SORGHUM CROP INPUTS AND GREENHOUSE GAS MODELING ASSUMPTIONS
Prepared by National Sorghum Producers
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Background

Over the past 15 years, a large amount of sorghum crop input data have been collected. The sources for these data are highly varied and include statistically significant surveys of sorghum farmers, biodiversity programs with wildlife NGOs, lifecycle analyses conducted at land grant universities as well as extension hybrid trials. This document summarizes this information and provides it in reference form for future citations as all this information is publicly available. Figure 1 includes an overview of the data sources and Figure 2 includes a data summary.

Figure 1. Data Sources.

Data Source	Abbreviation	Years Covered	Relevance
SGS North America[1]	SGS	2008-2011	Statistically significant third-party survey of sorghum farmers
Strategic Marketing Research & Planning (first survey)[2]	SMRP1	2017-2019	Statistically significant third-party survey of sorghum farmers
Strategic Marketing Research & Planning (second survey)[3]	SMRP2	2019-2021	Statistically significant third-party survey of sorghum farmers
Strategic Marketing Research & Planning (third survey)[4]	SMRP3	2021-2023	Statistically significant third-party survey of sorghum farmers
Sustainable Environmental Consultants[5]	SEC	2020-2022	Data for biodiversity program with key wildlife NGO
Kansas State University[6]	KSU	2011	Third-party lifecycle analysis
Land Grant University Extension Hybrid Trials[7]	Trials	2008-2022	Fifteen years of scientific trials at seven universities across 31 locations and 5,181 observations

[1] https://www.sorghumcheckoff.com/wp-content/uploads/2022/08/The-Carbon-Footprint-of-Sorghum-1.pdf
[2] https://www.sorghumcheckoff.com/wp-content/uploads/2022/08/2020-Carbon-Footprint-Study-1.pdf
[3] https://www.sorghumcheckoff.com/wp-content/uploads/2022/08/2022-Carbon-Footprint-Study-1.pdf
[4] https://www.sorghumcheckoff.com/wp-content/uploads/2024/01/SMRP3.pdf
[5] https://www.sorghumcheckoff.com/wp-content/uploads/2022/10/EP-ALL-Supply-Chain-Report_2020_V3.pdf
https://www.sorghumcheckoff.com/wp-content/uploads/2023/09/EP-Sorghum-Checkoff-Executive- Summary_2021-V2.pdf
https://www.sorghumcheckoff.com/wp-content/uploads/2023/09/EP-Sorghum-Checkoff-Executive-Summary_2022-V2.pdf
[6] https://www.sorghumcheckoff.com/wp-content/uploads/2023/10/nelson_diesel_work_ksu.pdf
[7] https://csucrops.com/sorghum/
https://krex.k-state.edu/handle/2097/16531
https://cropwatch.unl.edu/varietytest/sorghum
https://clovissc.nmsu.edu/research/trails.html
https://extension.okstate.edu/search-results.html?q=Grain+Sorghum+Performance+Trials
https://extension.sdstate.edu/sorghum-trial-results
https://ccag.tamu.edu/extension/soil-crop-sciences/grain-sorghum-hybrid-trial-results/

Figure 2. Data Summary.

Assumption	Unit	SGS	SMRP1	SMRP2	SMRP3	SEC	KSU*	Trials**	Average
Diesel	btu/bu	6,943.52	4,402.79	3,520.59	5,159.58	5,500.35	4,287.30	-	4,969.02
Gasoline	btu/bu	497.36	-	-	-	-	-	-	497.36
Natural Gas	btu/bu	0.00	-	-	-	-	-	-	0.00
Electricity	btu/bu	39.11	-	-	-	-	-	-	39.11
Nitrogen	g/bu	411.93	405.62	416.56	413.82	392.04	423.35	394.13	408.21
Phosphorus	g/bu	99.24	119.37	115.05	208.33	-	175.07	83.67	133.45
Potassium	g/bu	20.24	18.09	10.12	-	-	0.00	0.36	9.76
Herbicide	g/bu	27.23	-	-	-	-	7.77	-	17.50

