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Plant contribution to methane emission after irrigation of peat soil with municipal waste water

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A b s t r a c t. The ability of some plants to grow and develop in the soils with limited access to oxygen results not so much from the biochemical differences in their root metabolism, but from the access of oxygen from the aboveground plant parts via internal transport. By the same route, harmful gases (e.g., carbon dioxide and methane) get into the plant from the soil. Their toxic properties are neutralised in the aboveground plant parts or these gases are released into the atmosphere. The studies were carried out on a peat-muck soil (Eutric Histosol – pH in KCl 7.2, C org. 326 g kg^{-1}). The study plot was divided into three sections (A,B,C), in which three irrigation treatments were applied. The aim of the present study was to determine the contribution of a mixture of grasses (with *Alopecurus pratensis, Phalaris arundinacea, Festuca pratensis* as dominant species) to methane transportation via internal routes from the soil irrigated with municipal waste water after the second stage of purification (mechanical and biological treatment) during two flooding cycles. In spring, an increase in the methane emission from the mixture of grasses irrigated with a single and a double municipal waste water dose, up to the range 42.84–57.12 mg $m^{-2}h^{-1}$ was observed after 3 days from the onset of the stress conditions. In summer, an increased level of methane emission up to 47.84 and 57.12 mg $m^{-2}h^{-1}$ was observed 24 h after irrigation in the plots irrigated with a double and single dose of municipal waste water, respectively. Redox potential was a signal of the above changes as at a depth of 70 cm, it decreased to –150 mV.

K e y w o r d s: methane emission, irrigation, redox potential, waste water, grass

INTRODUCTION

Following O_2 depletion in flooded soils, anaerobic conditions ensue with a sequential reduction of alternate electron acceptors (NO_3^- , Mn^{4+}, Fe^{3+}, SO_4^{2-}, and finally CO_2), as predicted by thermodynamic principles (Stumm and Morgan, 1981; Ponnamperuma, 1984). The NO_3^-, Mn^{4+}, and Fe^{3+} are utilized by facultative aerobes and reduced to N_2 or N_2O, Mn^{2+}, and Fe^{2+}, respectively, while SO_4^{2-} and CO_2 are utilized by obligate anaerobes under intensely reduced conditions and reduced to H_2S and CH_4, respectively. The reduction of the inorganic redox system can be described in both intensity and capacity terms (DeLaune and Pezeshki, 1991). The intensity factor determines the relative ease of the reduction and is normally represented by the free energy of the reduction, or by the equivalent electromotive force of the reactions. The redox potential, Eh , is commonly used to denote the intensity of reduction. Understanding the regulation of CH_4 emission from fields is important for the calculation of more reliable estimates of the global CH_4 budget. Polymeric organic matter, such as polysaccharides, is anaerobically degraded via various intermediates to acetate and H_2, which serve as substrates for CH_4 production (Conrad 1989; 1993). Environmental factors, such as temperature, pH, substrate concentration, etc., may effect the microbiological metabolism and thus the change of CH_4 production rate (Neue and Roger 1993; Neue and Sass 1994; Yao *et al*., 1999). Methane is one of the greenhouse gasses that is reported to exert significant effects on the global heat balance, thus causing a possible elevation of global surface temperature (Bouwman, 1991). Whereas Masscheleyn *et al*. (1993) observed that a soil Eh value of – 150 mV was critical for CH_4 production; Gliñski and Stêpniewski (1985) reported CH_4 formation during anoxic incubation and in non-flooded soils at an Eh of 220 mV.

The major sources of CH_4 production under flooded conditions are natural wetlands (Sebacher *et al*., 1985) and

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cultivated rice paddy fields (Cicerone and Oremland, 1988). Wetland plants serve as direct conduits between reducing and oxidizing environments (Chanton *et al*., 1992). Holzapfel-Pschorn *et al*. (1986) investigated the effects of rice vegetation on CH_4 emission from submerged paddy soils and reported that whereas emission of CH_4 from unvegetated fields was insignificant, > 90% of the CH_4 emitted from rice-vegetated fields was plant mediated. Similar results were reported by Cicerone and Shetter (1983), who investigated the phenomenon of CH_4 transport through aerenchyma of rice plant.

