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EMISSIONS OF BIOGENIC VOLATILE ORGANIC COMPOUNDS IN A REGIONAL CROPPING SYSTEM

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Abstract: Biogenic volatile organic compounds (BVOCs) emitted from vegetation participate in many atmospheric reactions that can contribute to the formation of carbon dioxide, ozone, secondary organic aerosol (SOA) and particulate matter (PM). BVOCs will impact on not only air quality but also climate change. Previous studies mainly focused on BVOCs emissions from forests at local and global scales, while few concentrated on the contribution of crops to BVOCs emission. Some aspects in the estimation of BVOC emission from crops, including emission rates of different crop species remained unclear. This study aimed to evaluate the regional and periodical isoprene emission of spring wheat. Air temperature, solar radiation and other meteorological parameters as well as crop yield will be collected and used to investigate crop biomass (B) and photosynthetically available radiation (PAR), and then input to the updated BEIS model. The results showed that the isoprene emission rate was 0.056 $\mu g \cdot m^{-2} \cdot h^{-1}$ on average, and it varied greatly among different stages (Cv = 57.19%) and slightly in districts (Cv = 13.65%). Spring wheat emitted more isoprene during earlier stages than that in later stages, with a highest emission rate at jointing stage (0.119 $\mu g \cdot m^{-2} \cdot h^{-1}$) and followed by booting stage (0.088 $\mu g \cdot m^{-2} \cdot h^{-1}$) and emergence stage (0.071 $\mu g \cdot m^{-2} \cdot h^{-1}$). This study provided a new method for the assessment of isoprene emission rates from spring wheat. The results can be used to develop appropriate strategy for regional emission management.

1. INTRODUCTION

Biogenic volatile organic compounds (BVOCs) have an impact on not only air quality but also climate change. Global warming is increasing the Earth's average surface temperature at a century-scale due to rising levels of greenhouse gases (GHGs) and its long-term persistence in the atmosphere. Human influence has been the probably dominant cause of global warming since the mid-20th century (IPCC, 2013). Aerosol particles, as the important composition of GHGs, not only have a direct effect on climate change, but also cause changes in cloud properties. As the precursors to carbon dioxide, ozone, secondary organic aerosol (SOA) and particulate matter (PM), BVOCs emitted from vegetation participate in many atmospheric reactions (Ormeño et al., 2010; Peñuelas et al., 2003). On a global scale, BVOCs are the main source of tropospheric VOCs, with annual emissions of 1150 Tg $C \cdot yr^{-1}$, accounting for 90% of total VOCs emissions and much higher than AVOCs emissions (Guenther et al 1995; 2006). These BVOCs represent a large carbon loss and can be up to ~10 % of that fixed by photosynthesis under stressful conditions and up to 100 g $C \cdot m^{-2}$ per year in some tropical ecosystems (Peñuelas et al., 2003). Due to the wide variety of vegetation and the release of VOCs by all plants, there are more than 30,000 species of BVOCs, which can be divided into four categories (mass ratio): isoprene (44%), monoterpenes (11%), other active BVOCs

(22.5%) and inactive BVOCs (22.5%) (Guenther et al., 1995; Kesselmeier et al., 1999; Peñuelas et al., 2003).

Previous studies mainly focused on BVOCs emissions of forests at local and global scales, while few concentrated on the contribution of crops to BVOCs emission. Some aspects in the estimation of BVOC emission from crops, including emission rates of different crop species, remain unclear. Since the 1960s, emissions observations and simulations of BVOCs have gradually attracted attention (Went, 1960), and four observation technology systems were introduced: laboratory analysis, portable detection, micrometeorology and remote sensing estimation. Among them, the first three observe the BVOCs emissions at local scale while the fourth method observes them at regional and global scale. BEIS, named Biogenic Emissions Inventory System, was the earliest emission model established by the US Environmental Protection Agency (EPA) to simulate large-scale BVOCs emissions for a county by using land use areas, leaf biomass factors, emission factors and environmental factors since the 1990s (Pierce and Waldruff, 1991). However, the model was very limited in its application, so it was gradually improved and transformed into MEGAN (Model of Emissions of Gases and Aerosols from Nature). MEGAN was designed to estimate BVOCs emissions at both the global and regional scale (Guenther et al., 2006; 2012; Sakulyanontvittaya et al. 2008).

In this study, an emission model was developed with the assistance of biogenic emission inventory system. Some meteorological parameters such as relative humidity, air temperature and some solar radiation parameters were collected and used to investigate crop biomass (B) and photosynthetically available radiation (PAR). This study could provide an updated method for the assessment of isoprene emission from spring wheat or other crops. The results can be used to develop appropriate strategy for regional emission management.

2. METHODOLOGY

2.1 BVOC Emission Model

Referred to BEIS and MEGAN as well as Guenther's calculation methods (Guenther et al., 1991; 1993; 1995), the isoprene emission rate (*ER*, μg C·m^{-2}·h^{-1}) was estimated by Equation 1:

[1] $ER = \varepsilon \times B \times \gamma$

where ε is the standard emission factor for any species (μg·g^{-1}·h^{-1}), and the standard condition includes a temperature Ts=303 K and a PAR flux equal to 1,000 μmol·m^{-2}·s^{-1} photons in the range of 400 -700 nm;

B is the dry weight of wheat biomass (g C·m^{-2}) at different growing stages;

γ is the environmental correction factor mainly related to light and temperature.

2.2 Normalized Emission Factor (ε)

In this study, the isoprene emission factor of wheat was determined by previous studies (Li et al., 2017; Morrison et al., 2016; Wang et al., 2003; Zhao et al., 2004). The values vary between 0 and 0.5 μg g^{-1} h^{-1} and the average was regarded as 0.25 μg·g^{-1}· h^{-1}.