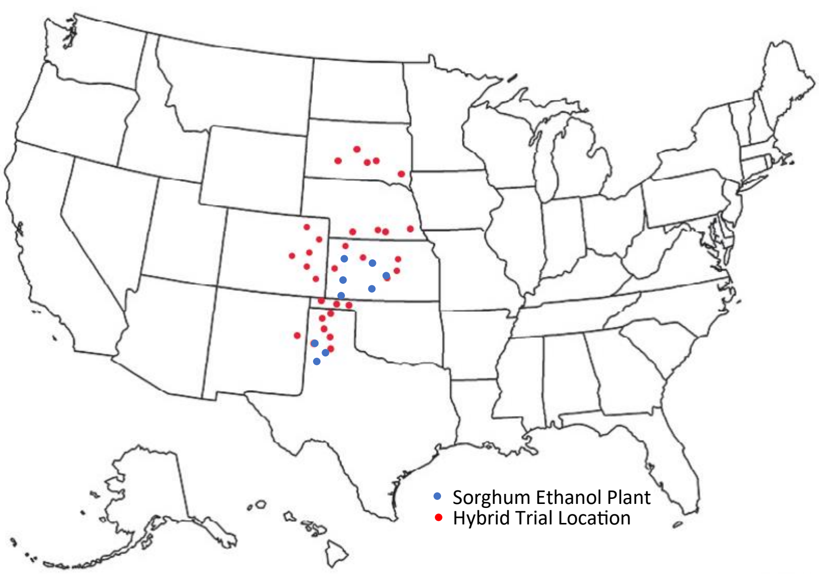
*Given this study was an LCA, it was assumed that it covered the equivalent of one acre.

**Given these were land grant university hybrid trials, it was assumed that each observation covered the equivalent of one acre.

Base Assumptions

The total area covered by the seven data sources was 173,384.28 acres. Note, however, that KSU and Trials were much lower. KSU was a lifecycle analysis, so it was assumed that it covered the equivalent of one acre. Similarly, Trials included 15 years of scientific hybrid trials at seven universities across 31 locations and 5,181 observations, so it was assumed that each observation covered the equivalent of one acre. With both KSU and Trials, this is a reasonable assumption as these values will scale. Figure 3 includes a map of the 31 locations represented in Trials overlaid with sorghum ethanol plants for reference. Each of the six other data sources were also based on production within the confines of this region, which includes more than 85 percent of U.S. sorghum area and produces 100 percent of U.S. sorghum ethanol.

Figure 3. Trials and Sorghum Ethanol Plant Locations.



Energy Inputs

Average diesel usage in British thermal units per bushel across the seven data sources was 4,969.02. In SGS, SMRP1, SMRP2, SMRP3 and SEC, diesel usage was calculated using fuel consumption data from Virginia Cooperative Extension[8] per this equation:

$$D = [\sum (N_{share} * N_{diesel} + R_{share} * R_{diesel} + C_{share} * C_{diesel} + R + P + S + H)] / n$$

Where D is average diesel usage in British thermal units per bushel, N_{share} is the percentage of acres in no-till systems, N_{diesel} is the amount of diesel used in no-till systems, R_{share} is the percentage of acre in reduced till systems, R_{diesel} is the amount of diesel used in reduced till systems, C_{share} is the percentage of acres in conventional till systems, C_{diesel} is the amount of diesel used conventional till systems, R is the amount of residual diesel used, P is the amount of diesel used for planting, S is the amount of diesel used for spraying and H is the amount of diesel used for harvesting. Diesel usage was given in KSU, and residual diesel, gasoline, natural gas and electricity usage were given in SGS. For each fuel type, energy usage associated with field activities, trucking and storage are included in the combined value.

Fertilizer Inputs

Average nitrogen, phosphorus and potassium applications in grams per bushel were 408.21, 133.45 and 9.76, respectively. If applicable, these values were given in all seven data sources.

