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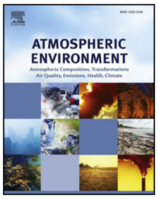

Effect of straw incorporation on aldehyde emissions from a maize cropping system: A field experiment

Shuangqi Zhang[a], Mengsi Deng[a], Ming Shan[a,*], Chuang Zhou[b], Wei Liu[b], Xiaoqiu Xu[b], Xudong Yang[a]

[a] *Department of Building Science, Tsinghua University, Beijing, 100084, China*
[b] *Energy & Environmental Research Institute of Heilongjiang Province, Harbin, 150027, China*

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ABSTRACT

Aldehyde may occupy an important role in the volatile organic compound (VOC) emissions from soil and plant residue. However, aldehyde emission from agricultural soil as well as the effect of straw incorporation is poorly understood. Therefore, a field straw incorporation experiment comprising two treatments, (1) S0 (no straw incorporation) and (2) S1 (incorporation of maize straw at a rate of 9000 kg ha^{-1}), was performed in a maize cropping system to characterize the emissions of aldehyde as well as to estimate the effect of straw incorporation on aldehyde emissions. Nine kinds of aldehydes were investigated and three emission dynamic modes were observed during the experiment. Total aldehydes emissions were significantly different (426.8 and 540.2 g ha^{-1} for S0 and S1, respectively). Generally speaking, decanal and nonanal had an obvious predominance in both treatments, taking up 33.1% and 29.2% of the total aldehydes emission for S0, and 30.4% and 28.4% for S1, respectively. In addition, the practice of straw incorporation significantly increased the emissions of the 9 kinds of aldehydes by 11.2%–103.3%, and the total aldehydes emission from incorporated straw alone was calculated as 2918.8 ng kg $straw^{-1}$ h^{-1}. These results showed that straw incorporation substantially influenced the emissions of aldehydes from the agricultural soil. Additionally, a rough comparison indicated that straw incorporation might not have much advantage over straw open burning in terms of reducing VOC (i.e., aldehyde) emissions. The results also suggested that environmental conditions (i.e., soil temperature, moisture and pH), especially soil pH, played an important role in aldehyde fluxes from the agricultural soil.

1. Introduction

Atmospheric volatile organic compounds (VOCs) originate from three main sources including anthropogenic activities, biomass burning and the biosphere, among which the biosphere (e.g., trees and other vegetation) is the main source of VOCs for the atmosphere (Guenther et al., 2012, 1995). VOCs which are generously emitted from terrestrial ecosystems have received much attention due to their important influence on atmospheric chemistry, soil processes, and biotic interactions in soil. VOCs, especially those of biogenic origin, can alter atmospheric photochemistry by interacting with other atmospheric trace compounds, which affect distributions of air pollutants such as nitrogen oxides (NOx), peroxyacyl nitrates (PANs), and particles (Atkinson and Arey, 2003; Griffin et al., 1999; Torkmahalleh et al., 2016) and contribute to the production of tropospheric ozone (Chen and Griffin, 2005; Xie et al., 2017; Zhang et al., 2017). The presence of VOCs in the soil atmosphere can also influence biogeochemical processes, thereby altering rates of carbon and nitrogen cycling including nitrification (Bending and Lincoln, 2000), denitrification (Amaral et al., 1998), nitrogen mineralization (Smolander et al., 2006), and methane oxidation (Chiemchaisri et al., 2001). In addition, some VOCs can also directly influence the plant growth (Farag et al., 2006; Raza et al., 2017).

