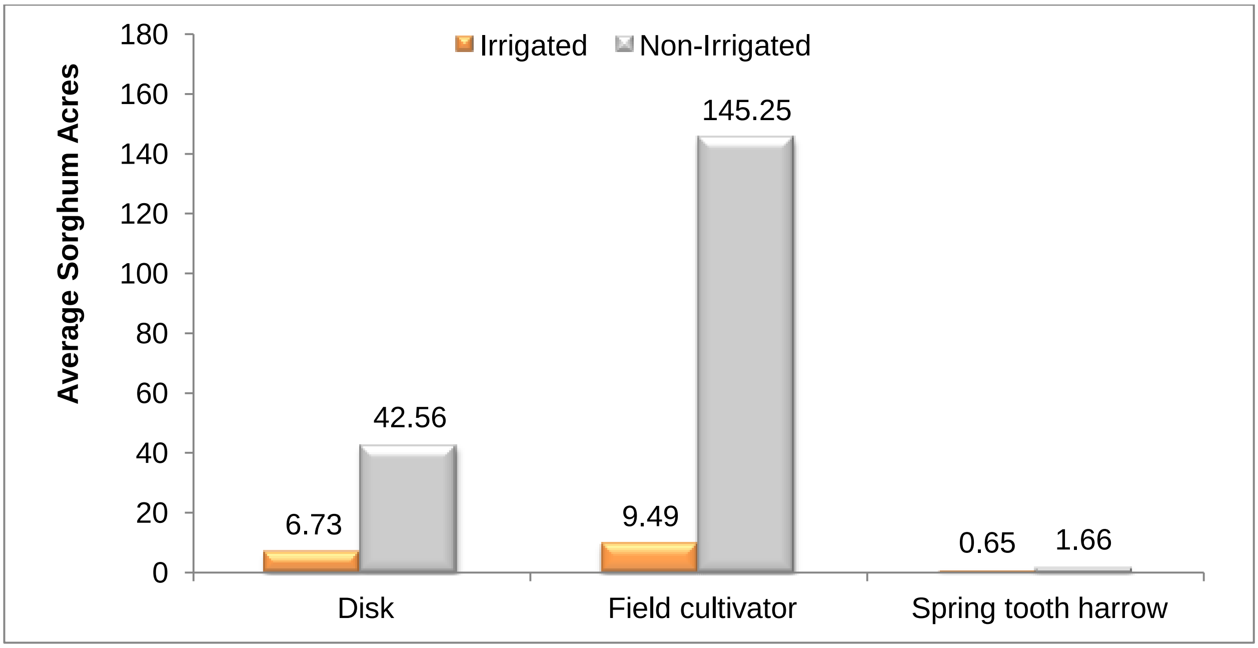
9.5 Average Acres Covered by Indicated Primary Tillage Practices

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



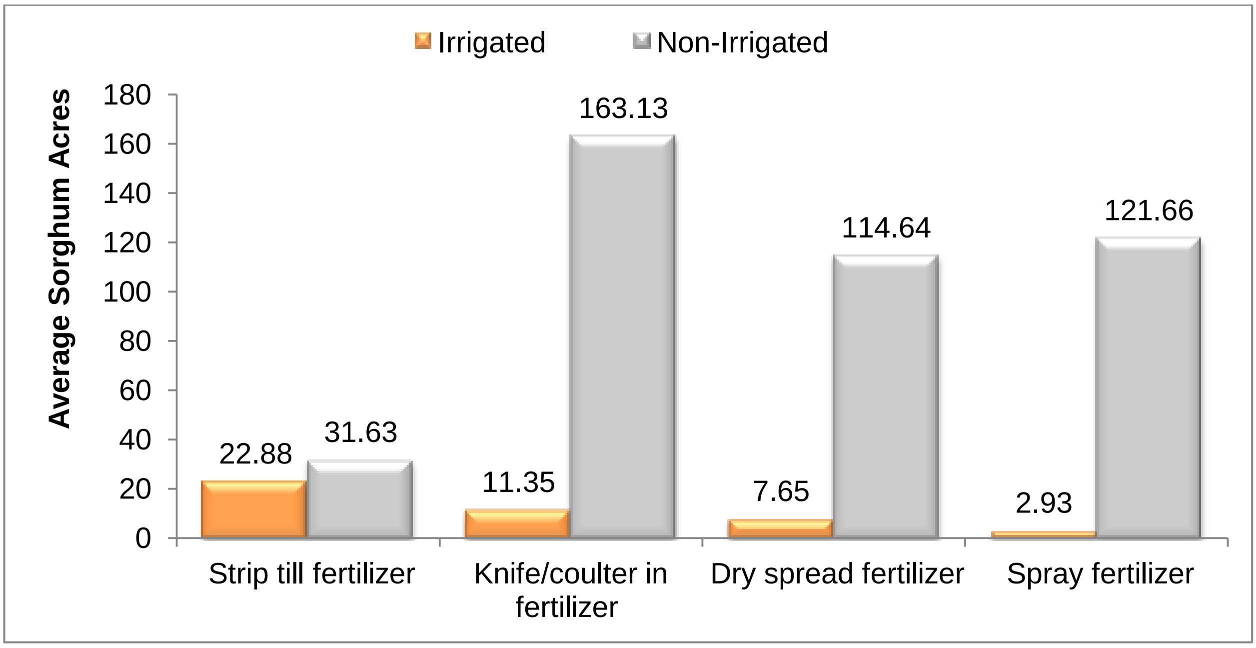
9.6 Average Acres Covered by Indicated Secondary Tillage Practices

