Research Note:

Revision of Parameters of the Grain Sorghum Ethanol Pathway in GREET

Hao Cai, Michael Wang, and Jennifer Dunn

Systems Assessment Group

Energy Systems Division

Argonne National Laboratory

We recently reviewed publications and data concerning sorghum farming to revise several grain sorghum ethanol pathway parameters in the Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET^{TM}) model. In this research note, we present our revision of sorghum grain yields, the grain sorghum harvested-to-planted acreage ratio, the grain sorghum stover nitrogen content, and nitrogen fertilizer application rates. The latter two parameters are very important because previous GREET life-cycle analysis concluded that nitrous oxide emissions from nitrogen fertilizer application and from decay of residual grain sorghum stover in the field are major contributors to the life-cycle greenhouse gas (GHG) emissions of grain sorghum ethanol (Cai et al., 2013).

1. Nitrogen fertilizer application rates

In our 2013 study (Cai et al., 2013), we estimated the nitrogen fertilizer application rates based on the 2011 data from the Quick Stats 2.0 database published by the National Agricultural Statistics Service (NASS) of the United States Department of Agriculture (USDA) (USDA, 2014). That year, however, was a drought year with low grain yields and a low harvested-to-planted acreage ratio, resulting in a high nitrogen fertilizer application rate per bushel harvested. To better characterize typical grain sorghum farming fertilizer application rates, we analyzed data from the NASS Quick Stats 2.0 database for the four most recent years with available data: 1991, 1998, 2003, and 2011. We obtained application rates per planted acre and the percentages of nitrogen, phosphate, and potash fertilized planted acres in major sorghum-growing states in 1991, 1998, 2003, and 2011. We calculated the planted acreage weighted average fertilizer application rates and percentages of fertilizer-treated acres in 1991, 1998, 2003, and 2011, by state as shown in Table 1.

Table 1. Application rates and treated acre percentages for nitrogen, phosphate, and potash fertilizers in 1991, 1998, 2003, and 2011 (based on planted area)

	Nitrogen				Phosphate				Potash			
	1991	**1998**	**2003**	**2011**	**1991**	**1998**	**2003**	**2011**	**1991**	**1998**	**2003**	**2011**
	Applications, in pounds/ acre											
COLORADO			47	45			51	17			2	0
KANSAS	70	68	76	63	34	29	29	25	27	27	35	15
MISSOURI			117				56				70	
NEBRASKA	68		86	84	27		23	31			9	11
OKLAHOMA			74	49			33	22			22	5
SOUTH DAKOTA			57	68			30	28			10	0
TEXAS	89		90	79	34		33	28	19		12	22
Planted acreage weighted average	**77**	**68**	**82**	**71**	**33**	**29**	**32**	**27**	**23**	**27**	**23**	**17**
	Treated acres, %											
COLORADO			61	75			39	41				0
KANSAS	90	90	97	83	47	54	55	51	13	9	4	8
MISSOURI			100				75				72	
NEBRASKA	91		99	88	27		40	41	2		1	15
OKLAHOMA			69	81			36	58			11	13
SOUTH DAKOTA			84	88			54	45			3	0
TEXAS	79		63	77	48		43	63	13		14	11
Planted acreage weighted average	**86**	**90**	**84**	**82**	**44**	**54**	**49**	**53**	**11**	**9**	**11**	**11**

The planted acreage weighted average of the fertilizer application rates do not show significant variation across the 1991-2011 timespan that is represented by the four-year data, as shown in Table 1. With this relatively small temporal variation in fertilizer application practices, we adopt the four-year average of the fertilizer application rates and the treated acreage percentages, as shown in Table 2.

Table 2. Four-year average of fertilizer application rates and treated acreage percentages of grain sorghum production (based on planted acres)

	Nitrogen		Phosphate		Potash	
	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation
Applications, in pounds/acre	74.6	6.4	30.1	2.7	22.3	4.3
Treated acres, %	85.3	3.6	49.9	4.7	10.4	1.0

On the other hand, the NASS data show a notable variation in grain yield (Table 3).

