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Methane reduction of a perennially waterlogged rice paddy

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Abstract— The ridge cultivation has great potential for reducing CH_4 emissions from the perennially waterlogged rice paddies. This was strongly supported by the data from our field experiments carried out during an entire rice growing season of 1992. Compared with the normal cultivation, the ridge cultivation reduced 30.8% more CH_4 emissions, and it did not show any negative effects on rice productivity. All of these suggest that in the regions with a vast areas of perennially waterlogged paddies, ridge cultivation should be a very promising option for both CH_4 reduction and sustainable rice productivity.

Keywords: CH_4 reduction; waterlogged rice paddy; field experiments; ridge cultivation.

1 Introduction

Atmospheric methane concentrations have been increasing at a rate of about 1% per year over the last 100–150 years (Rasmussen, 1981; Blake, 1988). Among the biologically active greenhouse gases, methane is second only to carbon dioxide in its potential effect on global warming (Dickinson, 1986; Schneider, 1989). Meanwhile, methane represents an attractive opportunity for controlling greenhouse gas emissions since methane is potent (i. e., 20 to 60 times more effective in trapping heat in the Earth's atmosphere than carbon dioxide) and relatively short-lived. This means that reductions in emissions will be transformed relatively quickly into reductions in the expected warming of the Earth's atmosphere. The Intergovernmental Panel on Climate Change (IPCC) concluded that a 10% to 15% reduction in total methane emissions would stabilize concentrations in the atmosphere. Scientists also stated at an IPCC workshop that a 10% to 30% reduction in methane emission from rice cultivation, relative to current levels, may be possible over the long term if comprehensive research programs are undertaken and to demonstrate the required technologies. Rice cultivation constitutes an important source of methane on a global scale, annually contributing approximately 25% of total atmospheric emissions (Crutzen, 1991).

Since 1990, we have been carrying out field experiments to explore the possible measures to reduce methane emissions from rice fields. Through the early two years' experiments, we found out that the ridge cultivation might have great potential for reducing CH_4 emissions from rice fields. In order to further verify and quantify the contributions of the ridge cultivation to reducing CH_4 emissions, we continued field experiments in the late rice growing season of 1992. Our experimental site is to the southeast of Nanjing, 55 km away from the city. Experimental field is a perennially waterlogged paddy with only single rice cropping each year. Whenever rice is cropped, the field lies fallow and submerged by water naturally. The soil pH of the field is 6.27, the content of organic matter is 1.70%.

2 Experimental design and methods

2.1 Treatments

The experimental field was divided into 9 plots, each with 40 m_2 in area. Three treatments were arranged, each with 3 replicate plots.

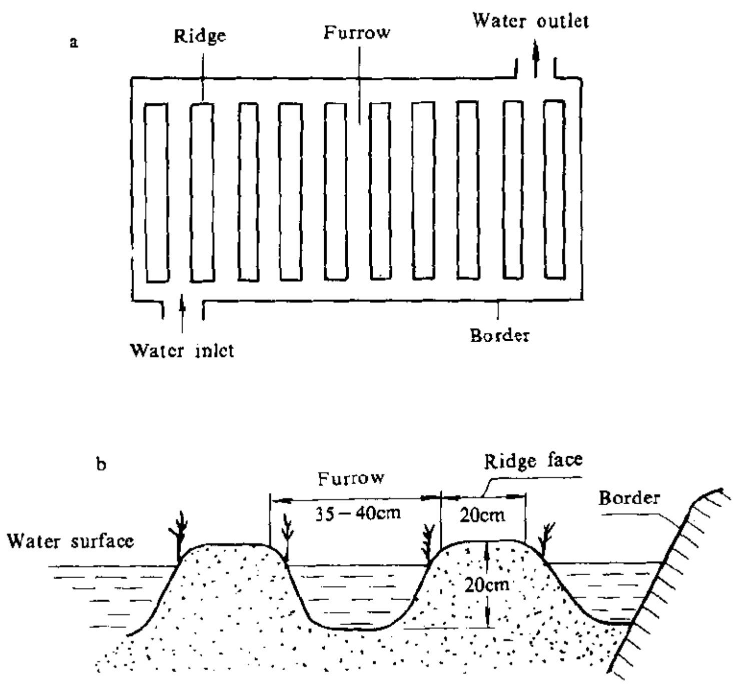

Fig. 1 Scheme of ridge cultivation

a. Plane drawing of ridging; b. Gross-sectional drawing of ridging

Treatment 1:50 kg barnyard manure per plot with plain cultivation; Treatment 2: 50 kg barnyard manure per plot with ridge cultivation; Treatment 3 : 100 kg barnyard manure per plot with ridge cultivation.