Herbicide Inputs

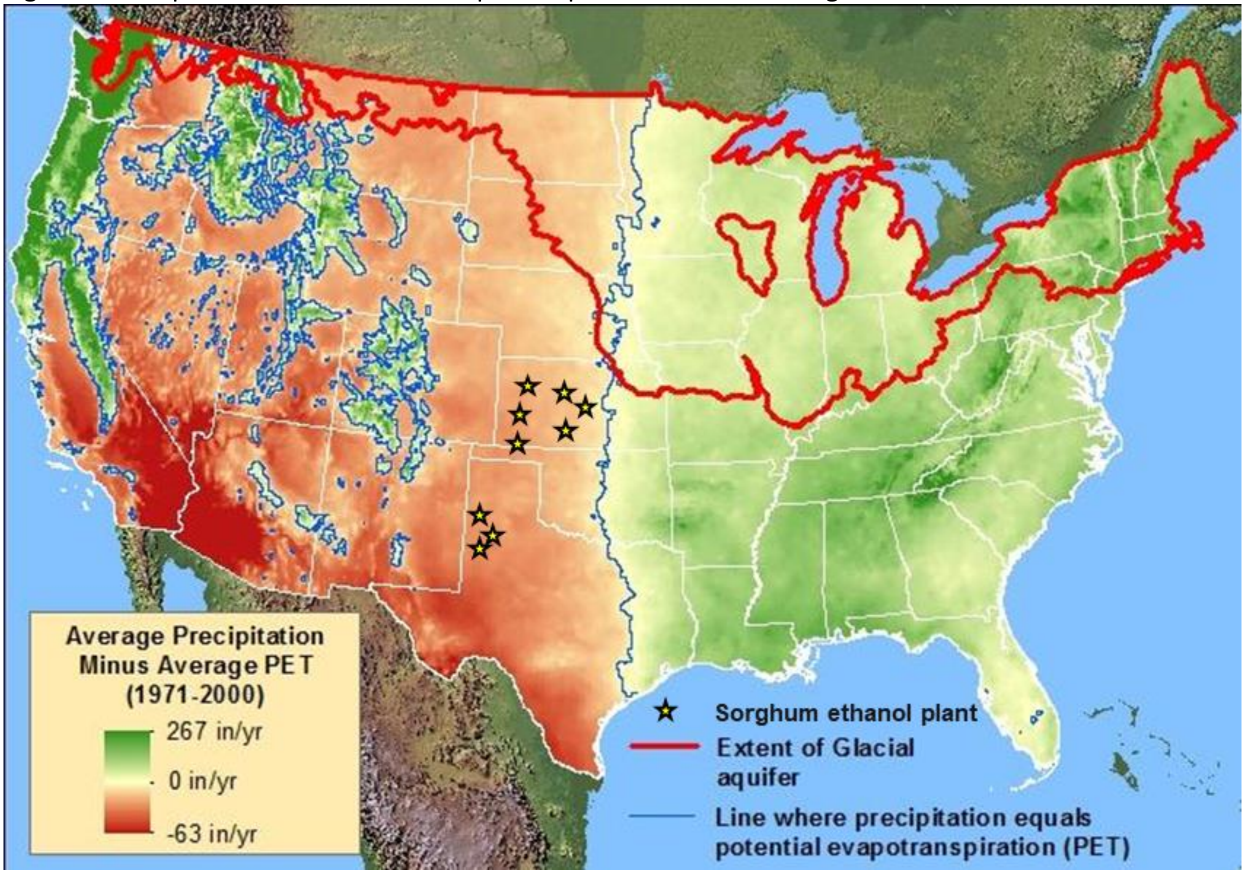
Average herbicide usage across the seven data sources was 17.50 grams of active ingredient per bushel. Pesticide usage was given in SGS in gallons per acre. To convert to grams of active ingredient, a weighted average active ingredient factor was calculated based on the pesticide program assumed by the GREET model. This program includes atrazine,[9] metalochlor,[10] acetochlor[11] and cyanazine.[12] This is a realistic program and results in a calculated pesticide usage value for SGS near that of GREET. Pesticide usage in active ingredient volume was given in KSU.

Nitrous Oxide Emissions

Given the U.S. sorghum ethanol industry is located entirely in a dry climate as defined by the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories,[13] we have undertaken a significant amount due diligence to confirm the assertion that dry climates will see lower nitrous oxide (N_2O) emissions. According to the 2019 refinement, "dry climates occur in temperate and boreal zones where the ratio of annual precipitation:potential evapotranspiration < 1." Figure 4 includes a map of the relationship between precipitation and potential evapotranspiration overlaid with sorghum ethanol plants for reference. According to USGS,[14] geographies to the left of the blue line lost more moisture to evapotranspiration than they received from precipitation on average from 1971 through 2000.

[8] https://vtechworks.lib.vt.edu/bitstream/handle/10919/47472/442-073_pdf.pdf
[9] https://www.syngenta-us.com/current-label/aatrex_4l
[10] https://www.syngenta-us.com/current-label/dual_magnum
[11] https://cs-assets.bayer.com/is/content/bayer/Warrant_Herbicide_Bayer1p_Labelpdf
[12] https://www3.epa.gov/pesticides/chem_search/ppls/000352-00470-19990115.pdf
[13] https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/4_Volume4/19R_V4_Ch11_Soils_N2O_CO2.pdf
[14] https://www.usgs.gov/media/images/map-gridded-values-1971-2000-avg-precipitation-minus-avg-pet

Figure 4. Precipitation and Potential Evapotranspiration as well as Sorghum Ethanol Plant Locations.



