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Mechanism of plant mediated methane emission in tropical lowland rice

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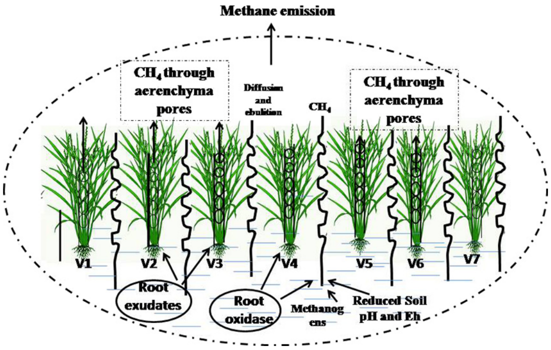
HIGHLIGHTS

- Seven rice cultivars, based on the life cycle duration tested in tropical eastern India.
- Aerenchyma pore space was quantified with regulation of CH_4 ransportation
- Rate of CH_4 emission was controlled by aerenchyma orientation, rhizosphere-enzymatic
- Significant variations in the methane emission was observed among the cultivars

GRAPHICAL ABSTRACT



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ABSTRACT

Methane (CH_4) is predominantly produced in lowland rice soil, but its emission from soil to atmosphere primarily depends on passage/conduit or capillary pore spaces present in rice plants. The gas transport mechanism through aerenchyma pore spaces of rice cultivars was studied to explore the plant mediated CH_4 emission. Seven rice cultivars, based on the life cycle duration (LCD), were tested in tropical eastern India. Three LCD groups were, (a) Kalinga 1 and CR Dhan 204 (LCD: 110–120 days); (b) Lalat, Pooja and CR 1014 (LCD: 130–150 days); and (c) Durga and Varshadhan (LCD: 160–170 days). Rate of CH_4emission, root exudates, root oxidase activities and shoot aerenchyma pore spaces were analyzed to study the mechanism of plant mediated emission from rice. Aerenchyma pore space was quantified in the hypothesis that it regulates the CH_4 transportation from soil to atmosphere. The ratio of pore space area to total space was lowest in Kalinga 1 cultivar (0.29) and highest was in Varshadhan (0.43). Significant variations in the methane emission were observed among the cultivars with an average emission rate ranged from 0.86 mg m^{-2} h^{-1} to 4.96 mg m^{-2} h^{-1}. The CH4 emission rates were lowest in short duration cultivars followed by medium and long duration ones. The greenhouse gas intensity considering average CH_4 emission rate per unit grain yield was also lowest (0.35) in Kalinga 1 and relatively less in short and medium duration cultivars. Root exudation was higher at panicle initiation (PI) than maximum tillering (MT) stage. Lowest exudation was noticed in (197.2 mg C $plant^{-1}$ day^{-1}) Kalinga 1 and highest in Varsadhan (231.7 mg C $plant^{-1}$ day^{-1}). So we can say, the rate of CH_4 emission was controlled by aerenchyma orientation, root exudation and biomass production rate which are the key specific traits of a cultivar. Identified traits were

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closely associated with duration and adaptability to cultivars grown in specific ecology. Therefore, there is possibility to breed rice cultivars depending on ecology, duration and having less CH_4 emission potential, which could be effectively used in greenhouse gas mitigation strategies.

1. Introduction

Agriculture contributes near about 52% of global anthropogenic methane (CH_4) emissions (Sun et al., 2016). Rice field is one of the major agricultural sources of atmospheric CH_4 emission accounted for 10% (21–30 Tg yr^{-1}) of total global CH_4 flux to atmosphere (Sun et al., 2016). Methane is present in the rice fields either in gaseous phase or as dissolved in soil-surface water suspension (Tokida et al., 2005). Strack et al. (2008) estimated that 33–88% of the total sub-surface CH_4 is stored in the gaseous phase. The amount of dissolved CH_4 is low due to its low solubility (17 mg l^{-1}) at 35 °C in water, and the lack of its ionic form present in soil-water system (Green et al., 2013). The regulation of CH_4 cycle in rice soil is governed by the methanogenesis, methanotrophy and atmosphere-soil CH_4 interchanges. The production of CH_4 in soil depends on agriculture management practices viz. water management, organic amendment, inorganic fertilizers, and status of soil environment such as Eh, pH and temperature. However, rice plants have also direct influence on CH_4 emission, starting from production, oxidation and transport from soil to atmosphere.

