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An Appraisal of Methane Emission of Rice Fields from Kerian Agricultural Scheme in Malaysia

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ABSTRACT

Methane (CH_4) emission from rice field at Kerian Agricultural Scheme, Perak, Malaysia was evaluated to ascertain its effect on rice yield with respect to water management and climate change mitigation strategies. A closed gas chamber technique was used for gas entrapment, sampling bag for collection and portable gas analyzer (GA2000) was used to detect CH_4 and other gases. The measurement was conducted on hourly basis with 10 min intervals in a week at different growth stages of rice cultivation. Other soil and water analyses were carried out using standard procedures. The CH_4 emission was not detected during the selected rice growing season due to the timing of measurement, however CO_2 ranged between 0.1 and 1.2%, O_2 between 17 and 20%, inert gases 78.9 and 81% and H_2S between 5 and 14 ppm. Other factors that had indirect effects on the CH_4 emission which were determined included the soil type, water level and type of fertilizer applied which depended on SO_4^{2-} or NO_3^- constituents.

Key words: Paddy rice, methane, yield, Malaysia

INTRODUCTION

One of the most serious long-term challenges facing the world today is climate change and the most affected sector is agriculture since climate is the primary determinant of agricultural productivity (McCarl *et al.*, 2001). Atmospheric methane (CH_4), nitrous oxide, (N_2O) and carbon dioxide (CO_2) are the major Greenhouse Gases (GHG) that had potential of contributing to global warming (Tsuruta, 2002). However, an attempt to reduce GHG emission is likely to mitigate such impacts on food production especially rice (McCarl *et al.*, 2001).

Rice, the major staple food in Malaysia and the most important source of rural employment and income generation is being threatened by yield reduction occasioned due to the global effects of climate change. It is one of the most important cereal crops, with over 170 million ha under cultivation globally and grown in wide range of climatic zones (Singh *et al.*, 2011). South and southeast Asia are generally accepted and regarded as origin of Rice and Malaysia belongs to these regions (Bounphanousay *et al.*, 2008). Rice is the third most important crop in Malaysia after rubber and palm oil in terms of production and productivity which is mainly grown in the eight granary areas in Peninsular Malaysia covering an area of about 209,300 ha (Akinbile *et al.*, 2011). The two major rice growing areas are Muda Agriculture Development Authority (MADA) and Kemubu Agriculture Development Authority (KADA) and the latter was only able to produce

230,000 tonnes of rice while it was expected to increase to 260,000 tonnes in 2010 (Akinbile *et al.*, 2011). It has been predicted that Malaysian rice production will reduce by 0.36 t ha^{-1} to a 2°C temperature rise and will cause the economy loss of Malaysian Ringgit (RM) 162.531 million per year (Vaghefi *et al.*, 2011). Similarly for the increase in CO_2 from the current concentration level of 383 to 574 ppm, a decline in rice yield of about 0.69 t ha^{-1} will be incurred, economic implications of RM 299.145 million per year (Vaghefi *et al.*, 2011). Tsuruta (2002) reported that methanogenic bacteria in paddy soils under anaerobic conditions facilitate CH_4 emission from rice fields during flooded and rice growing season. Rice fields are one of the major anthropogenic sources on methane (CH4), a greenhouse gas to the atmosphere. The CH_4 concentration is expected to increase further due to expansion of rice cultivation (Singh and Singh, 1995). Yue *et al.* (2010) also established that CH_4 flux was high during flooding while N_2O was emission was small. Other Greenhouse gases (GHG) such as (CO_2) and (N_2O) have significant effect on yield as their emissions were the strongest in rice fields. The concentration of CH_4 increased by 4.9 ppb/year and N_2O by 0.8±0.2 ppb/year and this has affected yield in rice production (Yue *et al.*, 2010).

Several rice varieties were developed and cultivated in Malaysia rice fields. The commonly grown varieties were MR211, MR219, MR220 and MR232. However, the Kerian Agricultural Scheme (KAS), which is located at Perak state in Peninsular Malaysia, is grown MR219. Such variety is a hybrid type of MR137 and MR 151 varieties. Due to cross-hybridization, MR 219 is having improved plant morphology and good rice texture with uniformity of ripening on the stalks to achieve high yield over original local varieties (MAEP, 2010). Several research works such as (Towprayoon *et al.*, 2005; Khalil *et al.*, 2000; Chakraborty *et al.*, 2000; Tyagi *et al.*, 2004; Purkait *et al.*, 2007; Naser *et al.*, 2007; Pathak *et al.*, 2005) had been carried out on GHGs on rice fields in most part of Asian continents in countries such as Thailand, China, Japan, India and Sri Lanka however, considerably fewer research works were conducted in Malaysia. Therefore, the aim of the study was to determine methane and other gases emissions from rice field at Kerian Agricultural Scheme as well as to ascertain the effect of control factors on the emissions on the paddy fields under the same conditions.

MATERIALS AND METHODS

Study area characteristics and pre-measurement activities: The KAS, located at the northwest of Perak State in Peninsular Malaysia, is one of the oldest irrigation schemes in Malaysia. It has an area of 23,800 ha was divided into eight irrigation compartments, which were further divided into a total of 28 blocks (Fig. 1). It covered 24,100 ha of rice cultivable land and over 19,000 rice farming families those practicing double cropping of rice for their livelihood. The primary source of irrigation supply for the KAS is from the Bukit Merah Reservoir having a total storage capacity of approximately 75 million cubic meters (m^3) of water. The Bukit Merah Reservoir with an active storage capacity of 56 million m^3 collects runoff from a 489 km^2 catchment. The Bogak Pumping Plant supplements irrigation water supply through the main canal (Terusan Besar), from Bukit Merah Reservoir, which was split into the three sub-branches namely, Terusan Alor Pongsu, Terusan Tg. Piandang and Terusan Serong.

