Journal of Environmental Sciences Vol. 8, No. 1, pp. 38—47, 1996 ISSN 1001-0742

Methane emission in a rice field of Thailand

Rong Xiang, Chuen-How Ng

Environmental Engineering Program, School of Environment, Resources
and Development, Asian Institute of Technology, Bangkok 10501, Thailand

Su Weihan

Research Centre for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China

Abstract—In this study, emission of methane have been measured in a Thai rice field. Clear patterns of diurnal variations of methane emission have been observed and were found to follow the diurnal variation of the soil temperature. A detailed explanation was given for explaining the occurrence of a methane emission peak at night. The effects of urea fertilization and field draining on methane emissions were discussed. Methane emission from Thai rice fields is estimated to be 3.32 Tg CH_4 (2.49 Tg CH_4-C) each year, contributing about 3.4% to global methane budget due to rice cultivation.

Keywords: methane emission; rice field; greenhouse gas.

1 Introduction

Methane (CH_4) is the second most important greenhouse gas, contributing 15% to global warming as compared with 61% for carbon dioxide (IPCC, 1990). It is a chemically and radiatively active trace gas produced from a wide variety of anaerobic processes. The current atmospheric CH_4 concentration, at 1.72 ppmv, is now more than double the pre-industrial (1750—1800) value of about 0.8ppmv, and is increasing at a rate of about 0.015 ppmv (0.9%) per year (IPCC, 1990). Human activities such as rice cultivation, domestic ruminant rearing, biomass burning, coal mining and natural gas venting have increased the input of CH_4 into the atmosphere, which yields the observed rise in global CH_4.

Rice is one of the most important food crops in the world. More than 90% of the world's rice is grown and consumed in Asian , where more than half of the world's population lives. Three decades later, the earth will be the home of 8 billion people. More than one half——4.3 billion, almost as many as the current earth inhabitants——will be rice consumers. Feeding them will require a massive increase in global rice production, from today's 510 million tons to 760 million tons. Rice production gains seem to have been achieved, but at the same time methane emission from rice fields is increasing and contributes to global warming.

Until recently, estimates of annual global CH_4 emissions from rice cultivation were based on measurements in temperate research sites. It is necessary to obtain CH_4 flux measurement data from tropical countries like Thailand.

2 Experimental investigation

2.1 Field description

All field measurements were performed in a rice field at the Asian Institute of Technology (AIT), Bangkok , which is located at latitude 13°45′ N and longitude 100°35′ E. Rice is the main crop in Thailand. Annual rainfall average 1397 mm, of which about 86% occurs in May through October, or about 200 mm/month during this period. The field was previously cropped to *Aesehynomene afraspera*, a nitrogen-fixing grass which can be used as a green manure. Immediately prior to rice planting, *Aesehynomene afraspera* was harvested and the remaining crop stubble was incorporated into the soil by shallow tilling on November 5, 1993.

The rice cultivar "RD23" was chosen for this experiment because of its similarity to the high-yielding rice grown throughout Thailand. Planting basically followed the normal practice in Thailand. On November 8, 1993, sprouted seeds of RD 23 was sown directly on the paddled soil in rows spaced some 30 cm apart at a seeding density ranging from 270 to 320 per square meter.

The soil used for this field experiment is classified as very fine mixed, Isohyperthermic Sulfic Tropaquept belonging to Rangsit Series (pH=5.2). It has very little slope, poor internal drainage, and other physico-chemical properties that promote water containment and rice growth.

Flood water management consisted of normal irrigation water management practices for rice in Thailand which consist of periodic brief flush irrigations to maintain adequate soil moisture until rice plants reach approximately 15 cm in height (about 30 days after planting) and thereafter a 10cm flood maintained until 10 to 14 days prior to harvest.

2.2 The experimental set-up

The closed chamber technique has been used in this study (Mitra, 1992). A galvanized channel base was fixed at the measurement site well in advance (at least 12 hours before sample collection). The base was mounted with a U-shaped channel to hold water. The acrylic box ($71 \times 53 \times 31.4\ cm^3$, H×L×W) with its open bottom rests in the channel. The water in the channel isolated the air inside the acrylic chamber from the outside atmosphere. The chamber has been shaded with paper originally adhered to the acrylic sheet to prevent excessive heat built-up due to strong sunshine. Soil temperature was measured at 10cm depth below soil surface.

