



# Effects of plant-derived dissolved organic matter (DOM) on soil CO<sub>2</sub> and N<sub>2</sub>O emissions and soil carbon and nitrogen sequestrations



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## ABSTRACT

Dissolved organic matter (DOM) in soils play an essential role in soil physical, chemical and biological processes, but little information is available on the biodegradability of plant-derived DOM and its effect on soil carbon and nitrogen sequestration in field soils. The objectives of this study were to investigate the impacts of crop residue-derived DOM on soil CO<sub>2</sub> and N<sub>2</sub>O emissions, as well as soil carbon and nitrogen sequestration by adding water extracts of maize stalk (i.e., plant-derived DOM) to soils. In this study, wheat was grown in pots under field conditions with treated soils, the soils treatments were: plant-derived DOM (PDOM), urea nitrogen (N), PDOM + urea nitrogen (PDOM + N), as well as a control with no additions to soil (CK). Adding plant-derived DOM to soil increased soil CO<sub>2</sub> and N<sub>2</sub>O emissions ( $P < 0.05$ ). During the wheat growing season, the cumulative CO<sub>2</sub>-C emission from CK, PDOM, N and PDOM + N was  $107 \pm 1$ ,  $157 \pm 7$ ,  $136 \pm 2$  and  $149 \pm 6$  g C m<sup>-2</sup>, respectively. Meanwhile, the cumulative N<sub>2</sub>O-N emission from CK, PDOM, N and PDOM + N was  $188 \pm 8$ ,  $256 \pm 5$ ,  $239 \pm 10$  and  $258 \pm 7$  mg N m<sup>-2</sup>, respectively. Compared with N treatment, DOM addition had little effect on soil N sequestration, but it accelerated the decomposition of native soil organic carbon (SOC) and caused a net loss of SOC. The soil C sequestration decreased about  $151 \pm 67$  and  $51 \pm 45$  g C m<sup>-2</sup> in PDOM and PDOM + N treatments, respectively. The increased microbial biomass and root biomass were responsible for the greater CO<sub>2</sub> emission in DOM-amended soils. Negative correlation between dissolved organic carbon (DOC) content and N<sub>2</sub>O flux suggested that the release of N<sub>2</sub>O was dependent on the supply of DOC. These results indicated that the supply of plant-derived DOM exacerbated soil CO<sub>2</sub> and N<sub>2</sub>O emissions and reduced soil C sequestration. Therefore, agricultural management practices that increase the stability of highly soluble C inputs and/or retard the decomposition of crop residues should be adopted to decrease soil greenhouse gas emission and increase soil C sequestration.

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## 1. Introduction

Dissolved organic matter (DOM) is readily decomposable and can be preferentially utilized by the microorganisms than the recalcitrant fraction of SOC (Cleveland et al., 2004, 2007; Ghani et al., 2013; Kalbitz et al., 2003). It is estimated that about  $3.8 \times 10^9$  Mg yr<sup>-1</sup> of total crop residues are produced in global agricultural ecosystems (Thangarajan et al., 2013), and large quantities of crop residues are retained in soils every year

(Rochette and Gregorich, 1998). The litter-derived soluble organic carbon accounts for 5–15% of the total C content, which corresponds to 5–25% of the litter biomass (Cleveland et al., 2004). The plant-derived DOM represents a major source of soil DOM (Kalbitz et al., 2000), while adding this kind of soluble organic matter to soil may lead to an increase in microbial activity and subsequently accelerate the turnover of SOC through priming effect (PE) (Derrien et al., 2014; Fontaine et al., 2004; Kuzyakov et al., 2000; Paterson and Sim, 2013). The PE is generally neglected in soil C balance calculation because it is commonly accepted that the PE is temporary leading to small soil C losses (Kuzyakov et al., 2000). However, recent studies have shown that the PE could persist several months after the complete decomposition of added fresh organic matter, and having a marked effect on the final C