Where the plain cultivation means normal cultivation, which are adopted commonly by the local farmers; the ridge cultivation means to make ridges with designed standards in plain field, rice seedlings are transplanted on both sides along ridges, irrigation water submerges about the two thirds depth of furrows. All of these can be shown as Fig.1.

2.2 Sample collection

Each gas collector consists of two sectors, i. e., base and chamber. The base is a grooved square stainless steel collar enclosing 0. 1521 m^2; the chamber is an open-bottom box of transparent polycarbonate material with 44 cm×44 cm in cross-sectional area. Two sampling points were set up at each plot, totally 18 collars were permanently sunk 3 – 4 cm into the soil in 9 plots, each collar enclosed 5 holes of rice plants. The sampling points can be reached via small wooden foot-bridge to allow working at the chambers without disturbance of environment. During sampling period, the chamber was placed over the vegetation with the rim of the chamber below the water surface and fitted into a groove in the permanent collar, thus preventing gases exchange with the atmosphere. Further, a thin plastic tube extended from the top opening of the chamber downward to the midpoint of the chamber. The opening at the top was sealed up with a special gasket. A syringe needle pierced through the gasket and connected with the plastic tube, which allowed internal pressures to equalize without appreciable air flow. So long as a syringe was joined to the needle, the internal gases can be withdrawn into the syringe. Five samples were taken from one chamber in an entire sampling period of approximately 12 minutes. Then the chamber was moved to the other sampling point, repeating the same sampling processes. When rice plants reached a height of 80 cm, an improved chamber was used to collect gas, which consisted of two separable sectors. The upper sector still was an open-bottom box with height of 50 cm; the lower sector was a barrel without bottom and cover, its cross-section kept same size in area with that of the upper sector, its height was 80 cm. A flexible rubber belt was fixed in the top rim of the barrel. Whenever sampling, place the barrel into the groove in base, a few minutes later, put the upper sector on the barrel and connect both of them. The crevice between the upper and lower sectors was sealed up automatically by the rubber belt. Sampling processes just kept the same as those described as above. Normally, gas samples were taken from every sampling points every other morning and afternoon respectively. All gas samples were brought to the temporal laboratory near the experimental site for determination of their CH_4 concentrations by using a gas chromatography equipped with a flame ionization detector. Analysis method was quite similar to those described by Cicerone *et al.* (1981).

2.3 Data processing

The individual CH_4 emission rate E was calculated from the temporal increase of the CH_4 mixing ratios inside the chamber as follows:

$$E=\rho \frac{v}{s} \cdot \frac{dc}{dt},$$

where ρ is the density of the CH_4 at the pressure and temperature recorded in the laboratory, V is the real volume of the chamber (deducting the part flooded by water), S is the area enclosed by the base, in present experiments, S is 0.1521 m^2 constantly because all the bases are in the same size, dc/dt is the linear increase in CH_4 mixing ratio inside the chamber during a sampling period of approximately 12 minutes.

Daily average CH_4 emission rate of a plot is equal to the average CH_4 emission rates coming from the same plot; the daily average CH_4 emission rate of a treatment can be calculated from the daily average CH_4 emission rates of three replicate plots.

3 Results and discussion

3.1 Seasonal CH_4 emission rates

In the entire rice growing season of 1992, about 8000 gas samples collected from the experimental plots were determined. In the light with the above data processing methods, each treatment gets 44 daily average CH_4 emission rates. Totally, 132 daily average CH_4 emission rates from three treatments are listed in Table 1.

The bottom line in Table 1 shows the general averages of the daily average CH_4 emission rates of each treatment. These three general averages just right represent the seasonal CH_4 emission rates of each treatment. Among them, CH_4 emission rate of treatment 1, or plain cultivation plots, reflects the general level of the CH_4 emission rates from the local rice paddies. Such emission rate is slightly higher than the average seasonal CH_4 emission rates measured by Cicerone (Cicerone, 1992) in a California rice paddy and Schutz (Schutz, 1989) in an Italian rice paddy, though the organic matter content of our experimental field was not large. Thus it can be inferred that the CH_4 emission rates from perennially waterlogged paddies might be higher than that from common paddies.

