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Discrepant responses of methane emissions to additions with different organic compound classes of rice straw in paddy soil

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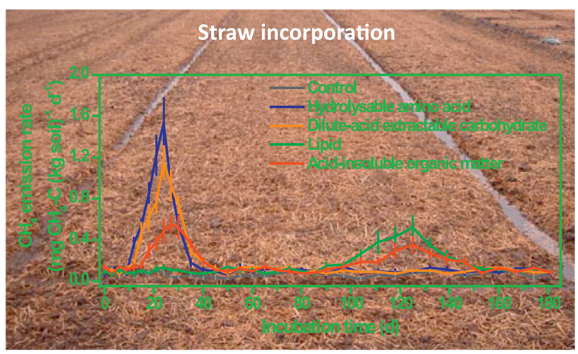
HIGHLIGHTS

- We assessed the effects of HAA, CHO, lipid and AIOM of rice straw on CH_4 emissions.
- Straw incorporation stimulates CH_4 emissions across organic compound classes.
- Occurrence time of the stimulation varies depending on organic compound classes.
- Incorporations of HAA and CHO exert the greatest intensities to stimulate CH_4 emission.

GRAPHICAL ABSTRACT



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ABSTRACT

Crop straw incorporation has become a prevailing agricultural practice that guarantees the food production and security. There is a significant body of work on the effects of straw incorporation on the methane (CH_4) emissions in paddy fields. However, it is unclear whether there are diverse links between CH_4 emission dynamics and incorporations of different organic compound classes of straw to paddy fields. In this study, soil incubations were conducted to assess the respective effect of incorporations of hydrolysable amino acid (HAA), dilute-acid extractable carbohydrate (DAC), lipid and acid-insoluble organic matter (AIOM) fractions of rice straw on the CH_4 emission in paddy soil. It is revealed that incorporations of HAA and DAC fractions exert the greatest intensities to stimulate the CH_4 emissions, which mainly takes place in the early period of incubation; on contrary, the incorporation of lipid fraction exerts the lowest intensity and mainly takes place in the late period. The pattern of CH_4 emission after incorporation of AIOM fraction occurs peaks both in the early and late periods of incubation. Our findings highlight that the time of occurrence and intensity of effects of rice straw incorporation on CH_4 emissions vary significantly depending on the different organic compound classes of rice straw, which may be key to proposing a promising management strategy for mitigating CH_4 emissions in paddy fields in the context of straw incorporation.
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1. Introduction

Methane (CH_4) is an important long-lived greenhouse gas that is expected to further increase in the atmosphere due to human activities (Vergé et al., 2007). CH_4 features over 25 times the global warming

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potential of CO_2 over a 100-year time frame prediction (IPCC, 2007; Shindell et al., 2009); therefore, slight variations in atmospheric concentration of CH_4 significantly impact the energy balance of the Earth's ecosystem and global climate change (Bridgham et al., 2013). Previous works have provided evidence that anthropogenic CH_4 emissions account for about 60% of global CH_4 emissions, whereas one-third of anthropogenic CH_4 emissions originate from agricultural practices (IPCC, 2013). As an extremely important agricultural production resource, rice paddy fields bear significance in developing food production and guaranteeing food security. However, rice paddy fields have also been demonstrated as important sources of CH_4 emissions (Liu and Whitman, 2008; Bridgham et al., 2013), thereby aggravating global warming.

There is a significant body of work on the CH_4 emission characteristics and assessment in rice paddy fields, whereas a series of recent studies have focused on the identification of key processes governing CH_4 production and oxidation (Han et al., 2016; Malyan et al., 2016; Kajiura et al., 2018; Yuan et al., 2018), because it is crucial for the development of agricultural practices to reduce CH_4 emissions while sustaining rice production. Straw incorporation is an advanced agricultural practice and has become an important component of sustainable and ecological agriculture due to its close relationship to soil fertility and ecological environment (Huang et al., 2013; Turmel et al., 2014; Wang et al., 2015). However, straw incorporation creates favorable conditions for CH_4 production in rice paddy fields (Conrad and Klose, 2006; Bhattacharyya et al., 2012). Although a number of research related to the association of CH_4 production in rice paddy fields with straw incorporation have been studied (Feng et al., 2013; Liu et al., 2014, 2015; Hu et al., 2016; Zhang et al., 2017), whether different organic compound classes of straw exert discrepant impacts on CH_4 emissions after incorporation to paddy fields presently remains unknown. Such impacts warrant investigation given their expected importance in gaining insights into the mechanisms of CH_4 emission in rice paddy fields and in promoting sustainable development of rice agriculture in the context of straw incorporation, which is widely applied all over the world.