A battery-operated air circulation pump (pulse pump with a maximum flow rate of 1.0 L/min) connected with polythene tubes via a three-way stopcock mixed the air inside the chamber and was also used to draw the air sample in 1-liter special air sampling bags coated with aluminum foil. The sampling bag had a septum encased in a fitting mounted at the middle of the bag. The sampling bag was evacuated with a vacuum pump after use, flushed with pure nitrogen gas (purity 99.99%, manufactured by Thai Industrial Gas Co., TIG), and evacuated again for reuse.

2.3 Sample collection

Air samples were extracted from the chamber as a function of time elapsed after covering the chamber on the rice plants. The rate of change of CH_4 concentration was determined by subtracting ambient CH_4 concentrations from the concentrations in these samples. The collection period was 200 minutes and air samples were taken from the chamber only at the beginning and end of the period. Water level and temperatures inside the chamber were also measured during each sample collection for calculating the chamber air volume at STP(Standard Temperature and Pressure). The chamber was lifted up and kept aside after 20 minutes after every sample collection.

For measurement of diurnal variations of CH_4 emissions, samples have been taken every three hours. For measurement of seasonal variations, samples were taken every day at 10:00 o'clock and 16:00 o'clock local time (MITRA, 1992).

Methane concentrations were analyzed by a Shimadzu GC-15A gas chromatograph equipped with a flame ionization detector (FID). Separation was performed with a stainless steel chromatographic column (3m in length and 3mm in inner diameter) packed with molecular sieve 5Å. Temperatures of the detector block, injection block and column oven were set at 220, 200 and 200℃, respectively. Ultrapure nitrogen gas (purity 99.999%, TIG) was used as the carrier gas and the flow rate was normally set at 30ml/min. The standing current was set at zero. Under these conditions ambient levels of CH_4 can be quantitatively measured in 0.25 ml air sample injections. Hydrogen flow rate indicated by pressure gauge was 0.5 kg/cm^2, which is equivalent to about 36ml/min. Compressed air was used as the oxygen supply at a flow rate of about 470ml/min (or 0.5kg/cm^2 as indicated by the pressure gauge). The moisture in the air was filtered out with a silica gel cylinder. With this system, a methane peak with retention time of about 3.66 minutes appeared in the sample chromatograph. The total run time was five minutes per sample.

Methane concentrations in whole-air samples (including water vapor) were determined by comparing the sample with the peak areas obtained from the analysis of reference gases. Methane gas standards were prepared by static dilution method at five concentrations: 1.61, 5.08, 14.05, 35.14 and 91.50 ppm by volume (ppmv). The gas chromatographic responses were essentially linear over the concentration range of these standards. For routine analysis, therefore, the 5.08 ppm gas standard was used to calibrate the gas chromatograph before and after sample analysis.

Methane emission fluxes F were calculated from the measured concentrations inside the chamber according to the following equation(Matthias, 1980):

$$F = K(273/T)(V/A)(\Delta c/\Delta t), \qquad (1)$$

where F is the rate of emission (mg $CH_4/m^2 . h$); k is a unit conversion factor (0.43 for methane) for calculation of emission as mg $CH_4/m^2 . h$; T is the temperature of the air within the chamber (K); V is the above-water volume of the collector (cm^3); A is the collector cross-sectional area (cm^2); and $\Delta c/\Delta t$ is the rate of change in the concentration of CH_4 in the air within the chamber (ppmv/min).

3 Results and discussion

3.1 Ambient concentrations of methane

Measurements of ambient concentrations of methane have been made at the location of the flux measurement. Samples were taken at about 80 cm above the ground of the rice field without putting the chamber on the channel base. The values for ambient CH_4 concentrations have a range of 1.70—4.18 ppmv. However, values higher than 2 ppmv for CH_4 were obtained due to static wind and possible lack of mixing and /or on days when straw burned in the nearby fields. As is known, biomass burning is a source of methane.

3.2 Diurnal variation of methane emissions

Fig. 1 shows the diurnal variation in the rate of CH_4 emission on December 6—7, 1993 when the atmospheric temperature was high and the solar radiation was very strong. This pattern of diurnal variation shows two maximum emission values (one at around 15:00 o'clock and the other at around 0:00 o'clock local time) and two minimum values (one at around 6:00 o'clock and the other at around 18:00 o'clock local time).