Table 1 Daily average CH_4 emission rates from three treatments (mean/standard deviation mg/m²h)

Date	Treatment 1	Treatment 2	Treatment 3
July 2	5.88/1.68	6.70/1.95	6.40/0.96
4	8.09/3.09	11.30/1.83	6.64/2.48
6	5.50/3.53	7.46/1.12	7.47/2.11
8	11.05/3.90	10.34/3.04	4.84/1.11
10	8.54/1.81	8.43/4.41	7.15/2.43
12	12.65/2.24	12.55/1.64	8.31/2.89
14	16.40/4.91	9.45/3.53	5.43/1.59
16	17.10/5.90	7.58/5.64	14.14/8.49
18	29.15/8.87	9.42/0.68	14.26/10.56
20	20.69/6.72	14.13/7.11	16.26/9.96
22	23.48/7.48	10.65/8.40	12.72/7.67
24	27.42/6.36	31.08/12.94	25.51/9.80
26	29.35/6.66	17.60/3.85	17.64/8.25
28	17.76/4.64	22.39/4.77	18.00/8.16
30	28.58/7.69	22.10/1.97	25.24/12.39
Aug. 1	26.91/6.63	16.33/3.57	13.11/3.45
3	18.46/9.76	16.48/4.97	13.61/5.27
5	12.65/10.94	8.52/3.05	8.09/2.04
7	7.37/4.80	3.23/0.67	4.24/1.25
9	9.05/4.62	2.80/0.69	6.51/3.48
11	13.61/8.65	4.87/0.99	9.69/5.98
13	13.48/4.43	8.02/1.9	11.73/6.52
15	7.11/2.22	4.50/0.19	5.96/3.09
17	10.97/4.53	5.78/1.88	6.28/3.66
19	9.28/3.49	3.75/0.53	4.73/1.70
21	22.66/14.07	6.74/4.27	14.83/12.43
24	15.51/10.41	3.17/0.20	14.96/20.14
26	18.19/5.05	8.04/2.49	8.40/7.82
28	32.25/8.34	18.83/1.39	23.51/9.82
30	41.36/20.62	15.85/11.43	22.45/24.96
Sep. 1	33.89/3.11	12.68/4.75	24.20/21.98
3	25.10/19.30	6.77/2.48	14.42/10.69
5	34.00/13.78	10.75/4.21	19.84/15.03
7	34.05/25.21	13.46/7.90	23.52/11.31
9	23.56/4.82	11.86/3.78	17.25/9.06
11	30.12/8.20	8.70/4.78	17.89/16.26
13	31.57/8.53	15.51/9.41	19.91/10.88
15	19.06/10.92	14.49/6.26	11.63/5.56
17	25.58/15.24	13.16/4.05	18.93/11.68
19	25.66/3.70	17.30/10.25	14.56/6.38

Table 1 (continued)

Date	Treatment 1	Treatment 2	Treatment 3
21	22.32/4.34	14.60/8.58	22.31/6.95
23	25.07/6.57	18.11/6.04	23.89/3.70
25	15.92/6.83	9.35/3.54	13.26/9.13
27	7.07/4.42	4.51/0.94	4.36/0.48
Mean	19.85	11.35	13.73

3.2 Seasonal variations of CH_4 emission rates

Graphs based on the data in Table 1 displays the seasonal variations of the CH_4 emission rates from every treatment as Fig. 2a–c.