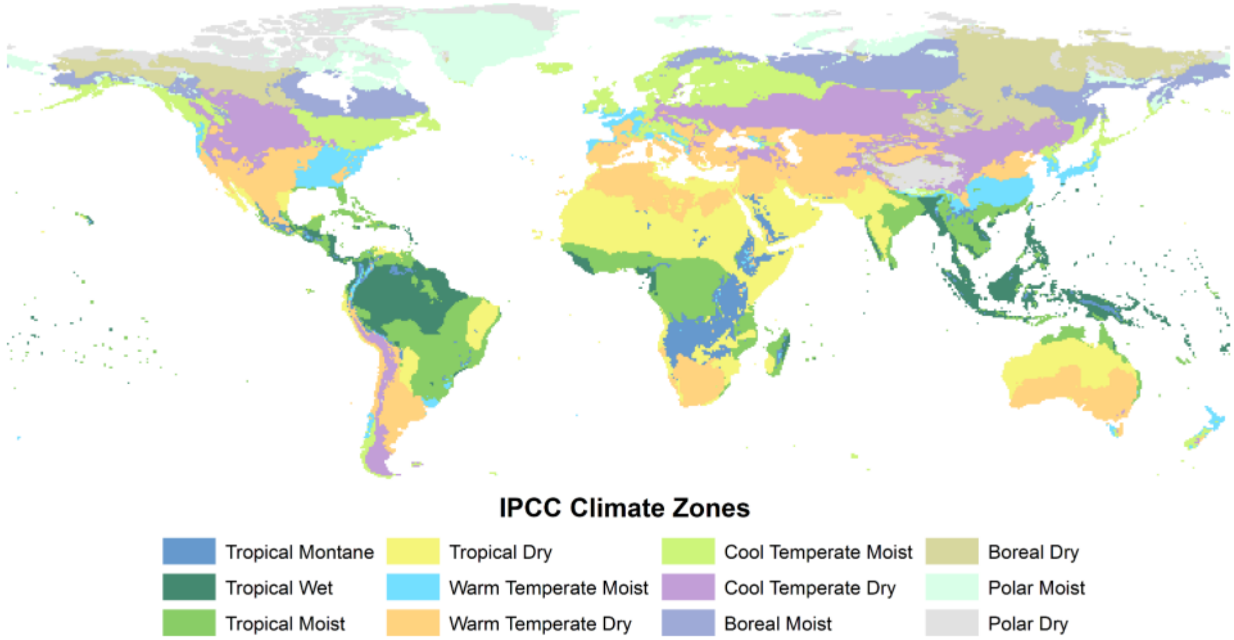
The 2019 refinement goes on to reference a map of dry climates: "cf. Figure 3A.5.1 in Chapter 3 of Vol. 4 provides a map subdividing wet and dry climates based on these criteria." This map[15] can be found in Figure 5. Note that much of western North America is now considered a dry climate by IPCC. Available scientific literature confirms the assertion that dry climates will see lower N_2O emissions. According to the 2019 refinement, the N_2O emissions factor should be 0.0050 in dry climates. In the 2006 guidelines[16] the default factor was double, or 0.0100 for all climates. For the wheat-based rotations common to the U.S. Sorghum Belt, Dusenbury, Engel, Miller, Lemke and Wallander (2008) suggested a 0.0023 emissions factor compared to the IPCC default mean of 0.0125.[17] Gehl, Haag, Warren, Sharma and Tomlinson (2020) reached a similar conclusion in a long-term study of sorghum fields in western Kansas, where the emissions factor was found to be 0.0026.[18] Based on the 2019 refinement and the support provided by these studies, we recommend emissions factors of 0.0050, matching the refinement.

Conclusion

The sources for the data presented in this document are highly varied and include statistically significant surveys of sorghum farmers, biodiversity programs with wildlife NGOs, lifecycle analyses conducted at land grant universities as well as extension hybrid trials. They are all publicly available, third-party

[15] https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/4_Volume4/19R_V4_Ch03_Land%20Representation.pdf
[16] https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_11_Ch11_N2O&CO2.pdf
[17] https://pubmed.ncbi.nlm.nih.gov/18389938/
[18] https://newprairiepress.org/kaesrr/vol6/iss5/10/

Figure 5. Map of Major Climate Zones According to the 2019 IPCC Refinement.



sources covering a broad geography and 15 growing seasons. We will provide additional guidance on how calculations and assumptions in this document were made upon request.