Research Note

Parameters of Canola Biofuel Production Pathways in GREET

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September, 2015

Biofuel production pathways using rapeseeds grown in the Europe as the feedstock had been analyzed with the Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET^{TM}) model (Han et al., 2013). Today, discussions of rapeseed production in North America typically refer only to canola, while other areas of the world with less varieties of canola continue to use the term "rapeseed" for both edible and inedible varieties (USDA, 2012). For the purpose of analyzing the biodiesel production pathway that is using canola in North America in GREET, we reviewed a publication prepared for Canola Council of Canada with data on Canadian Canola farming (CCC, 2013). Canola is a registered trademark initiated by the Western Canadian Oilseed Crushers Association for low-erucic acid rapeseed varieties with low glucosinolate content, and CCC now owns the canola trademark. In 2014, Canada produced 15.6 metric ton (MT) of canola (Burgdorfer, 2014) and exported 953,000 MT of canola seed, 1.5 million MT of canola oil, and 3.3 million MT of canola meal to the United States (CCC, 2015a). The bulk of Canadian canola oil is exported to the United States (U.S.), with canola import from Canada dominating the U.S. canola imports. Canola is a cool season crop with both spring and winter varieties that require rich soil and a moist environment (Brown et al., 2008). The U.S. domestic production of canola remains small, and is concentrated in the Northern Plains where a drier, shorter growing season makes corn and soybean production less attractive. Trends in the much larger Canadian canola industry have a significant impact on production and processing of canola in the U.S. (USDA, 2012).

In this research note, we present our considerations of canola farming energy use, canola yields, the application rates of fertilizer, herbicide and pesticide, the nitrogen content in canola residues, and the conversion rates of synthetic nitrogen fertilizers and nitrogen contained in canola residues to nitrous oxide (N_2O) emissions in fields. These parameters are important in determining greenhouse gas (GHG) emissions of canola-based biofuels. Previous GREET life-cycle analysis concluded that fertilizer production and N_2O emissions from nitrogen fertilizer and nitrogen in canola residues in the field are major contributors to the life-cycle GHG emissions of canola-derived biofuels (Han et al., 2013). As the U.S. imports the bulk of canola oil from Canada but barely import any rapeseed from the EU, the Canadian canola is a better representative of the canola oil use for biofuel production in the U.S. Therefore, we add the farming data for Canadian canola production in the GREET1_2015 model, and remove the farming data specific to European rapeseeds in the GREET1_2015 model.

1. Fertilizer application rates and farming energy use

In GREET1_2014, we adopted the rapeseed farming energy use and fertilizer application rates shown in Table 1 based on Stratton et al. (2010). Stratton et al. (2010) compiled data that were reported in earlier studies (Mortimer and Elsayed (2006), Edwards et al. (2007), Richards (2000), Prieur et al. (2008), Bernesson et al. (2004), Schmidt (2007) for major rapeseed production countries in the European Union (EU), i.e., the United Kingdom, France, Sweden, and Denmark.

Table 1. Rapeseed farming energy use, fertilizer and pesticide use, and nitrogen content in canola residues in GREET1_2014 adopted from Stratton et al. (2010)

	Per metric ton (MT)
Farming energy use: MJ	1,062
Nitrogen fertilizer: grams	53,797
Nitrogen from rapeseed residues: grams	7,125
K_2O fertilizer: grams	14,105
P_2O_5 fertilizer: grams	15,417
Pesticides: grams	755

On the other hand, the canola farming data reported in the CCC study were from survey results of over 900 canola farmers out of about 1,000 survey recipients in Saskatchewan, Alberta, and

Manitoba of Western Canada (CCC, 2013). The survey recipients were from eight geographic regions called "reconciliation units" (RUs), which subdivide Canadian provinces by their ecological conditions. These survey recipients were targeted to ensure that they provided good representation of the Canadian production of canola, and that each single region was represented by its canola production data. Table 2 summarizes the canola production, yields, fertilizer and pesticide uses, and farming energy uses of the eight RUs according to the CCC report (2013). Within Canada, sulfur fertilizers are also applied in form of pure sulfur, ammonium sulfate, ammonium thio-sulfate and fertilizer blend. As the ammonium sulfate and the fertilizer blend are already considered in the nitrogen fertilizers, they are excluded from the scope of sulfur fertilizers to avoid double counting.

Using data in Table 2, we calculated the fertilizer use, pesticide use, and farming energy use in each RU (see Table 3). Furthermore, we calculated in Table 3 the production-weighted average farming inputs based on the region-specific farming inputs and the respective canola production in each region. The nitrogen content in canola residues (both above and below ground biomass) is calculated at 22.1 kg per MT of canola seed (9% moisture) by using the dry matter yields of above and below ground biomass, the nitrogen concentration in the above and below ground biomass, and the yield of canola seeds (CCC, 2013).

