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Application of the roundtable on sustainable biofuels method to regional differences in nitrous oxide emissions for the rapeseed hydrotreated renewable jet life cycle

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ABSTRACT

Hydrotreated Renewable Jet (HRJ) fuel has increasingly become important for the aviation sector to address energy security and climate change mitigation. Rapeseed (*Brassica Napus*) is a favored candidate feedstock for HRJ because of its high quality oil content and agroeconomic benefit to replace the fallow period in wheat/fallow rotations. We conducted research to evaluate regional differences in nitrous oxide (N_2O) emissions for rapeseed cultivation in several counties in 10 states in the United States (U.S.). The Roundtable on Sustainable Biofuels (RSB) methodology was applied, and results were compared to the Intergovernmental Panel on Climate Change (IPCC) guidelines. In this study, yield, nitrogen fertilizer rate, and types were held constant for all locations in order to understand the similarities and differences in the RSB and IPCC methods for estimating N_2O emissions. From the results, the RSB-calculated N_2O emissions varied for different U.S. states, though regional differences were very small, 0.72–0.73 kg N_2O Mg^{-1}seed, while N_2O emissions from IPCC method were the same for all sites, 0.87 kg N_2O Mg^{-1}seed. The difference between the RSB and IPCC methods is caused by the indirect N_2O emissions from ammonia emissions and nitrate leaching. However, the influence of indirect effect is relatively small compared to overall N_2O emissions. The utilization of the RSB method may not be justified for estimating regional variations in N_2O emissions. As a consequence, the preliminary greenhouse gas (GHG) of rapeseed HRJ fuel using the RSB method in several locations had small differences in result, 42.7–43.0 g CO_2 eq/MJ compared to 45.9 g CO_2 eq/MJ using the IPCC method.

1. Introduction

Increases in global population, depleting fossil fuels, increasing oil prices, and overall concern about global warming have increased interest in renewable biofuels. Renewable biofuels have the potential to not only improve energy security, but also result in increased jobs, economic benefits and environmental sustainability. The Energy Independence and Security Act of 2007 (EISA, 2007) established policies to promote and support biofuel production and use. Meanwhile, the Renewable Fuel Standard (RFS2) has announced the life cycle greenhouse gas (GHG) reduction threshold of 50% for advanced biofuels, and 60% for cellulosic biofuel compared to fossil fuel (EPA, 2010b). Therefore, evaluation of biofuels GHG emissions over the entire life cycle, by means of the life cycle assessment (LCA) method (ISO 14040, 2006) is the most significant sustainability criteria. LCA is an effective tool to evaluate environmental impacts of products over their entire life cycle from raw material extraction, processing, final product manufacture, product use, and end – of – life processes.

Hydrotreated Renewable Jet (HRJ) fuel derived from plant oils is becoming increasingly important as an alternative jet fuel for commercial airlines and the U.S. aviation fleets because it has the potential to replace fossil jet fuel and to reduce GHG emissions (Shonnard et al., 2010; Stratton et al., 2010). The U.S. Navy and U.S. Air Force have set goals that 50% of the Navy's total energy consumption afloat will be from alternative domestic sources by 2020, and 50% of the domestic aviation fuel will come from alternative fuel blends by 2016 (Blakeley, 2012), respectively.

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Rapeseed (*Brassica Napus*) is currently being considered as an energy feedstock for HRJ fuel because of its high seed yield and high oil content of 40–44%. Furthermore, rapeseed has a potential in the near-term to produce more HRJ fuel than jatropha, camelina, and soybean (Stratton et al., 2010) because of integration with existing crop production. However, to achieve the RFS2 sustainable biofuel criteria, rapeseed HRJ fuel needs to meet more than 50% reduction of GHG emissions compared to conventional jet fuel and to not compete with food production.

Carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are the dominant sources of GHG emissions of biofuel production. The production and use of inputs from feedstock cultivation (e.g., fertilizers, chemicals, and fuel), fuel conversion (e.g., electricity, heat, and chemical), and transportation have made contributions to GHG emissions. The GHG emissions for rapeseed biofuels generally are lower compared to fossil fuel, as shown in prior LCAs (Arvidsson et al., 2011; Stephenson et al., 2008; Stratton et al., 2010). The GHG balances can vary widely depending on important key factors such as: goal and scope, system boundary, allocation methods, N_2O emissions, and land use change (LUC) (Cherubini and Stromman, 2011; Malca and Freire, 2011; Whitaker et al., 2010). Several LCAs of rapeseed biofuels have concluded that the cultivation stage has the highest impact on overall GHG emissions, mostly due to N_2O emissions from the application of synthetic and organic nitrogen (N) fertilizer as well as from crop residues (Bernesson et al., 2004; Gasol et al., 2012; Malça and Freire, 2009; Ruslandi and Wu, 2010). Although the amounts of N_2O emissions are much smaller compared to CO_2 emissions from agricultural activities (e.g., field operation, fertilizer and chemical productions, and fuel used), the global warming potential (GWP) of N_2O is 298 times higher than CO_2. As a result, N_2O emissions could often make a significant contribution to the final result of life cycle GHG emissions of biofuels.