The ability of some plants to grow and develop in the soils with limited access to oxygen results not so much from the biochemical differences in their root metabolism but from the access of oxygen from the aboveground plant parts via internal transportation. By the same route, harmful gases (e.g., carbon dioxide and methane) get into the plant from the soil. Their toxic properties are neutralised in the aboveground plant parts or are released into the atmosphere.

Methane produced by anaerobes in flooded soils is transported to the atmosphere by water surfaces, as well as by plants. Aerenchyma tissue of rice or other plants capable of adapting to the conditions of excessive moisture, are able to transport methane form the soil to the atmosphere (Wagatsuma *et al*., 1990; Mariko *et al*., 1991). A well developed aerenchyma system in a plant would ensure an efficient exchange of gases between the atmosphere into the root rhizosphere to serve the dual purpose of maintaining the aerobic metabolism of roots and microbes and restricting movement of potentially toxic substances such as Fe^{+2}, Mn^{+2}, and H_2S into plant roots by oxidation (Armstrong and Armstrong, 1988).

The aim of the present study was to determine the contribution of a mixture of grasses to methane transportation via internal routes from the soil irrigated with municipal waste water after the second stage of purification (mechanical and biological treatment) during two flooding cycles.

MATERIALS AND METHODS

The studies were carried out on a peat-muck soil (Eutric Histosol) with undisturbed layers and structure (pH in KCl 7.2, C org. 326 g kg^{-1}). The study plot was divided into three sections (A, B, C), in which three irrigation treatments were applied: plot A – a control representing irrigation from atmospheric precipitation, plot B – irrigation with a 60 mm dose of municipal waste water after the second stage of purification (10 times a year), plot C – similarly irrigated with a double dose of the municipal waste water. During irrigation treatment, CH_4 emission and soil aeration status were determined by means of platinum electrodes permanently inserted into the soil profile at a depth of 10, 30, 50, 70 and 100 cm. Gas emission from the bare soil and the soil with a mixture of grasses (with *Alopecurus pratensis*, *Phalaris arundinacea*, *Festuca pratensis* as dominating grass species), was determined by means of plexiglas chambers mounted on steel platforms and tightened with water coats. Gas samples taken from the plexiglas covers at intervals of 30 and 60 min were analysed by a gas chromatography (Shimadzu GC-14).

RESULTS AND DISCUSSION

The studies carried out showed an increased level of methane emission on the plots with grasses irrigated both with the single and the double dose of municipal waste water as compared to control (Fig.1).

An increase of methane emission was observed on the third day from the commencement of spring irrigation of the plots with municipal waste water, and reached 44.27 mg $m^{-2}h^{-1}$ in the plot irrigated with the single dose; at the same time methane emission on the control plot was at a level of 8.57–15.72 mg $m^{-2}h^{-1}$. Emission from the plants grown on the plot irrigated with the double dose of mu- nicipal waste water reached as high as 54.26 mg $m^{-2}h^{-1}$ and was maintained until 8 days after irrigation. Soil redox potential (Eh) measured at a depth of 100 cm lowered to a level range between –110 and –150 mV, whereas in the control conditions it remained at a level of about 300 mV.

Summer irrigation of the soil with the single and the double dose of the municipal waste water resulted in a rapid increase of the transported methane. Emission from the plants grown on the plot irrigated with the single dose of municipal waste water reached as high as 53.55 mg m^{-2} h^{-1} after 24 h, and those with the double dose irrigation increased up to 47.84 mg m^{-2} h^{-1}. During the increase of methane emission the soil redox potential at a depth of 100 cm was lowered to a level of –153 mV.