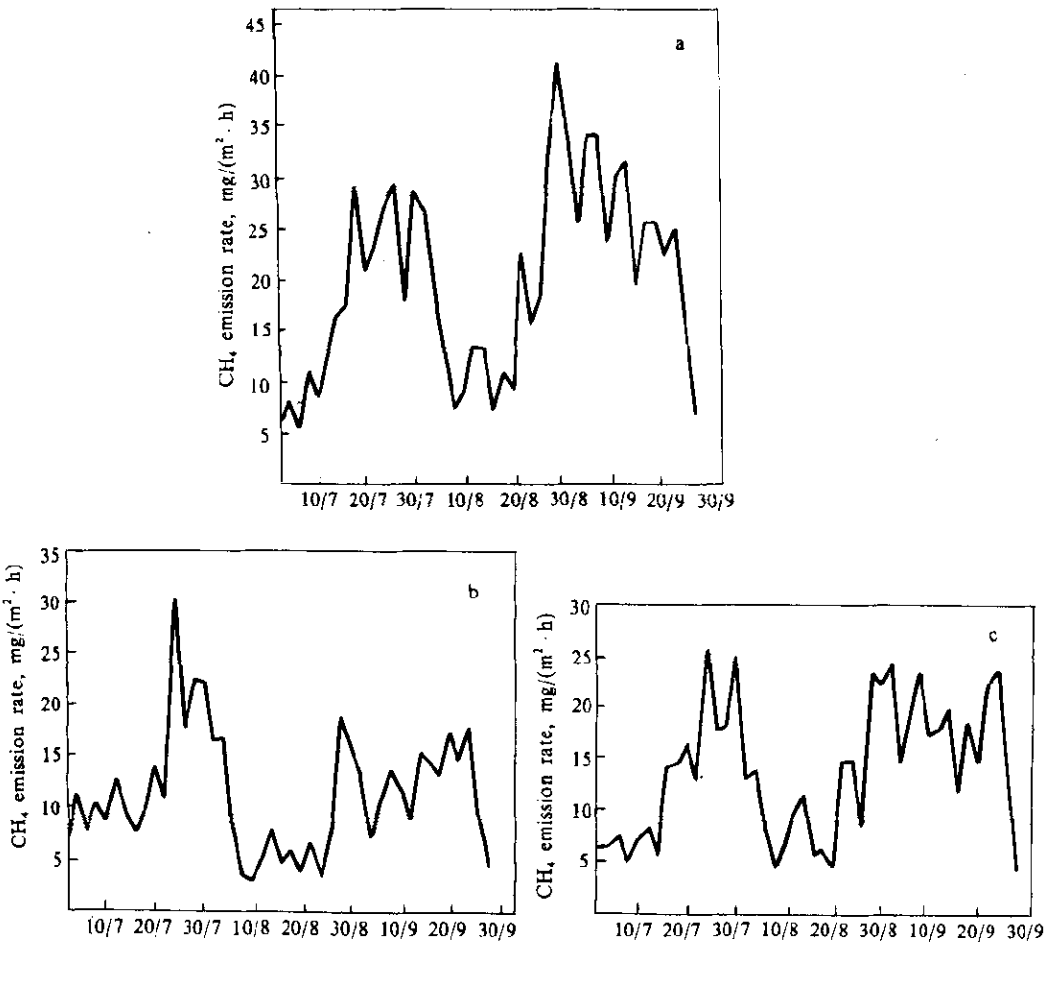

Fig. 2 Seasonal variation of the daily average CH_4 emission rates

All of the three curves show roughly similar patterns. CH_4 emission exhibited a rapid early rise followed by a drop around August 15 coincident with water shortage due to continuous drought weather. Recovery of emissions appeared around August 25. By the end of August, emissions reached another peak period, just corresponding to the rice reproductive stage. This observation was also made by Schutz *et al.* (Schutz, 1989) in an Italian rice paddy. It is therefore most likely that the emission peak is due to the activity of the rice plants which provide soil bacteria with organic root exudates or root litter (Balandreau, 1978). Root exudates of rice plants consists mainly of carbohydrates, organic acids, and amino acids (Boureau, 1977) which are readily decomposed by fermentative soil bacteria to CO_2, H_2, and acetate, · the predominant substrates used by methanogenic bacteria to produce CH_4 (Schutz, 1989b).

3.3 Comparison among the CH_4 emission amounts of three treatments

Total CH_4 emission amounts of treatment 1, treatment 2 and treatment 3 are 1683, 953 and 1164 g respectively in the whole rice growing season of 1992, which were calculated by integrating the area between the curves and level coordinate axis in Fig. 2a−c. It is obvious that the CH_4 emission amounts of treatment 2 and treatment 3 are 43.3% and 30.8% lower than that of treatment 1 respectively, or the ridge cultivation obviously reduced CH_4 emissions. This cultivation method has been popularized on a large scale in the southwest China where there are a vast area of perennially waterlogged paddies. The soils in those paddies are always in absolute anaerobic condition, which often cause plant roots to black or rot. After the ridge cultivation was introduced, the rice yields have been increased by 20% more (Sichuan Institute of Soil and Fertilizer, 1988). One of its reasons is that area of the root region is greatly improved, which might be very helpful to inhibit CH_4 formation as well as to the development of root system. Because almost no intermittent flooding and drying cycles occur during the whole rice growing seasons, the ridge cultivation may not cause N_2O production to increase (Reddy, 1975; 1976). It should be noted that the difference between the CH_4 emission amounts of treatment 2 and treatment 3 is not large relative to the difference between treatment 1 and treatment 2, though the additional barnyard manure differ in quantity. The reason is that the manure was largely composed of silt and ashes, only containing 5.3% of organic matter. So the real organic substances added into each treatment had no considerable differences, or the additional manure had little effects on CH_4 emissions of the present experimental field.

3.4 Rice yields of the treatments

Average rice yields of treatment 1, treatment 2 and treatment 3 are 24.3 kg, 25.5kg and 25.8 kg respectively. Here, treatment 2 and treatment 3 are 4.9 and 6.2 per cent respectively more than treatment 1 but there are no significantly statistical differences between average rice yields of any two treatments. Compared with the plain cultivation, the ridge cultivation did not obviously increase rice yields. The reason why it should be so might be that the absolute rice yields of our experiment plots have already been high enough to compare with the yields of the local common rice fields because of sufficient fertilizers and careful management. Therefore it would be more difficult to further increase rice yield.

4 Conclusion

The ridge cultivation uniformly reduced CH_4 emissions from our experimental field, and it at least could not have any negative effects on rice yield. All of these indicate that in the regions with a vast areas of perennially waterlogged paddies, ridge cultivation must be a very promising option for both CH_4 reduction and sustainable rice productivity.

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