In the present study, paddy soils amended with different organic compound classes of rice straw were incubated under anoxic condition. Anoxic incubation without any additive was considered as control. CH_4 emissions throughout anoxic incubations were monitored. The main objectives of this study included the following: (1) to verify the effects of rice straw incorporation on CH_4 emission under anoxic condition and (2) to test whether additions of different organic compound classes of rice straw exert discrepant effects on CH_4 emissions.

2. Materials and methods

2.1. Soil collection and preparation

Water-saturated paddy soil samples were obtained from the plow layer (0 cm to 20 cm depth) of a rice paddy field at the experimental station of Institute of Subtropical Agriculture, the Chinese Academy of Science located at Changsha County, Hunan Province, China. The collected soil samples were immediately placed in gas-tight glass vials (1 L), leaving no headspace, and preincubated in the dark at 25 °C for 48 h. The soil in the paddy field is clay loam (pH = 5.13 ± 0.17) and contains total organic matter of 28.7 ± 5.9 g kg^{-1}, total nitrogen of 3.08 ± 0.22 g kg^{-1}, Olsen phosphorus of 17.3 ± 1.86 mg kg^{-1}, and exchangeable potassium of 217 ± 14.5 mg kg^{-1}.

2.2. Collection of rice straws and fractionation of their organic compounds

Rice straws were obtained from the same rice paddy field where the soil samples were acquired. Straw samples were washed with deionized water and were freeze-dried, ground, and sieved through #100 mesh. The pretreated straw samples were subsequently separated into four organic compound classes, including hydrolysable amino acid (HAA), dilute-acid carbohydrate (DAC), lipid, and acid-insoluble organic matter (AIOM), according to a method modified from Wang et al. (1998). The improvement of method was to replace the concentrated acid with dilute acid (10%) to extract carbohydrate. These four organic compound classes were isolated as different additives in soil incubation experiments simulating rice straw incorporation. Table 1 summarizes the organic carbon contents of these four organic compound classes and their mass percentages in rice straw.

2.3. Experimental design and soil incubation

Soil incubations simulating rice straw incorporation were started by adding mixtures of preincubated soil and organic compound classes of rice straw to 150-mL serum vials with rubber stoppers equipped with silicon septum for gas sampling. Within each vial, the amount of soil added was equivalent to 80 g dry weight, and that of organic compound classes of rice straw added was measured based on a norm of 1 g organic carbon of organic compound class per 1 kg soil. Control treatment without rice straw addition was conducted to determine background CH_4 emissions. Subsequently, each vial was flushed with N_2 for 15 min to create an anaerobic environment and incubated in the dark at 25 °C and 60% water holding capacity. These incubation conditions were established to ensure that the assessment of the effects of rice straw additions on CH_4 emissions would not be affected by environmental changes, such as temperature, water and light conditions. Five treatment combinations, i.e., 1 soil type × (4 organic compound classes + 1 control) were utilized. Each treatment combination was replicated 4 times.

2.4. Gas sampling and analysis

CH_4 emissions were measured every 3 days during the first month of incubation. In months 2–3, CH_4 emissions were measured once every 5 days. In months 4–6, CH_4 emissions were measured once every 7 days. During measurements of CH_4 emissions, each incubation vial was ventilated by flushing the headspace with N_2 for 5 min and then sealed to accumulate CH_4. After subsequent anaerobic incubation of 2–3 h, gas samples were obtained from the headspaces of incubation vials using miniaturized gas samplers to determine CH_4 emission rates. CH_4 concentrations were measured within 24 h by using a gas chromatograph (Agilent 6890) coupled with thermal conductivity detector and flame ionization detector.

2.5. Calculations and statistical analysis

CH_4 emission rates on each sampling day were calculated based on accumulation rate of CH_4 concentration during a period of 2–3 h after ventilating the headspace of incubation vials. CH_4 emission rates between two successive samplings under anaerobic incubations were estimated by linear interpolation. Cumulative emissions of CH_4 during the entire incubation period were quantified by integration of CH_4 emission rate responses to incubation time. Contribution of each organic compound class to changes in CH_4 emission by rice straw incorporation was calculated by multiplying the difference in cumulative CH_4 emission between treatment with the addition of corresponding organic

Table 1
Organic carbon contents of hydrolysable amino acid (HAA), dilute-acid carbohydrate (DAC), lipid and acid-insoluble organic matter (AIOM), and their mass percentages in rice straws. Mean ± S.E. (n = 4 replicates).

Component	Mass percentage (%)	Organic carbon (g (kg d.w.)$^{-1}$)
HAA	21 ± 5.7	375 ± 54
DAC	23 ± 6.1	418 ± 41
Lipid	16 ± 3.6	501 ± 62
AIOM	35 ± 5.3	247 ± 23

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