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balance (Fontaine et al., 2004, 2011). Some studies, based on positive priming effect, stated that organic amendments were not favorable for soil C sequestration (Ding et al., 2010). This is unjustified since they did not consider the amount of added C remaining in the soil (Kuznyakov, 2010). Although many previous studies have observed that DOM can be rapidly decomposed by microbes (Chantigny, 2003; Kalbitz et al., 2000), a few studies have reported that DOM is comprised of a rapidly decomposable fraction with a turnover rate of <1–5 days (Gregorich et al., 2003; Uselman et al., 2000), and a slowly decomposable fraction with a turnover rate of between 80 days and 9 years (Gregorich et al., 2003; Kalbitz et al., 2003). The slowly mineralized fraction of DOM contributes to the accumulation of slowly mineralized C in the soil (Neff and Asner, 2001; Qualls and Bridgman, 2005). Therefore, both the DOM-C input from crop residues and the CO<sub>2</sub>-C output from organic matter mineralization should be taken into account to determine the net effect of residue-derived DOM on soil C balance.

Many studies on the biodegradation of DOM were conducted in forest ecosystems (Cleveland et al., 2004; Kalbitz and Kaiser, 2008; Kalbitz et al., 2003; Qualls and Haines, 1992), yet very few studies have been performed in agricultural ecosystems, and moreover, these studies were only conducted in laboratory environments. For example, Kalbitz et al. (2003) extracted DOM from 13 different samples (maize straw, forest floors, peats, agricultural soils) to investigate the biodegradation in a 90-day solution culture. They found that 89% and 17–32% of the DOM derived from maize straw and agricultural soils were mineralized at the end of the experiment, respectively. Cleveland et al. (2004) used both live foliage and senesced litter from temperate and tropical ecosystems to investigate the decomposition of plant-derived DOM in a 100-day solution culture. They observed that more than 70% of the initial litter-derived DOM was decomposed in the first 10 days. Chen et al. (2014) also reported that 28.7–35.7% of the initial rice plant-derived DOM was mineralized in 100 days incubation. However, these studies on the biodegradability of plant-derived DOM were conducted in solution cultures without the soils. These results may not reflect the biodegradability of plant-derived DOM in the presence of soils, since soil microorganisms as well as soil physical sorption and desorption can affect the fate of DOM in the soil (Kalbitz and Kaiser, 2008; Kalbitz et al., 2000). Moreover, the environmental conditions varies in the field, and the responses of the biodegradation of DOM to the external environmental changes remain unknown in the agricultural ecosystems. Therefore, the laboratory findings await verification under field conditions especially with growing crop.

It is estimated that about  $7 \times 10^8$  Mg yr<sup>-1</sup> of crop residues (equivalent to 5.3 t ha<sup>-1</sup> yr<sup>-1</sup>) is produced in China (Bi et al., 2009; Gong et al., 2012). Incorporation of crop residues directly to soil will be the major way of crop residues management by using the combine harvest in future farming practices. A flush of DOM into soil may occur following the input of crop residues (Cleveland et al., 2004; Kalbitz et al., 2003), especially when the environmental conditions are favorable for the decay (Thangarajan et al., 2013). Such a high rate of plant-derived DOM incorporated in soils may activate microorganisms and accelerate SOC decomposition through priming effect. It remains unclear whether the amount of CO<sub>2</sub>-C loss because of priming effect exceeds the amount of added C retaining in the soil. Therefore, an experiment with winter wheat grown in pots under field conditions was set up to investigate the effects of plant-derived DOM on soil CO<sub>2</sub> and N<sub>2</sub>O emissions, as well as soil carbon and nitrogen sequestration by adding water extracts of maize stalk (i.e., plant-derived DOM) to soils.