Table 3. National average of grain yields of grain sorghum from 1990 to 2014 (based on harvested acres)

	Bushel/acre		Bushel/acre		Bushel/acre		Bushel/acre		Bushel/acre
2014	66.1	2009	69.4	2004	69.6	1999	69.7	1994	72.7
2013	59.6	2008	65.1	2003	52.7	1998	67.3	1993	59.9
2012	49.6	2007	73.2	2002	50.6	1997	69.2	1992	72.6
2011	54.0	2006	56.1	2001	59.9	1996	67.3	1991	59.3
2010	71.9	2005	68.5	2000	60.9	1995	55.6	1990	63.1

We estimated the average grain yield based on the historical data as shown in Table 3, which is 63.4 bushels per acre. Calculating the average yield from multiple years' data better represents the production performance of the sorghum industry than calculating this parameter with yield data from a single year in which the yield might have significantly been affected by unusual natural conditions.

2. Harvested-to-planted acreage ratio

In our 2013 study (Cai et al., 2013), we estimated the harvested-to-planted acreage ratio for grain sorghum based on the total planted acreage of grain sorghum and silage sorghum, the harvested acreage of grain sorghum acreage, and the harvested acreage of silage sorghum, using Equation 1.

$$\frac{H}{P}_g = \frac{\text{Harvested}_g + \text{Harvested}_s}{\text{Planted}_{g+s}} \qquad \textbf{Equation 1}$$

Where: $\frac{H}{P}_g$ is the harvested to planted acreage ratio for grain sorghum; Harvested_g and Harvested_s are the harvested acreages of grain sorghum and silage sorghum, respectively; and Planted_{g+s} is the total planted acreage of grain sorghum and silage sorghum.

Using this approach, we assumed that the harvested-to-planted acreage ratios for grain sorghum and silage sorghum were the same, because no separate planted acreage data were available for the two different sorghum types. This ratio, however, could be significantly different for grain and silage sorghum. We therefore modified our estimate of $\frac{H}{P}_g$, assuming that silage sorghum has a planted-to-harvested ratio of 100%.

Table 4 shows harvested-to-planted acreage ratios for 1990 to 2013 using this modified approach and the national data from the NASS database. Significant temporal variations in the ratio were revealed. The average ratio from 1990 to 2013 is 89.0%, in comparison to 82.7%, the value previously used in GREET. Use of an average based on multiple years' data reduces the risk associated with single-year statistics.

Table 4. Estimation of harvested-to-planted acreage ratios for grain sorghum from 1990 to 2013

Year	Total planted acres	Harvested acres, grain	Harvested acres, silage	Estimated planted acres, grain	Estimated harvested-to-planted acreage ratio, grain
2013	8,061,000	6,530,000	380,000	7,681,000	85.0%
2012	6,259,000	4,995,000	353,000	5,906,000	84.6%
2011	5,451,000	3,945,000	226,000	5,225,000	75.5%
2010	5,369,000	4,806,000	272,000	5,097,000	94.3%
2009	6,599,000	5,502,000	255,000	6,344,000	86.7%
2008	8,404,000	7,312,000	412,000	7,992,000	91.5%
2007	7,712,000	6,792,000	392,000	7,320,000	92.8%
2006	6,522,000	4,937,000	347,000	6,175,000	80.0%
2005	6,454,000	5,736,000	311,000	6,143,000	93.4%
2004	7,486,000	6,517,000	352,000	7,134,000	91.4%
2003	9,420,000	7,798,000	343,000	9,077,000	85.9%
2002	9,589,000	7,125,000	408,000	9,181,000	77.6%
2001	10,248,000	8,579,000	352,000	9,896,000	86.7%
2000	9,195,000	7,726,000	278,000	8,917,000	86.6%
1999	9,288,000	8,544,000	320,000	8,968,000	95.3%
1998	9,626,000	7,723,000	308,000	9,318,000	82.9%
1997	10,052,000	9,158,000	412,000	9,640,000	95.0%
1996	13,097,000	11,811,000	423,000	12,674,000	93.2%
1995	9,429,000	8,253,000	413,000	9,016,000	91.5%
1994	9,787,000	8,882,000	362,000	9,425,000	94.2%
1993	9,882,000	8,916,000	351,000	9,531,000	93.5%
1992	13,177,000	12,050,000	453,000	12,724,000	94.7%
1991	11,064,000	9,870,000	483,000	10,581,000	93.3%
1990	10,535,000	9,089,000	527,000	10,008,000	90.8%