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



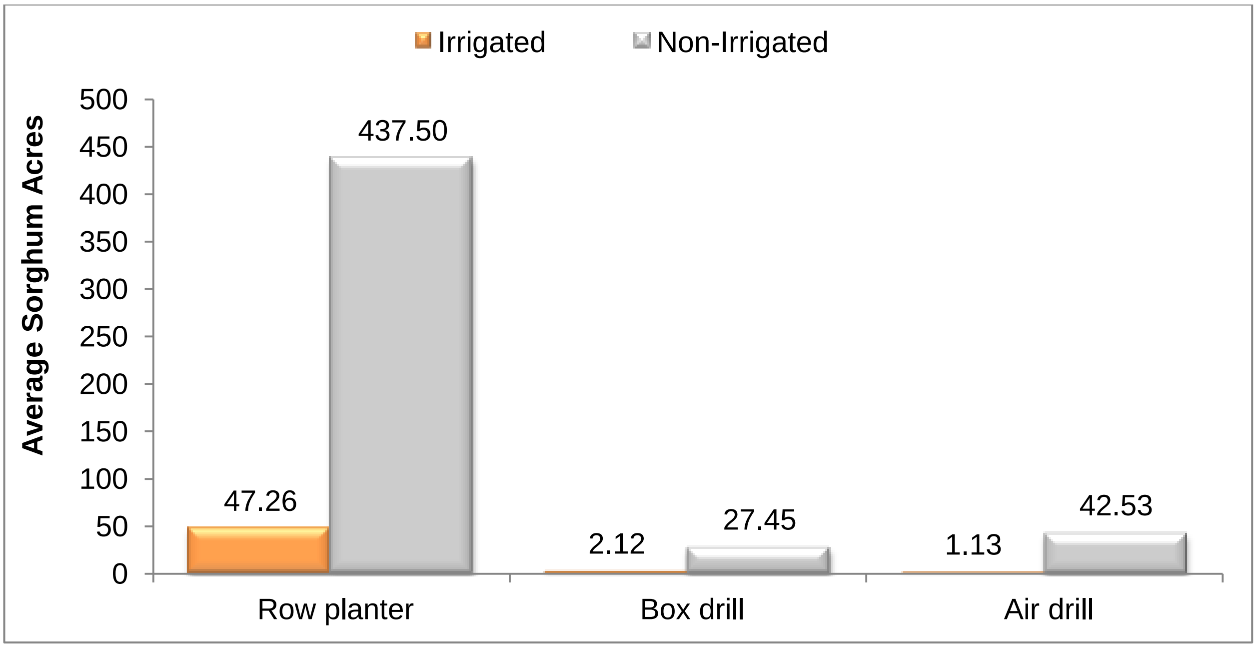
9.7 Average Acres Covered by Indicated Fertilizer Applications

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).