According to the Intergovernmental Panel on Climate Change (IPCC) guidelines, there are direct and indirect N_2O emissions due to the application of N fertilizers (IPCC, 2006). The direct N_2O emissions are produced by microbial activities in soil through nitrification and denitrification processes. The N_2O emissions increase directly with the addition of N fertilizer (e.g., synthetic or organic fertilizers, manure, and crop residues) due to enhanced N nutrient availability in soil causing increased nitrification and denitrification. Indirect N_2O emissions result from the volatilization of N as ammonia (NH_3) and from leaching of nitrate to groundwater from soils where N fertilizers are applied. The emissions of N_2O vary widely depending on management practices (e.g., tillage, cropping system, lime, N fertilizer and type), soil physical properties and moisture content, climate condition, and crop type in different locations (Stehfest and Bouwman, 2006).

The methodologies to estimate N_2O emissions can be generally divided into three tiers (IPCC, 2006). Tier 1 accounts for direct and indirect N_2O emissions when site-specific data is not available. Most of prior rapeseed biofuel LCAs have applied Tier 1 to quantify N_2O emissions (Arvidsson et al., 2011; Iriarte et al., 2010; Stratton et al., 2010). Tier 2 is recommended to be used for the country or region-specific analyses because it is more reliable than Tier 1. Many rapeseed biofuel LCAs (Bernesson et al., 2004; Gasol et al., 2012; Stephenson et al., 2008) considered country-specific data to estimate N_2O emissions (e.g., precipitation, soil type, crop type, and emissions factor). ADEME (2010) studied biofuels in France from rapeseed feedstock. They calculated N_2O emissions using country-specific data (amount of N contained in crop residues and nitrate leaching) combined with default values from IPCC (2006) in order to compare the result with the IPCC guidelines and DNDC (Denitrification–Decomposition) model from the JRC (2007) study. The results showed that annual N_2O emissions of rapeseed cultivation were 2.9, 3.7, and 2.7 kg N_2O–N ha^{-1}, respectively. Smeets et al. (2009) evaluate the GHG emission balance of many feedstocks including rapeseed for biodiesel in North America, EU25, and East EU, using the statistical model presented by Bouwman et al. (2002) to determine the impact of fertilizer and manure on N_2O emissions in different reference land use types: cropland, grassland and natural vegetation. The total GHG emissions of rapeseed biodiesel changed by −81% to 72% when compared to fossil diesel fuel, with the wide range largely due to different reference land use types. Tier 3 refers to measuring N_2O emissions in a field or using biogeochemical based models to simulate N_2O emissions, which is likely the most accurate method (IPCC, 2006) because it considers the effect of biological mechanisms and chemical process at site-specific locations. Few LCAs on rapeseed biofuels applied Tier 3 modeling or measurement at the field. Barton et al. (2010) investigated soil N_2O and CH_4 emissions from growing canola in one semi-arid region in Australia. They found that the emission factor (EF) of applied N was 17 times lower than IPCC. Merino et al. (2012) measured the N_2O emissions of rapeseed crop on loamy clay soil in Northern Spain, where the measured direct N_2O emissions factor was 2.54% of applied N, higher than the IPCC default value of 1%. Biswas et al. (2011) studied canola biodiesel in a semiarid environment by measuring soil N_2O emissions in the field and estimated N_2O emissions using IPCC emissions factor. The GHG emissions for biodiesel decreased from 63 to 37 g CO_2 eq/MJ of biodiesel when changing the method to determine N_2O emissions from IPCC (2006) to field measurements. JRC (2011) applied the DNDC model to estimate N_2O emissions of several feedstocks for biofuel GHG life cycle assessments in Europe. Adler et al. (2007) used the DAYCENT (Daily Century) model to evaluate N_2O emissions, soil organic carbon changes and crop yield for corn, soybean, alfalfa, hybrid poplar, reed canarygrass, and switchgrass as bioenergy cropping systems on GHG emissions of biofuels in Pennsylvania, U.S. Kim et al. (2009) studied the GHG emissions of corn grain and corn stover life cycles (cradle-to-farm gate) using the DAYCENT model to predict N_2O emissions and soil organic carbon in 8 counties of 7 U.S. states. They found that the GHG emissions associated with field emissions (i.e., N_2O emissions and soil organic carbon changes) from corn grain varied across locations in the range of 91–618 g CO_2 eq/kg grain. The US EPA predicted N_2O emissions using the DAYCENT model for energy crop cultivation and for the regulation of biofuels (EPA, 2010a); however rapeseed crop does not exist in the current version of DAYCENT.

Based on this literature, the methodology used to determine N_2O emissions plays an important role in GHG emissions of feedstock cultivation and biofuels production and use. Few authors have studied regional variations of N_2O emissions for rapeseed cultivation and the effects of these regional differences on life cycle GHG emissions of rapeseed biofuels. Therefore, this study will focus on the application of the Roundtable on Sustainable Biofuels (RSB) GHG calculation methodology for estimating N_2O emissions for rapeseed cultivation in 10 U.S. wheat-growing states where rapeseed cultivation as a rotation crop is being considered: California (CA), Kansas (KS), Montana (MT), North Dakota (ND), Nebraska (NE), Oklahoma (OK), Oregon (OR), Texas (TX), South Dakota (SD), and Washington (WA). These obtained results were compared to the results obtained from the IPCC (Tier 1) reference method. In order to understand the similarities and differences in the RSB and the IPCC methods for estimating N_2O emissions, we maintain the same N fertilizer application rates, the same types of N fertilizers, and the same rapeseed yield in each state. The final results of regional N_2O emissions from rapeseed cultivation will be combined with the fuel conversion and use in order to evaluate the GHG emissions balance of rapeseed HRJ fuel.