VOCs are generously emitted from terrestrial ecosystems, and for this reason, studies have been conducted intensively to identify the sources and quantify the amounts of VOCs from terrestrial ecosystems (Asensio et al., 2007a; Insam and Seewald., 2010; Peñuelas et al., 2014; Singh et al., 2011). However, the vast majority of the studies on the VOC emissions from terrestrial ecosystem have focused on natural ecosystems (forest, grassland, wetland, etc.), whereas less attention has been paid to VOC emissions from agricultural ecosystem. Considering that the global agricultural land area is approximately 4912 million hectares, comprising 37.4% of the global land area (FAO, 2013), and that agricultural land can emit a large variety and quantity of VOCs (Leff and Fierer, 2008; Redeker et al., 2003; Wang et al., 2015), VOC

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[*] Corresponding author.
E-mail address: mshan@tsinghua.edu.cn (M. Shan).

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emissions from agricultural land are expected. Therefore, more studies are needed to quantify VOC emissions from the agricultural soil. Moreover, the global annual production of agricultural crop straw is approximately 2476 million tons (FAO, 2013), a large proportion of which is incorporated into the soil as organic fertilizer across the world (Liu et al., 2014; Sanchis et al., 2012; Shan and Yan, 2013). Accordingly, the impact of incorporated straw on VOC emissions from agricultural soil would be expected when they are incorporated and decomposed in the agricultural soil. However, to the best of our knowledge, the data on the effect of straw incorporation on VOC emissions from the agricultural soil is scarce, and the data that are available were obtained via pot experiments under laboratory conditions (Wang et al., 2015). Thereby, more studies, especially in the field, are needed to estimate the effect of straw incorporation on VOC emissions from the agricultural soil.

Previous studies have observed that aldehyde emissions occupied an apparent predominance in VOC emissions from soil and litter samples (Asensio et al., 2007a; Leff and Fierer, 2008). In particular, Asensio et al. (2007a)Asensio et al. (2007a) reported that the exchange rates of aldehydes (i.e., formaldehyde and acetaldehyde) were one order of magnitude higher than those measured for monoterpenes. In addition, Leff and Fierer (2008) found that aldehyde (i.e., furfural) was the most common VOC detected from soil and litter samples and that aldehyde (i.e., furfural) takes a percentage of up to 76.6% of the total VOC emissions from the agricultural soil. It is also worth mentioning that the aldehyde emissions from the agricultural soil were higher in the presence of organic fertilizers (Raza et al., 2017). These results, taken together, suggested that special attention should be paid to the emissions of aldehydes from the agricultural soil.

In addition to the lack of information on aldehyde emissions from the agricultural soil as well as on the effect of straw incorporation on such, little is known about the factors controlling aldehyde emissions from the agricultural soil. Thus, the present study explored the correlations between aldehyde emissions and environmental conditions (i.e., soil temperature, moisture and pH value), as these factors have been reported to have an influence on the exchange rates of VOCs (Cho et al., 2005; Johnsen et al., 2005).

Motivated by the lack of information on aldehyde emissions from the agricultural soil as well as on their variations with straw incorporation, especially under filed conditions, the present study conducted a field straw incorporation experiment to: (1) characterize the aldehyde emissions from agriculture soil under non-straw incorporated and straw incorporated conditions; (2) quantify the effect of straw incorporation on aldehyde emissions from the agricultural soil; (3) investigate the correlations between aldehyde emissions and environmental conditions (i.e., soil temperature, moisture and pH value). This study aimed to achieve a better understanding on the impact of straw incorporation on aldehydes emission from the agricultural soil and its unknown mechanisms.

2. Materials and methods

2.1. Site description

The field experiment was performed at Songhua River Village (45°83′N latitude, 126°67′E longitude and at an altitude of 118.1 m above sea level), Songbei District of Harbin City, Heilongjiang Province, Northeast China, with a medium-temperate continental monsoon climate. The typical cropping system in Heilongjiang Province is single cropping maize. Heilongjiang Province has a growing area of 5.8 million hectares and a maize production of 35.4 million tons, occupying 15.3% of the total growing area and 15.8% of the total maize production in China (National Bureau of Statistics of China (NBSC), 2016). The mean annual temperature is 3.5 °C with maximum and minimum temperatures of 37.8 °C and −42.6 °C, respectively. The frost-free period is 135–140 days. More than 60% of annual precipitation (mean annual precipitation: 569.1 mm) is concentrated from June to September. The soil has a texture of clay loam and is classified as Udic Mollisols according to the United States Soil Taxonomy (Xing et al., 2005). The soil was frozen and covered with snow from the beginning of October 2016 to the middle of March 2017.