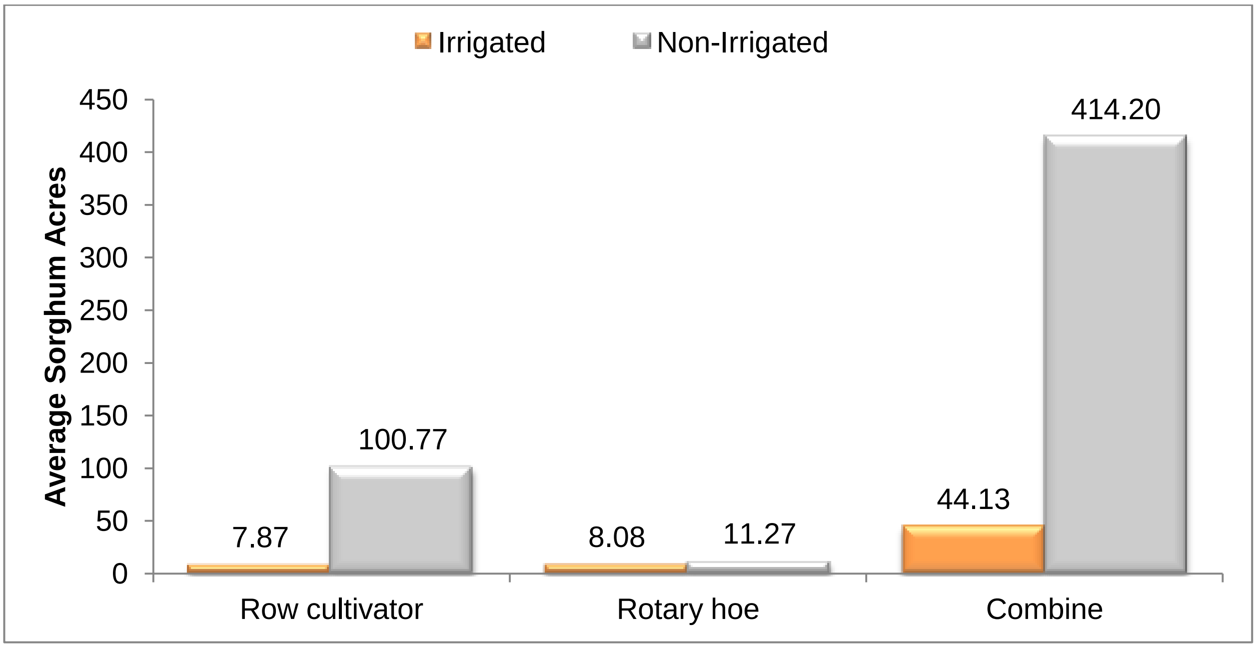
9.8 Average Acres Covered by Indicated Planting Operations

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



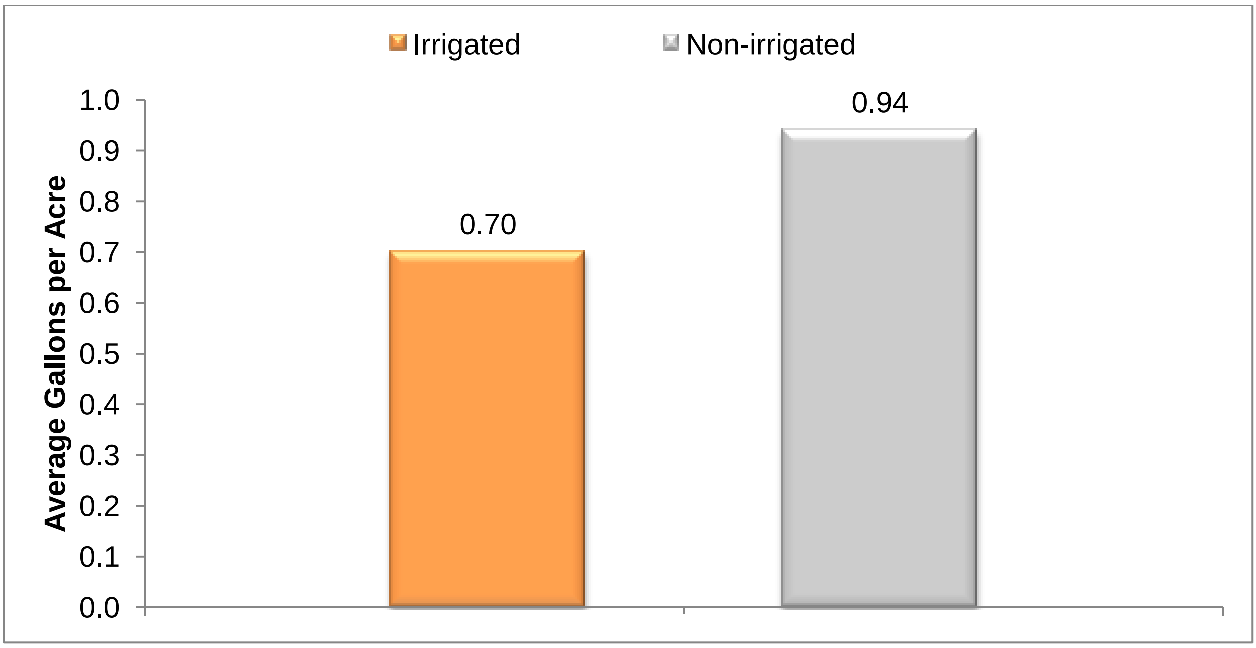
9.9 Average Acres Covered by Indicated Cultivation and Harvest Operations