This pattern of diurnal variation of methane emission was not observed in the United States and Europe (Cicerone, 1983; Seiler, 1984). Furthermore, it does not seem to completely follow the variation of the soil temperature, especially the peak at night when the air and soil temperature were lower than at noon. The following paragraphs offer a possible explanation for this phenomenon.

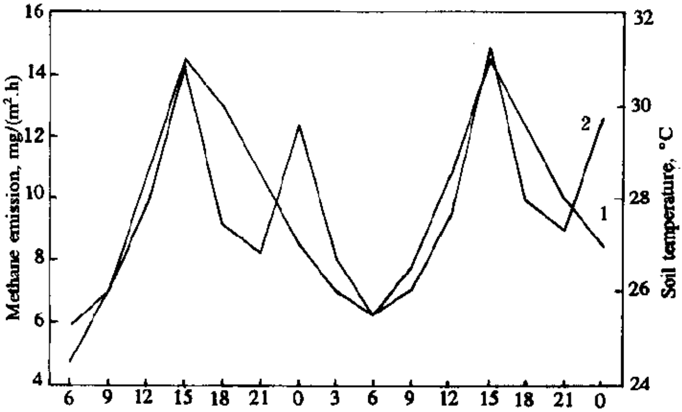

Fig. 1 Diurnal variation of CH_4 emission versus diurnal variation of soil temperature (10 cm) on Dec. 6—7, 1993

1. Methane emission; 2. Soil temperature

The emission of methane from rice paddies is controlled by three processes: production, re-oxidation and transport. Methane is generated mainly at soil depths of 5—15 cm in rice fields and transported principally through pores of stomata of the rice plants to the atmosphere (Greulach, 1973; Noggle, 1976). The term stoma, from the Greek meaning "mouth", is used to refer to a pair of specialized epidermal cells known as guard cells and the pore between them; the plural of stoma is stomata. The air-transporting system of the rice plant develops to a greater extent under flooded condition than under upland conditions (Yoshida, 1975). The contribution to total emission is relatively small by formation of gas bubbles and subsequent ebullition (bubbling) at the water surface and by diffusion of the gas molecules. Cicerone and Shetter(Cicerone, 1983) and Seiler(Seiler, 1984) have demonstrated that over 95% of the CH_4 released from rice paddies is due to transport through the rice plant.

When methane generation is slow in the soil and /or the methane generated can not be transported smoothly into the atmosphere, most of the methane is re-oxidized or accumulates in soil, leading to lower emissions. In contrast, if methane is produced at a high rate and /or transported rapidly to the atmosphere, the possibility of its re-oxidation or accumulation in soil becomes lower, resulting in high emissions. Methane production in soil is positively correlated to the soil temperature within the temperature range of the soil environment. Highly soil temperatures are more favorable to the formation of methane. Therefore, there is a maximum value of methane efflux in the afternoon.

However, Bangkok is located in the tropical region (latitude 13°45′ N and longitude 100° 35′ E), with strong solar radiation and high temperature during the day. When the temperature of the air becomes higher than about 30—35℃——at these air temperatures, the temperature of leaves exposed to strong sunlight may be 45℃ or even higher——stomata often close, at least partially. This type of stomatal closure often occurs at midday and is referred to as midday closure(Noggle, 1976). The pattern of behavior of midday closure—wide opening in the morning, partial closure at midday , followed by re-opening of stomata in the afternoon or evening——is likely to occur in many plants exposed to strong sunlight on hot dry days. Midday closure is thought to be due to the inability of the plant to absorb and replace water as rapidly as it is lost by transpiration.

As a consequence, leaf water content is reduced and subsequent temporary closing of the stomatal pores occurs in the afternoon. The stomatal closure blocks the pathway of gas exchange between the rice plants and the external atmosphere and results in a accumulation of the methane in the soil which can not be emitted into the atmosphere. At the same time, the oxygen in the atmosphere can not be transported to the roots of the rice plants due to stomatal closure, thus lowering the re-oxidation rate of the methane accumulated in the flooded soil. In the evening, when the temperature is lower, the stomatal pores re-open gradually and release large amount of methane which has been generated and accumulated in the afternoon, thus leading to the maximum efflux value at night.