2.2. Experimental design

The experiment was performed in the field from May 17th, 2017 to October 15th, 2017, which included two treatments: control group with straw removal (S0) and test group with incorporation of maize straw at a rate of 9000 $kg\,ha^{-1}$ (S1). Each treatment contains three replicates. The field prior to the experiment was uniformly cultivated in 2016 to eliminate soil heterogeneity (Ni et al., 2012) and was split into 6 plots (2 m × 3 m) in October 2016. Three replicates of each treatment were laid out in a randomized block design. On October 24th of 2016, after harvesting all aboveground biomass, the chopped straw (at a length of 0–5 cm) from the previous crop was manually incorporated into the top 30 cm of soil. The maize straw characteristics were as follows: total C content of 436 $g\,kg^{-1}$, total N content of 7.5 $g\,kg^{-1}$, total P content of 2.4 $g\,kg^{-1}$, water content of 61.3%. Maize was planted on May 11th of 2017, with row spacing of 65 cm and seeded at 25 cm intervals following the regional recommendations. The maize variety Xianyu 335 was used and the fertilizer was applied twice during the growing season. Before seeding, commercial compound fertilizer (i.e., 25% N, 10% P_2O_5, and 10% K_2O) was evenly spread onto the soil surface at a rate of 187.5 $kg\,N\,ha^{-1}$, 75 $kg\,P_2O_5\ ha^{-1}$, and 75 $kg\,K_2O\ ha^{-1}$ and immediately plowed into about 30 cm soil layer. At jointing stage (July 7th of 2017), urea (i.e., 46% N, at a rate of 70 $kg\,N\,ha^{-1}$) was evenly applied into the small holes with the depth of approximately 10 cm near the crop within 8 cm, and was then buried with soil. There was no artificial irrigation during the experiment period, and manual weeding was performed throughout the experiment. The maize was harvested on October 11th of 2017.

2.3. VOC sampling

Measurements of soil aldehyde exchange were conducted in situ using a dynamic chamber method (Asensio et al., 2008; Wang et al., 2015). A dynamic chamber consisted of a base frame (a cylinder with a diameter of 15.9 cm and a height of 20 cm) and a removable lid. Six pairs of base frame and lid were made of mirror stainless steel with the mirror facing inward, which were verified to have no production or degradation of target VOCs through pre-test. Each base frame was inserted immediately to a depth of 15 cm in the middle of two adjacent maize plants in the same row after sowing and remained in the fields throughout the experiment. Each base frame had an air inlet on the side (4 cm from the top of the base frame) while each lid had an air outlet in the center. All connecting tubes were made of Teflon.

When sampling, a thin rubber mat was used on the top of each base frame to prevent leakage. Clean air from the compressed air tank was drummed into each chamber at a constant rate of 0.4 $L\,min^{-1}$ via a gas mass flow controller (DSN-D-600CD, Dongguan Dexin Electronic Technology Co., Ltd.), and meanwhile air inside the chamber was pumped out at the same rate as air entry, using an atmospheric sampling pump (QC-2, Beijing Institute of Labor Protection, China). Equilibration of aldehyde concentrations in the effluent stream occurred after 45 min, which was determined through pre-test. Then, VOC samples were collected into the Tenax TA tubes (Markes, UK) at a flow rate of 0.4 $L\,min^{-1}$ for 10 min, using the atmospheric sampling pump. In order to minimize the error during the measurements, the flow rates of gas mass flow controllers and atmosphere sampling pumps were calibrated prior to each sampling.

On each sampling day, one VOC sample was taken from each of the six plots (including three in S0 and three in S1) between 11:00 and 16:00 to present the average flux of the day. And, in order to estimate