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



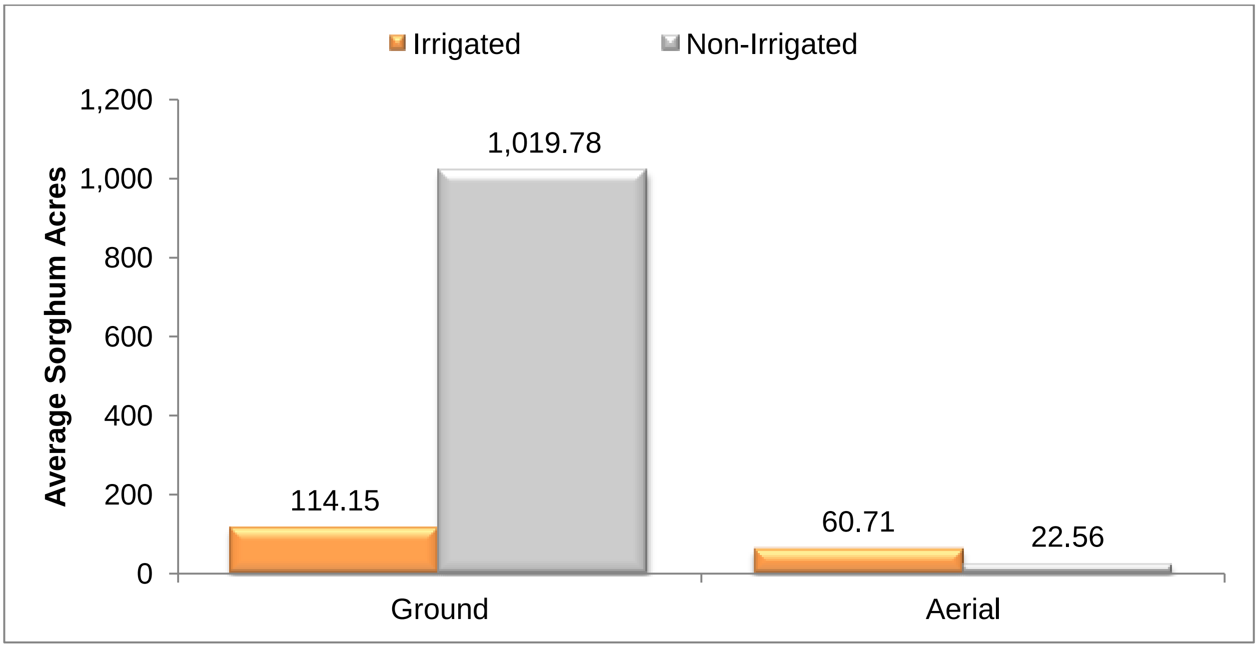
9.10 Average Gallons of Herbicide Applied

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?