Generally speaking, the emission of methane from rice fields is controlled by the above mentioned processes. However, their relative contributions are different under different conditions. That this pattern of diurnal variation (Fig. 1) was unable to be observed in California and Europe (Cicerone, 1983; Sliler, 1984) might be due to the geographical locations of the measurement points up in the north, without enough strong solar radiation and /or high temperature that cause temporary closing of the stomatal pores. The main control process for methane emission was the production of methane which varies with the temperature. The transport process had little control over the whole process. Furthermore, methane emission is also related to the kind of rice cultivar planted. Different rice cultivars may have different transport and root-oxidizing capacities, and the environmental conditions that control their transport and root-oxidizing capacities may be different.

3.3 Seasonal variations of methane emissions

Fig. 2 displays methane fluxes measured over the whole growing season; daily averages are shown for the period of November 9, 1993 through March 8, 1994. Samples were taken twice a day at 10:00 and 16:00 o'clock local time respectively. Daily average emission is taken as the average of the two samples.

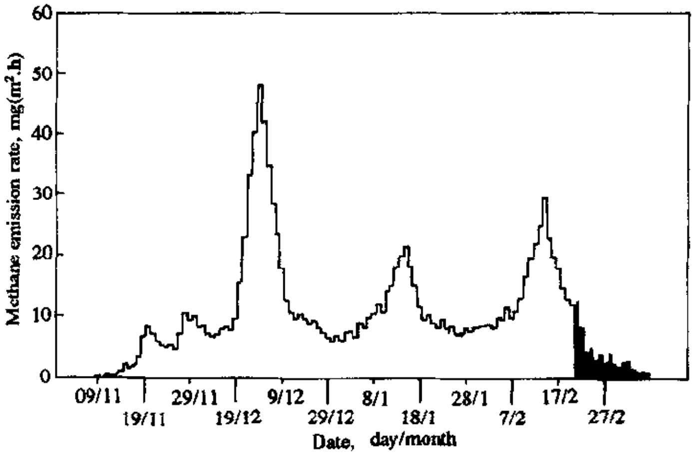

Fig. 2 Seasonal variation of CH_4 emission measured between November 9, 1993 and March 8, 1994

The first seasonal maximum emission value appeared 36 days after seeding, i. e. at the tallering stage of growth. The second maximum emission value appeared after panicle initiation and urea application. The third peak occurred after heading or panicle emergence.

The seasonal variation is related to the level of organic matter in the soil and the activity of the rice plants. The first maximum was caused by the straw incorporated into the soil and flooding. Flooding of the rice created anaerobic condition of the soil and caused decomposition of the organic matter into methane. However, the rice plants were not well developed in the early days of planting with very limited transport capacity; thus the methane generated could be released smoothly into the atmosphere and accumulated in the soil or was partly oxidized. Among the various gas components that evolve in flooded soil after flooding, methane is the only known gaseous hydrocarbon accumulated in large amounts (Yoshida, 1975). During the tillering stage, the growth of the rice plants gradually widened the transport path and the methane trapped in the soil was rapidly released, forming the first peak of emission. It can be seen from Fig. 2 that the added organic matter was the sole most important contributor to CH_4 emission.

As the organic matter in the soil was gradually consumed, the rate of methane production and release gradually decreased. After the tillering stage, the rice plants grew bigger and bigger, and the root system was more and more developed and was able to provide more organic matter to soil bacteria in the form of root exudates, which were mainly hydrocarbon compounds, organic acids and amino acids (Rao, 1985). These organic substances constituted readily available substrates for methanogenic bacteria and were decomposed under anaerobic conditions of the flooded soil into H_2, CO_2, acetic acid or acetate which could be used to produce more methane by methanogenic bacteria. Hence the two maximum values after panicle initiation and heading were likely caused by root exudates or dead cells of root hairs.

Methane emission integrated over the entire growing season of 120 days (Fig. 2) is 30.3g/m^2 in the test field. The average rate of methane emission is 0.25g/(m^2·d). Table 1 compares the result of this study with the results from literature.