3. Grain sorghum fertilizer application rates

The changes in our approach to estimating grain sorghum yields, fertilizer application rates, and the harvested-to-planted acreage ratio change the grain sorghum average fertilizer application rates previously used in GREET. The grain sorghum fertilizer application rates in Table 5 are now adopted in the GREET grain sorghum ethanol pathway.

Table 5. Grain sorghum fertilizer application rates, in grams/bushel of grain produced

	Nitrogen	**Phosphate**	**Potash**
Revised GREET parameter	512	121	19
Previous GREET parameter	613	162	17

4. Nitrogen content of grain sorghum stover

To evaluate the life-cycle GHG emissions from U.S. grain sorghum-based ethanol, the nitrogen content in the field stover is needed because this residual stover degrades and releases nitrous oxide. In our 2013 study, we estimated the nitrogen content of grain sorghum stover based on the measurement of 12 sorghum genotypes, including six inbred lines and six non-commercial hybrids in Mahama (2012). The study primarily examined nitrogen responses across genotypes and did not represent grain sorghum varieties currently planted in sorghum fields from a compositional, harvest index, and yield standpoint. For this revision, we sought data to inform the selection of a stover nitrogen content value reflective of grain sorghum cultivars commonly planted today. Two publications reported stover nitrogen content, grain yields, and stover yields of three sorghum cultivars including a conventional grain sorghum type that were planted in three locations over two years (Hons et al., 1986; Powell et al., 1991). Even though the publications are more than 20 years old, they contain data representative of residual stover. The results of both papers suggested a stover nitrogen content ranging from 5,153 to 6,830 grams N per tonne of grain produced. These values are well below the 10,000 grams N per tonne of grain we estimated based on the data presenting non-commercial hybrids. Compared to the field grain, the non-commercial hybrids have much lower grain yield per tonne of stover yield than the field grain type does, as shown in Table 6. As a result, the non-commercial cultivars exhibited a much higher nitrogen content per tonne of grain yield than the field cultivars even though the non-commercial hybrids had a lower nitrogen content in the stover.

Table 6 Grain-to-stover yield ratio and stover nitrogen content of field cultivars and non-commercial sorghum hybrids

	Field sorghum cultivar (Hons et al., 1986; Powell et al., 1991)	Noncommercial sorghum cultivar (Mahama, 2012)
Grain-to-stover yield ratio by mass	0.93 – 1.16	0.33
Stover nitrogen content, mass%	0.600 – 0.632	0.465
Nitrogen content per tonne of grain yield, grams per tonne grain produced	5,153 – 6,830	10,000

In the GREET model, we now adopt the average grain-to-stover yield ratio and the average stover nitrogen content of field sorghum cultivars from multiple years' field experiments (Hons et al., 1986; Powell et al., 1991), as shown in Table 7, to estimate the nitrogen content per tonne of grain yield.

Table 7 Grain-to-stover yield ratio and stover nitrogen content for the GREET grain sorghum ethanol pathway

	GREET parameter
Grain-to-stover yield ratio by mass (dry matter basis)	1.05
Stover nitrogen content, mass%	0.616
Nitrogen content per tonne of grain yield, grams per tonne grain	5,867

5. Life-cycle GHG emissions of grain sorghum ethanol

The reduced nitrogen and phosphate fertilizer application rates, higher harvested-to-planted acreage ratio, and reduced stover nitrogen content contribute to a reduction of life-cycle GHG emissions of grain sorghum ethanol from 61 grams per mega joules (g CO_2e/MJ) in previous analysis (Cai et al., 2013) to 54 g CO_2e/MJ.

Reference

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