## 2. Materials and methods

### 2.1. Site description

This study was conducted at Yucheng Agricultural Experiment Station, Chinese Academy of Sciences (36°50'N, 116°34'E), located in the North China Plain at 26 m above mean sea level and part of the Yellow River alluvial plain. The weather is warm-temperate and sub-humid monsoon climate with the long-term average annual precipitation of 593 mm and mean annual temperature of 13.1 °C, the average frost-free period is 220 days. Nearly 70% of the annual precipitation falls between June and September.

### 2.2. Experimental design and operation

A pot experiment with winter wheat was set up on October 10, 2013 using the soils collected from the top 20 cm of a field with a long-term wheat/corn double cropping annually for about 30 years. Soils were air-dried and passed through a 2-mm sieve, any visible roots and organic residues were removed, and after that it was mixed thoroughly prior to the experiment. This soil is calcareous fluvisols according to the FAO-UNESCO system, a silt-loam texture with 12% sand, 66% silt and 22% clay, and an average pH<sub>H2O</sub> of 7.90. It contained 14.57 g kg<sup>-1</sup> of SOC, 0.87 g kg<sup>-1</sup> of total nitrogen (N), 2.06 g kg<sup>-1</sup> of total phosphorus (P), 22.90 g kg<sup>-1</sup> of total potassium (K), 118.54 mg kg<sup>-1</sup> available N, 18.47 mg kg<sup>-1</sup> available P, 165.66 mg kg<sup>-1</sup> available K and 144.65 mg kg<sup>-1</sup> DOC.

The experiment consisted of four treatments with six replications in a completely randomized design. The treatments were as follows: a control with no DOM additions to soil (CK), plant-derived DOM added to soil (PDOM), urea nitrogen added to soil (N), and a combination of plant-derived DOM and urea N added to soil (PDOM+N). The size of pots used in the experiment was 30 cm in height and 40 cm in diameter. A total of 40 kg of soil was packed into each pot at a density of 1.3 g cm<sup>-3</sup> and at a depth of 24.5 cm. Pots were equilibrate under field conditions for two weeks before seeds were sowed. The initial soil moisture was adjusted to 70% of field capacity. Winter wheat grown in each pot was evenly sown in two rows with row spacing of 15 cm on October 10, 2013, and harvested on June 4, 2014. Each pot grew 60 wheat plants. To determine the root biomass at harvest, a soil core of 4.9-cm diameter was taken randomly between the wheat rows in each pot to a depth of 20 cm. All root samples were washed in 0.5 mm mesh size nylon bags, and then separated the roots from soil through 0.5 mm sieve (Bernard and Fiala, 1986). The root samples were dried at 70 °C to constant weight.

### 2.3. Plant-derived DOM preparation and application rate

Corn stalk (including leaves, 1014 g dry-weight equivalent; 70 °C) was machine-ground, then placed into a 80 L barrel and 50 L of deionized water was added. After one month of extraction at 25 °C, the supernatant solution was filtered through 0.45 μm membrane and stored at -20 °C, and thawed overnight prior to use (Kalbitz et al., 2003). In wheat growing phase, all treatments (PDOM, N, and PDOM+N), excluding the control (CK), received the same total amount of N addition at a rate of 24.52 g N m<sup>-2</sup>, which is equivalent to 77 mg N kg<sup>-1</sup> dry soil, and it is the typical application rate of farmers in the North China Plain. The PDOM treatment received 24.52 g DOM-N m<sup>-2</sup>, and the N treatment received 24.52 g urea-N m<sup>-2</sup>, while the PDOM+N treatment received 12.26 g DOM-N m<sup>-2</sup> and 12.26 g urea-N m<sup>-2</sup>. The amount of DOM-C applied to soil associated with the addition of DOM was 331.53 g DOM-C m<sup>-2</sup> in PDOM and 165.76 g DOM-C m<sup>-2</sup> in PDOM+N, resulting in a C:N ratio of 13.52 and 6.76 in PDOM and PDOM+N treatments, respectively. The DOM and urea-N were surface-dressed in two

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