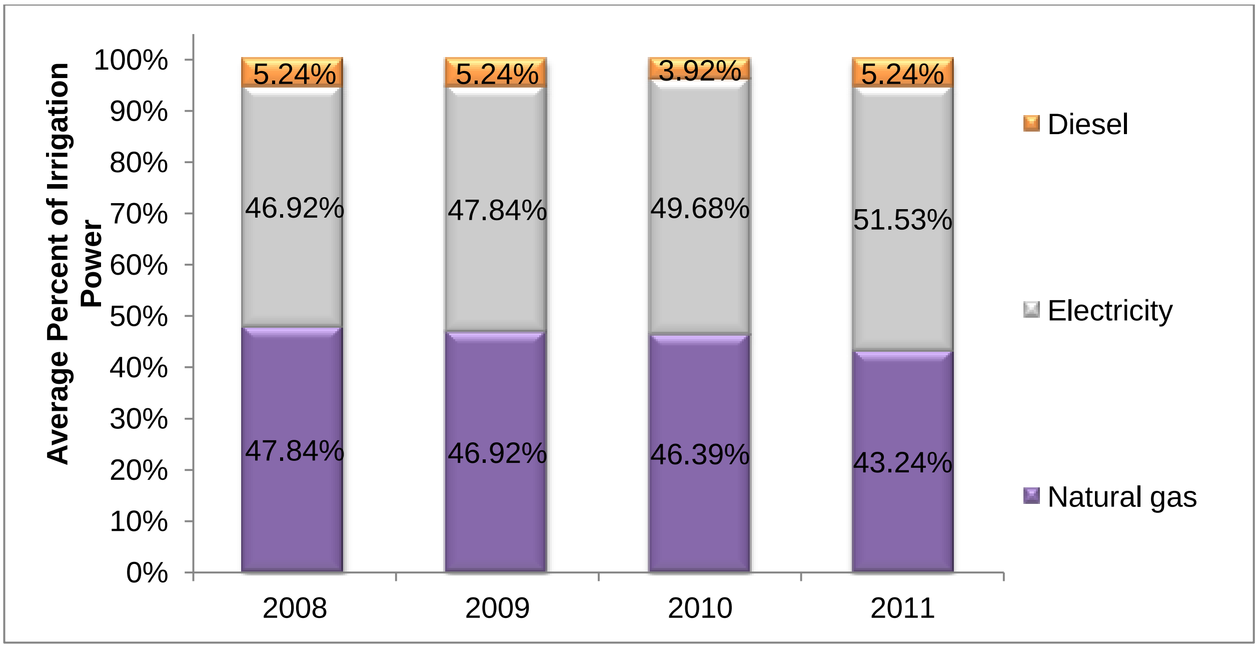
9.12 Average Irrigation Water Application and Lift Distance

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…?



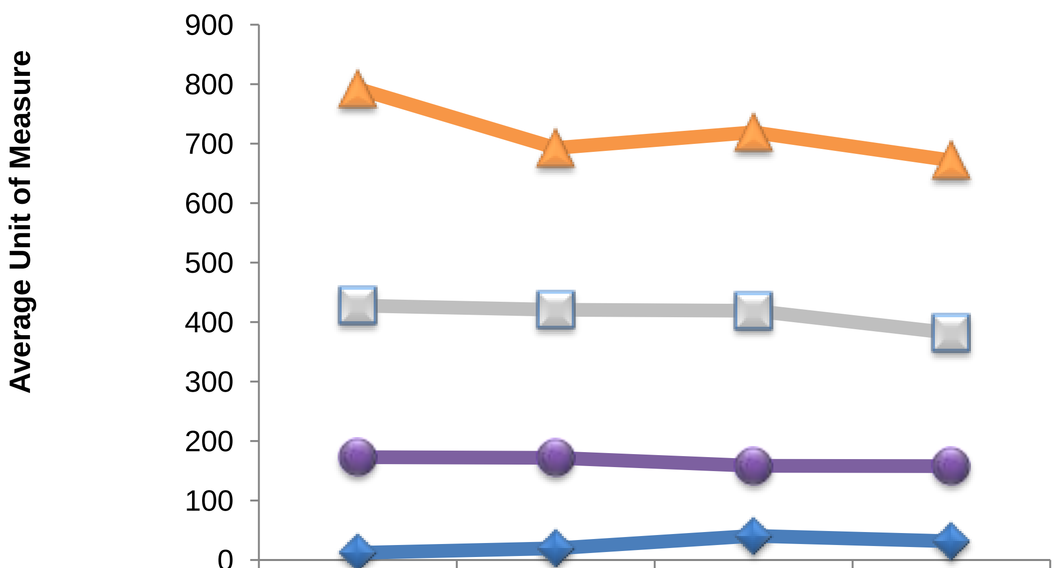
9.14 Fertilizer Applications (Irrigated - IR and Non-Irrigated – NI Sorghum Acres)

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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