Table 2. Annual canola production, yields, fertilizer and pesticide uses, and farming energy uses in each of the eight Canadian RUs in 2011

	Unit	**RU 23**	**RU 24**	**RU 28**	**RU 29**	**RU 30**	**RU 34**	**RU 35**	**RU 37**
Canola production[a]	MT	757,300	1,683,300	2,375,200	2,455,900	3,273,000	1,749,000	1,873,800	2,079,000
Canola acreage	ha	394,000	930,000	1,087,000	1,217,000	1,664,088	743,000	743,000	803,000
Yield[a]	kg ha^{-1}	1,922	1,810	2,186	2,018	1,967	2,354	2,522	2,589
Nitrogen fertilizer	kg ha^{-1}	120.22	125.97	121.12	94.43	89.65	104.61	105.4	115.1
-Anhydrous ammonia	kg ha^{-1}	50.08	47.67	38.95	21.16	6.81	23.48	15.26	13.48
-Urea	kg ha^{-1}	35.34	26.96	23.54	34.65	46.89	46.04	58.81	70.19
-Urea-Ammonium nitrate	kg ha^{-1}	20.13	21.06	3.46	10.81	10.78	2.53	0	2.35
-Ammonium nitrate	kg ha^{-1}	0	1.97	2.15	3.6	0.69	1.21	1.36	1.71
-Ammonium sulfate	kg ha^{-1}	7.84	7.16	5.07	5.14	4.66	7.1	6.22	5.89
-Fertilizer blend	kg ha^{-1}	6.83	11.45	20.55	17.37	18.02	20.85	15.45	13.48
-Manure	kg ha^{-1}	0	9.7	27.4	1.7	1.8	3.4	8.3	8
Nitrogen from canola residues	kg ha^{-1}	42.5	40.0	48.3	44.6	43.5	52.0	55.7	57.2
K_2O fertilizer	kg ha^{-1}	7.0	5.4	6.7	2.9	3.5	10.6	10.3	4.5
P_2O_5 fertilizer	kg ha^{-1}	28.4	30.2	31.1	26.8	28	34.2	29.5	33.1
Sulfur fertilizer	kg ha^{-1}	10.4	11.6	12.3	13.2	10.2	8	11.3	5.6
Pesticides	kg ha^{-1}	0.85	0.80	0.68	0.65	0.57	0.69	0.63	0.65
-Herbicides	kg ha^{-1}	0.71	0.64	0.57	0.59	0.52	0.63	0.56	0.56
-Other pesticides	kg ha^{-1}	0.13	0.16	0.10	0.06	0.05	0.06	0.07	0.09
Diesel consumption	liter t^{-1} of canola	17.17	19.73	15.62	12.96	12.49	11.7	11.21	10.91
Electricity consumption	kWh $t^{-1}$of canola	2.5	2.75	2.5	2.75	3.74	2.5	2.5	7.05
Natural gas consumption	MJ $t^{-1}$of canola	0	0.35	0	0.31	1.6	0	0	4.87

a: The canola seeds have a moisture content of 9%.

Table 3. Region-specific and production-weighted averaged fertilizer use, pesticide use, and farming energy use per metric ton of canola (with a moisture content of 9%) produced in western Canada

	Unit[a]	**RU 23**	**RU 24**	**RU 28**	**RU 29**	**RU 30**	**RU 34**	**RU 35**	**RU 37**	**Weighted Average**
Production Shares	%	5%	10%	15%	15%	20%	11%	12%	13%	
Nitrogen fertilizer	g/MT	62,549	69,597	55,407	46,794	45,577	44,439	41,792	44,457	49,776
-Anhydrous ammonia	g/MT	26,056	26,337	17,818	10,486	3,462	9,975	6,051	5,207	11,269
-Urea	g/MT	18,387	14,895	10,769	17,170	23,838	19,558	23,319	27,111	19,637
-Urea-Ammonium nitrate	g/MT	10,473	11,635	1,583	5,357	5,480	1,075	0	908	4,071
-Ammonium nitrate	g/MT	0	1,088	984	1,784	351	514	539	660	799
-Ammonium sulfate	g/MT	4,079	3,956	2,319	2,547	2,369	3,016	2,466	2,275	2,702
-Fertilizer blend	g/MT	3,554	6,326	9,401	8,608	9,161	8,857	6,126	5,207	7,669
-Manure	g/MT	0	5,359	12,534	842	915	1,444	3,291	3,090	3,630
Nitrogen from canola residues	g/MT	22,112	22,099	22,095	22,101	22,115	22,090	22,086	22,093	22,099
K_2O fertilizer	g/MT	3,642	2,983	3,065	1,437	1,779	4,503	4,084	1,738	2,681
P_2O_5 fertilizer	g/MT	14,776	16,685	14,227	13,280	14,235	14,528	11,697	12,785	13,922
Sulfur fertilizer	g/MT	5,411	6,409	5,627	6,541	5,186	3,398	4,481	2,163	4,932
Pesticides	g/MT	440	443	311	322	290	294	252	251	312
-Herbicides	g/MT	372	355	263	294	266	267	223	216	273
-Other pesticides	g/MT	68	87	48	28	24	27	29	35	39
Diesel consumption[b]	Btu/MT	582,628	669,496	530,032	439,770	423,822	397,015	380,388	370,208	459,863
Electricity consumption	Btu/MT	8,530	9,383	8,530	9,383	12,761	8,530	8,530	24,056	11,587
Natural gas consumption	Btu/MT	0	332	0	294	1,517	0	0	4,616	975

a: On a per wet tonne basis, with a moisture content of 9%;

b: We assume that the diesel has a lower-heating value of 128,450 British Thermal Units (Btu) per gallon.