2.3 Wheat Biomass at Different Stages (B)

In this study, the wheat biomass (B, g·C/m^2) was calculated with net primary productivity (NNP, g·C·m^{-2}). The wheat yield (g·m^{-2}) can be predicted by the amount of dry matter corrected by the ground-measured harvest index (HI) of wheat, so the NNP can be estimated as follows (Zhou et al., 2017):

[2] $NPP_i = \frac{Yield \times (1-M) \times C}{HI_i \times R}$

where i represents different growing stages of wheat;

$Yield$ represents estimated crop yield of spring wheat (Crop Report, 2017);

HI is the harvest index of wheat (the ratio of crop yield to above-ground biomass), varying with growing stages (Xu et al., 2015);

R is the ratio of aboveground biomass to whole biomass of crops;

M is the water content of the wheat-harvested part;

C is the carbon content of the wheat-harvested part.

2.4 Environmental Correction Factor (γ)

The emissions of isoprene depend on light and temperature whereas emissions of monoterpenes depend only on temperature. Therefore, the environmental correction factor of isoprene was estimated as follows (Aleksandropoulou et al., 2011, Li et al., 2017):

[3] $\gamma_{iso} = \gamma_t \times \gamma_p$

where γ_t and γ_p are the environmental correction factors for temperature dependence and light dependence of isoprene emission, respectively.

3. RESULTS AND DISCUSSION

Table 1 showed the isoprene emission rates of spring wheat during different growing stages in Saskatchewan in 2017. The isoprene emission rate was 0.056 μg·m^{-2}·h^{-1} on average, and it varied greatly among stages (Cv = 57.19%) and slightly in districts (Cv = 13.65%). For the district perspective, isoprene emission rates decreased from west to east except for central parts, and they showed the highest at northeast with a value of 0.067 μg·m^{-2}·h^{-1}, and the lowest at northwest with a value of 0.045 μg·m^{-2}·h^{-1}. From a stage perspective, isoprene emission rates varied with plant growth between 0.014 μg·m^{-2}·h^{-1} and 0.119 μg·m^{-2}·h^{-1}. The values were higher during earlier stages than those in later periods.The isoprene emission rates during different growing stages were ordered as follows: jointing (0.119 μg·m^{-2}·h^{-1}) > booting (0.088 μg·m^{-2}·h^{-1}) > emergence (0.071 μg·m^{-2}·h^{-1}) > sowing (0.047 μg·m^{-2}·h^{-1}) > heading (0.046 μg·m^{-2}·h^{-1}) > filling (0.038 μg·m^{-2}·h^{-1}) > senescence (0.028 μg·m^{-2}·h^{-1}) > flowering (0.014 μg·m^{-2}·h^{-1}).

Table 1 Periodical isoprene emission rates (ER, μg·m^{-2}·h^{-1}) in Saskatchewan in 2017

Stage	Southeast	Southwest	East Central	West Central	Northeast	Northwest	Provincial
sowing	0.049	0.048	0.052	0.042	0.047	0.042	0.047
emergence	0.069	0.053	0.068	0.076	0.088	0.072	0.071
jointing	0.137	0.108	0.109	0.125	0.155	0.081	0.119
booting	0.076	0.093	0.071	0.117	0.105	0.063	0.088
heading	0.057	0.037	0.057	0.045	0.047	0.031	0.046
flowering	0.015	0.010	0.016	0.014	0.013	0.013	0.014
filling	0.039	0.029	0.040	0.038	0.049	0.036	0.038
senescence	0.033	0.028	0.031	0.029	0.029	0.019	0.028
average	0.059	0.051	0.056	0.061	0.067	0.045	0.056

These results were consistent with some previous studies (Guenther et al., 1994; Li et al., 2017; Wang et al., 2003). However, Morrison et al. (2016) held a different view that isoprene emission rates from wheat were negligible but monoterpenes had relatively high values. This may be because these emissions are strongly dependent on various environmental conditions, such as temperature, solar radiation, plant water

stress, ambient ozone and CO2 concentrations, and soil moisture (Guenther et al., 2012; Jiang et al., 2018). For example, temporal sesquiterpene emission variations appear to be dominated mainly by ambient temperatures although other factors contribute (e.g., seasonal variations). Sesquiterpene emissions have increased significance at certain times of the year, especially in late spring to mid-summer. The strong temperature dependency of sesquiterpene emissions also creates the distinct possibility of increasing sesquiterpene emissions in a warmer climate (Duhl et al, 2008).

4. CONCLUSIONS

This study updated BEIS model by converting wheat yield to wheat biomass. Isoprene emission rates of spring wheat during different growing stages were estimated for Saskatchewan in 2017. The results showed temporal variations and spatial differences in isoprene emission rates. The average of these values was 0.056 $\mu g \cdot m^{-2} \cdot h^{-1}$, and it presented a great difference among growing stages but a slight variation among districts. Spring wheat emitted more isoprene during earlier stages than in later stages, with a highest emission rate at the jointing stage (0.119 $\mu g \cdot m^{-2} \cdot h^{-1}$), followed by the booting stage (0.088 $\mu g \cdot m^{-2} \cdot h^{-1}$) and the emergence stage (0.071 $\mu g \cdot m^{-2} \cdot h^{-1}$). Spring wheat in different districts of Saskatchewan show a low variation in isoprene emission rates between 0.045 $\mu g \cdot m^{-2} \cdot h^{-1}$ and 0.067 $\mu g \cdot m^{-2} \cdot h^{-1}$, decreasing from west to east except for central districts.

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