Masscheleyn *et al.* (1993) observed that a soil Eh value of –150 mV was critical for CH_4 production, while Gliñski and Stêpniewski (1985) reported CH_4 formation during anoxic incubation and in nonflooded soils at an Eh as high as 220 mV.

The Eh level observed is a signal of anaerobic changes taking place in the soil and a possibility of methanogenesis in the soil environment irrigated with municipal waste water.

The review concerning rice paddy fields in China (Cai, 1997) gives the interval of methane flux in the range from 0.2 to 76 mg CH_4 $m^{-2}h^{-1}$.

Kludze and DeLaune (1994) performed a model experiment to determine the influence of soil redox intensity (Eh) on the growth, CH_4 production, and emission in *Spartina patens*. They stated that *Spartina patens* grown for 20 days at a redox potential of –200 mV emitted about 7 times more methane than the control plants grown in the conditions of redox potential of 200 mV. The tendency towards increased methane emission under the conditions of a lowered redox potential agrees with the result obtained in our experiment.

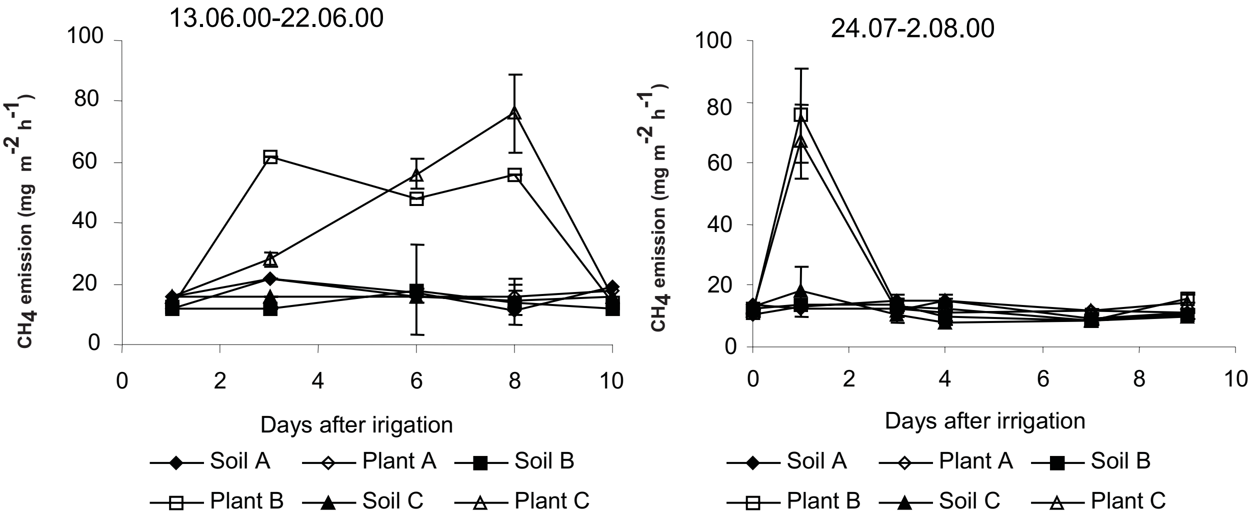

Fig. 1. Plant contribution to methane emission from the peat-muck soil at spring and summer irrigation with municipal waste water: A – control plot, B – irrigation with a single dose, C – irrigation with a double dose). Mean values and standard deviations are given in the graphs.

CONCLUSIONS

1. Flooding the soil with municipal waste water increased methane emission several times at a presence of grasses without significantly affecting the emission from bare soil.

2. Spring and summer flooding the soil gave similar peaks of methane emission (42.84–57.12 mg m^{-2} h^{-1}), but in spring time the effect was more extended in time (up to 8 days) as compared to the summer flood (up to 3 days).

3. Flooding the soil resulted in a decrease of soil redox potential from 300 to –150 mV.

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