Table 2 Comparison of results from different authors

Seasonally averaged daily emission rate, gCH$_4$/(m^2.d)	References
0.16—0.60	Schutz, 1989
0.25	Cicerone, 1983
0.28—0.56	Sass, 1991
0.50	Matthews, 1991
0.19—0.69	IPCC, 1991
0.25	This study

The result of this study is quite close to the lower end of the range of CH_4 emission rate (0.19—0.69 g/m^2.d) recommended by IPCC (IPCC, 1991) and generally lower than that the results of other studies. As we know, Thailand is a tropical country and the average soil temperature is relatively high, which should result in high methane emissions. The low seasonally averaged methane emission rate is most probably because of the low pH(5.2) of the soil of the test field. As is known, soil with a neutral pH(6.5— 7.5) is most favorable to methanogenic bacteria.

3.4 Effect of field draining on methane emission

Field dranage on Feb. 22, 1994 decreased the rate of CH_4 emission dramatically (Fig. 2). The reason for this decrease in CH_4 emission is obvious. Field drainage greatly increased the rate of oxygen diffusion into the soil. The higher availability of oxygen in the soil, which is highly toxic to methanogenic bacteria, could effectively reduce the rate of methane production. In addition, greater availability of oxygen in the soil could speed up the metabolism of methane-oxidizing bacteria, thus increasing the rate of CH_4 re-oxidation. Therefore, the decrease in CH_4 production and increase of CH_4 re-oxidation due to field drainage are responsible for the observed decrease in CH_4 emission.

3.5 Effect of urea application on methane emission

As can be seen in Fig. 2, methane emission increased significantly after application of urea (67kg N/ha) on January 11, 1994. In addition to increase root exudates and dead cells of the root hairs, this increase was also attributable to two other factors. First, urea is a source of nitrogen, which acts as a nutrient for methanogenic bacteria. The application of urea, and hence better availability of nutrient, could have speeded up the metabolism of the methanogens, thus increasing the rate of methane production and emission. Second, urea is a weak base(i.e., slightly alkaline) and its application in the rice field could slightly increase soil pH. Any agricultural management practice having the possibility of increasing soil pH, e.g. urea fertilizer or lime treatment, may have the risk of increasing CH_4 production rate (Wang, 1993).

3.6 Estimation of methane emission from Thai rice field

Estimation of methane emission from Thai rice paddies is based on the methodology proposed by IPCC(IPCC, 1991)

Thailand had an average harvested rice area of 9644000 hectares between 1987—1989 (Ministry of Agriculture & Cooperatives, Thailand, 1991), 90% in the cropping cycle (153 days) planted in July, and 10% in the cropping cycle planted in March (121 days; Matthews, 1991).

The International Rice Research Institute(IRRI, 1988) reported that 5% of the total harvested rice area in Thailand is deep water floating (floating depth greater than 100 cm) and 3% is upland rice. Upland rice fields are not flooded for any significant period of time and therefore do not produce significant quantities of CH_4. Deepwater floating rice fields are not belied to produce significant quantities of CH_4 either because the lower stems and roots of the floating rice plants are dead, effectively blocking the primary CH_4 transport pathway to the atmosphere (IPCC, 1991). To estimate the average annual hectare-days from 1987—1989, the area of floating (5%) and upland rice (3%) is subtracted from the total to give 92% of 9.644 million ha, equalling 8.872 million ha.

(90% × 8.872 million ha × 153 days) + (10% × 8.872 million ha × 121 days) = 1329 million hectare-days.

As mentioned above, methane emission integrated over the entire growing season in Fig. 2 is 30.3g/m^2, with a daily average emission rate of 0.25g/(m^2. day). Therefore, methane emission from rice field in Thailand is estimated at:

(1329 million hectare-days) × (0.25 g CH_4/(m^2. day) × (10000m^2/ha) = 3320000 million g CH_4

or 3.32 Tg CH_4(1Tg=1 teragram = 10^{12} grams)

Convert to mass of carbon:

(3.32 Tg CH_4) × (12/16) = 2.49 Tg CH_4-C

Result:

Thailand emits 3.32 Tg CH_4(2.49 Tg CH_4-C) each year due to rice cultivation.

It is estimated that the globally averaged flux from rice paddies ranges from 25—170Tg. CH_4 per year (Neue, 1984; Yagi, 1990; Holzapfel-Pschorn, 1986; Cicerone, 1981; 1983), with a midpoint of 97.5 Tg CH_4 per year. Therefore, rice fields in Thailand contribute about 3.4% to the global methane budget due to rice cultivation.