The Canadian canola yield has been on the upward trend in the past couple of decades (CCC, 2015b), thus using the most recent available canola data for year 2011 is more representative of the current Canadian canola industry. Since most of the U.S. domestic canola production is in North Dakota (USDA, 2012), we assume that the farming practices and farming inputs required in North Dakota are similar to those in western Canada owing to their similar ecological conditions. Therefore, we adopt the average fertilizer application rates and farming energy use of Canadian canola production in Table 3 to update the U.S. canola biofuel production pathways in GREET. Table 4 compares the new canola farming inputs prepared for GREET1_2015 to those in GREET1_2014.

Table 4. Comparison of canola/rapeseeds farming inputs per metric tons of canola in GREET1_2014 and forthcoming GREET1_2015 release

	Unit[a]	GREET1_2015	GREET1_2014	Relative changes
Nitrogen fertilizer	g/MT	49,776	48,955	2%
Nitrogen from canola residues	g/MT	22,099	6,484	241%
K_2O-fertilizer	g/MT	2,681	12,836	-79%
P_2O_5-fertilizer	g/MT	13,922	14,030	-1%
Sulfur fertilizer	g/MT	4,932	0	
Herbicides	g/MT	273	687	-60%
Other pesticides	g/MT	39	0	

a: On a per wet tonne basis, with a moisture content of 9%.

2. Nitrous oxide emission conversion rate

In GREET1_2014, we adopted the IPCC Tier 1 methodology to calculate the conversion rate of the nitrogen content in nitrogen synthetic fertilizers and in canola residues to N_2O emissions in the field. For nitrogen synthetic fertilizers, the IPCC Tier 1 methodology suggests a total conversion rate of 1.325%, which includes a direct N_2O emission conversion rate of 1%, an indirect N_2O emission conversion rate of 0.1% from volatilization, and an indirect N_2O emission conversion rate of 0.225% from leaching and running off. For canola residues, the IPCC Tier 1 methodology suggests a total conversion rate of 1.225%, which includes a direct N_2O emission conversion rate of 1% and an indirect N_2O emission conversion rate of 0.225% from leaching and running off.

The IPCC Tier 2 methodology was used in the CCC report to estimate the combined direct and indirect conversion rate for nitrogen synthetic fertilizer application from the region-specific emission factors for direct N_2O-emissions and the fraction of applied organic nitrogen fertilizer materials that volatiles as NH_3 and NO_x provided by the Agriculture and AgriFood Canada (see Table 5). As a result, the CCC report estimated a combined direct and indirect N_2O conversion rate of 1.06% for nitrogen fertilizers, which includes a direct N_2O emission conversion rate of 0.74%, an indirect N_2O emission conversion rate of 0.1% from volatilization, and an indirect N_2O emission conversion rate of 0.22% from leaching and running off. For nitrogen in canola residues, the CCC report estimated a combined direct and indirect N_2O conversion rate of 0.96%, which includes a direct N_2O emission conversion rate of 0.74% and an indirect N_2O emission conversion rate of 0.22% from leaching and running off.

Table 5. Direct N_2O emission conversion rate and fraction of nitrogen from leaching and running off for nitrogen in synthetic fertilizers and nitrogen in canola residues

	Unit	**RU 23**	**RU 24**	**RU 28**	**RU 29**	**RU 30**	**RU 34**	**RU 35**	**RU 37**	**Weighted Average**
Direct N_2O conversion rate	kg N . kg_{-1} N	0.0096	0.0084	0.008	0.0065	0.0054	0.01	0.0082	0.0066	0.0074
Fraction of leaching and running off	%	19%	18%	16%	14%	12%	19%	16%	11%	15%

The CCC study pointed out that “Changed tillage types and different irrigation conditions within Canada lead to reduced mineralization of organic N and a smaller fraction of N leached or run-off. They are based on the 2006 Census of Agriculture. As land under no-tillage systems has increased in the past five years, these values are conservative”.

The CCC report also estimated the emission savings from such improved farming practices for cultivated crops as (1) shifting to reduced or zero-tillage, (2) improved crop rotations and/or cover crops, including crop residue management, (3) improved fertilizer or manure management, and (4) use of soil improver (e.g. compost), which lead to an increase in soil carbon. A modeling approach using the dynamic crop model, CENTURY, instead of *in situ* measurement, was employed to simulate the region-specific soil organic carbon (SOC) changes that depend on regional climate, soil type, land management practice and carbon input practice. The CENTURY model was fed with regional input data on climate, soil type, land cover and land management, and was calibrated and validated before it was run for simulations in each RU between the cultivation periods of 2007-2010. The RU-specific results were further processed to evaluate the SOC impacts of only canola producing areas. However, detailed modeling is needed to estimate the emissions associated with SOC changes from improved canola farming practices and the resultant emission savings.

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