Primarily, rice plants serve as the major conduits for the transfer of CH_4 from the reduced soil layers to the atmosphere. A well-developed intercellular space (aerenchyma) in leaf blade, sheath, culm and roots of rice plants makes a good passage for the gas exchange between the atmosphere and the anaerobic soil (Friedl et al., 2010; Li et al., 2013). Generally, up to 90% of CH_4 formed in rice soil and is emitted through the passage made up of aerenchyma pore spaces in rice plants (Bhattacharyya et al., 2016). Further, rice cultivars differ in their ability to transport oxygen to the rhizosphere (Lijima et al., 2017) which known to stimulate changes in the redox potential of rice rhizosphere. This makes a higher oxidation status in the soil-root interface which reduces the CH_4 production in soil. Apart from aerenchyma spaces the number of tillers per plant is also reported to be positively correlated with CH_4 emission rates. Moreover, it was reported that emission rates were higher in older tillers than younger ones even in the single plant (Watanabe et al., 1995; Win et al., 2016). Root exudation and decaying roots also playing an important role in CH_4 production and emission in rice by regulating labile carbon flow in rhizosphere along with aerenchyma orientation in shoots and tiller characteristics (Naser et al., 2007; Weller et al., 2015). Rice plants also trigger conversion of CH_4 to carbon dioxide (CO_2) by oxidation through the release of root-peroxidase and hydrogen peroxide (Matsuo et al., 1993; Jiang et al., 2017).

In spite of the acknowledged role of rice plants in gas transport, less information is available on the regulatory effect and mechanism of cultivars on CH_4 emission from rice (Inubushi et al., 2003; Tokida et al., 2013). Plant-mediated transport is generally small during the early vegetative stages of rice and widely varies in different growth stages up to maturity (Aulakh et al., 2000; Kerdchoechuen, 2005; Win et al., 2010). Therefore, there is need to quantify stage wise variation of aerenchyma orientation in shoots and other plant mediated drivers to CH_4 emission in order to develop strategies for reducing CH_4 emission from rice.

Considering the hypothesis that CH_4 emission is being regulated by rice cultivars having different aerenchyma orientation, root oxidation potential and root exudation behavior, the objectives of the study were formulated as to (i) quantify CH_4 emission rates in contrasting rice cultivars (different life cycle duration (LCD) and ecological preference) and (ii) estimate and correlate aerenchyma space orientation, root oxidase activities and root exudation pattern of different cultivars with CH_4 emissions at critical growth stages.

2. Materials and methods

2.1. Study site

This present study was conducted in the farm of ICAR-National Rice Research Institute, Cuttack (20° 82′ 50″ N, 85° 85′ 50″ E; 24 m above MSL), Odisha, India. The climate is tropical monsoon. Average annual rainfall is 1500 mm. The soil was classified as Aeric Endoaquept and the texture is sandy clay loam having bulk density of 1.42 ± 0.01 Mg m^{-3} and pH 6.6 ± 0.2 (1:2.5, soil: water suspension). The electrical conductivity (EC) in soil was 0.45 ± 0.03 dS m^{-1} with total soil organic carbon (TC) of 0.8 ± 0.1.

2.2. Establishment of crop

The study was conducted in wet season (WS) of rice-rice cropping system in Eastern India. Wet season corresponds with the monsoon season during the months of June–November. Seven popular rice cultivars of different LCD, viz., Kalinga-1, CR Dhan 204 (LCD: 110–120 days); Lalat, Pooja, CR 1014 (LCD: 130–150 days); and Durga, Varshadhan (LCD: 160–170 days) were grown in wet season. The size of each experimental plot was 5 m × 6 m and the experiment was laid out in randomized block design with three replications. The field was ploughed with keeping flooded conditions for 2–3 days before transplanting for puddling and leveling. Compost (5 t ha^{-1}) was applied in the field before puddling. Nitrogen (N) (80 kg ha^{-1}) was applied in the form of neem coated urea; 50% as basal dose and the rest in two equal splits at 23 and 76 days after transplanting. Full dose of Phosphorous (P) (40 kg P_2O_5 ha^{-1}) and Potassium (K) (40 kg K_2O ha^{-1}) was applied as basal in the form of single superphosphate (SSP) and muriate of potash (KCl), respectively. Above surface water depth of 5–7 cm was maintained during the entire crop growth period until 10 days before harvest. Recommended agronomic practices were followed for raising the crop.

2.3. Soil sample collection and processing

Soil samples were randomly collected at five locations in each plot (5 m × 6 m) by core sampler (0–15 cm depth) at different critical crop growth stages. Composite samples were prepared through quartering method. One part of fresh soil samples was kept in refrigerator at 4 °C for biochemical and microbial analyses. Rest was air dried and processed, passed through 2 mm sieve and stored in sealed plastic jars for chemical analyses.

2.4. Methane emission measurement

Manual close chamber method was used for measuring CH_4 flux from the plots having different rice cultivars (Bhattacharyya et al., 2013, 2016). Gas samplings were done at different critical crop growth stages (viz., Active tillering (AT), maximum tillering (MT), panicle initiation (PI), grain filling (GF) and harvesting (H)) in all replicated plots. Six rice hills were considered for gas collection. Aluminum base plate was used to hold Perspex chamber (dimension: 53 (L) cm × 37(B)cm × 71(H) cm) and a battery operated air pump with an air displacement of 1.5 L min^{-1} was used to circulate and homogeneously mixing the air inside the box. Pumped out gas was collected at the outlet to a Tedlar gas-sampling bag (M/s Aerovironment Inc.) at 0 and 30 min time