Towprayoon (Towprayoon, 1993) collected methane samples every two weeks of the planting period and obtain a methane emission rate of 0.287 $g/(m^2.d)$ for wet season and 0.225 $g/(m^2.d)$ for dry season. The average of these two figures is 0.256g/m^2, which is almost the same as the daily emission rate obtained from this study(0.25g/m^2). This might be just a coincidence since methane emission rate is critically dependent upon several factors including: (1) agricultural practices (e.g., fertilization, water management, density of rice plants, double cropping systems, application of manure or rice straw), (2) soil/paddy characteristics (soil type, acidity, redox potential, temperature, nutrient availability, substrate, profile of anaerobic environment), and (3) time of season. Different conditions could result in significantly different methane emission rate. Moreover, the daily emission rate should be a seasonally-averaged range, i.e., based on semi- continuous emission measurements(2—12 samples per day) taken over an entire growing season, so that the seasonal fluctuations are included(IPCC, 1991).

4 Conclusions

Ambient CH_4 and N_2O concentrations of as high as 4.18 ppmv have been recorded at about 80 cm above the test field. However, values higher than 2 ppmv were due to static wind and lack of mixing and /or biomass burning in the nearby fields.

Diurnal variation of CH_4 emissions generally followed the variation of soil temperature. On very hot dry days, however, midday closure of stomatal pores due to water stress blocked CH_4 transport to the atmosphere. Their re-opening led to the emission peak at night.

Urea fertilization was found to enhance methane emission.

Methane emission from Thai rice fields is 3.32 Tg CH_4(2.49 Tg CH_4- C) per year, accounting for about 3.4 % of the global methane budget due to rice cultivation.

References

Cicerone RJ, Shetter JD. Journal of Geophysical Research, 1981; 86:7203

Cicerone RJ, Shetterr JD. Journal of Geophysical Research, 1983; 88:11022

Glinski J, Stepniewski W. Soil aeration and its role for plants. Florida, USA: CRC Press. 1985

Greulach, NA. Plant function and structure. New York: The Macmillan Company, 1973:229

Holzapfel-Pschorn A, Seiler W. Journal of Geophysical Research, 1986; 91:11803

Intergovernmental Panel on Climate Change(IPCC). Climate Change. New York: Cambridge University Press. 1990

Intergovernmental Panel on Climate Change(IPCC). Estimation of Greenhouse gas emissions and sinks. Final report from the OECD experts meeting. 1991: 18

International Rice Research Institute(IRRI). World rice statistics. Manila: IRRI. 1987

Matthews E, Fung I, Lerner J. Global biogeochemical cycles. 1991; 5:3

Matthias AD, Blackmer AM, Bremner JM. Journal of Environmental Quality. 1980; 9; 2:251

Mitra AP. Global change: Greenhouse gas emission in India. 1992:1

Neue, HH, Scharpenseel, HW. Organic matter and rice, Philippines: Los Banos. 1984

Noggle GR, Fritz GJ. Introductory plant physiology. New Jersey: Prentice-Hall. 1976:420

Parashar DC, Rai, J, Gupta, PK, Singh, N. India Journal of radio and space physics, 1991;20:12

Rao AV, Sethunathan N. Microbiology of the rice soils(Ed. by Jaiswal PL). Rice research in India, New Delhi: Indian Council of Agricultural Research. 1985

Sass, RL. Fisher FM, Turner FT, Jund, MF. Global Biogeochemical cycles, 1991; 5:275

Schutzh, Holzapfel-Pschorn A, Conrad R, Rennenberg, H, Seiler W. Journal of Geophysical Research, 1989; 1(94):16405

Seiler W, Holzapfel-Pschorn A, Conrad R, Scharffe, D. Journal of Atmospheric Chemistry, 1984; 1:241

Towprayoon S, Asawapisit S, Wanichpongpan P. Methane emission from rice paddy field in Thailand. Proceeding of International Conference on regional environment and climate changes in East Asia. Taiwan. Nov. 30 — Dec. 3, 1993

Wang ZP, DeLaune RD, Masscheleyn PH, Patrick WH. Jr. , Soil Science Society of America Journal, 1993; 57:382

Yagi, Minami K. Soil Science and Plant Nutration, 1990; 36:599

Yoshida T, Soil Biochemistry. New York: Marcell Dekker Inc. 1975:83

(Received August 22, 1994)