The soil type is clayey soil with pH ranging from 4.0 to 6.5, Cation Exchange Capacity (CEC) is higher than 20 meq/100 and C: N ratio of 6.28 with nitrogen (N) 10 g kg^{-1} and total Carbon (C) 62. 8 g kg^{-1}, respectively. The scheduled management activities followed conventional procedures which included Integrated Pest Management (IPM), diseases control and fertilizer application using the mixture of urea and N-P-K as 15-15-15. The MR219 rice variety was planted using direct sowing method.

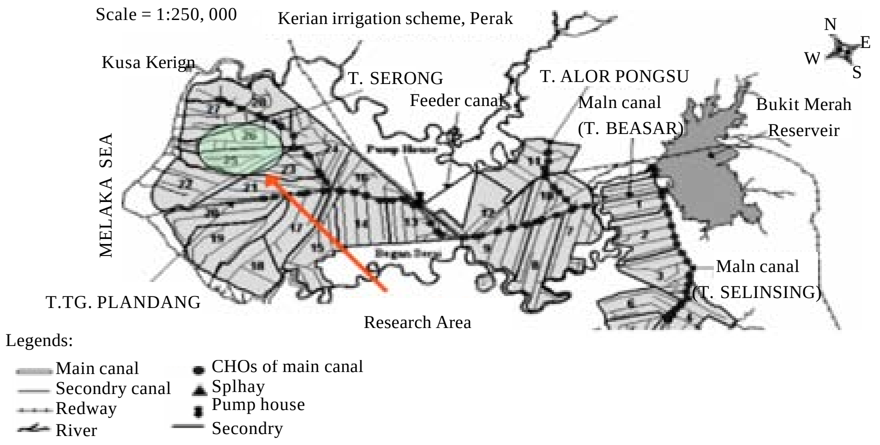

Fig. 1: Kerian irrigation scheme map

Sampling and on-site measurement method: Static-chamber method (Naser *et al.*, 2007) was used in collecting GHGs from the rice fields. Two transparent, rectangular Gas Chambers (GC) (with size 51×51×100 cm) constructed using 10 mm thickness transparent perspex materials and placed in the rice plants. The internal temperature of the GC was measured with thermometer attached inside the chamber. A silicon tube with valve was also attached to each chamber for gas sampling and in-situ measurement. A miniature electronic fan was attached to each of the GC to increase air circulation during measurement. In-situ measurement of the gas was carried out in the two gas collection chambers between 1000 and 1500 h weekly for one hour at 10 min intervals for the two sampling points. Sampling was conducted weekly and recorded according to the paddy growing stages. The GCs were installed at the respective sites at least 24 h before each measurement was conducted and were uninstalled from the sites 24 h after the measurement to allow conventional agricultural practices and development take place.

Although, the most commonest equipment for measuring gas generally is a laboratory Gas Chromatograph (GC) which has detectors and different sizes of columns depending on the type of gas to be determined, however for this in situ measurement in this study, a portable gas analyzer (model: GA 2000 Geotechnical Instrument-UK Ltd) was used for direct measurements. The GA 2000 measures CH_4, CO_2, O_2, H_2S and H_2 at the real-time basis and is expressed in percentage of the air within the gas chamber. Specialized polyethylene sampling bags (gas samplers) were used to collect gas from within the gas chamber before measurements took place.

Data analysis: Methane gas (CH_4) emissions were determined from the increase or decrease of gas concentration in the gas chamber per time using the equation adopted from (Naser *et al.*, 2007) as given below:

$$F\,(\text{mg m}^{-1}2\text{ h}^{-1}) = \frac{\rho\times V}{A}\times\frac{\Delta c}{\Delta t}\times\frac{273}{T}\times\alpha \tag{1}$$

where, F is the gas emission, ρ is the density of gas at the standard condition (CH_4 = 0.716 kg m^{-3}), V(m^3) and A(m^2) are the volume and base area of the chamber, respectively $\Delta c/\Delta t$ (10^{-6} m^3 m^{-3} h^{-1}) is the gas concentration change in the chamber during a given period, T is the absolute temperature (K) and α is the conversion factor for CH_4 to C (12/16).

This was however different from the approaches of Li (2000), Li *et al.* (2004), Jiao *et al.* (2006), Ma *et al.* (2009) and Yue *et al.* (2010) which adopted the more traditional Gas Chromatograph (GC) approach. The major setback in the GC approach, according to Streese-Kleeberg *et al.* (2009) was its inability to measure GHGs in situ. The use of Gas Analyzer was due to its availability and ability to determine the gases in situ. Methane emissions behavior was correlated directly with the local agricultural practice and the fluctuations of its limitations factors which included the water level, soil type and also the type of fertilizer applied. Akinbile and Yusoff (2011a) also confirmed the relationship between Methane emission and fertilizer applied.

RESULTS AND DISCUSSION

Table 1 showed the fives gases that were determined in-situ using gas analyzer (GA2000) and other related information such as the stage of paddy growth at the period of measurement, sampling date, Days After Sowing (DAS), water level and undetermined gases. The stages considered included, harvesting, sowing, emergence and tillering while the gases measured also included CH_4, CO_2 and O_2 emissions from the field at these stages. Methane gas was not detected throughout the entire planting season which might be due to the time of the day when measurements were carried out. Naser *et al.* (2007) and Purkait *et al.* (2007) reported that maximum gas (including CH_4) could be determined before the sunrise and after the sunset. At these periods, the emissions would still be measurable due to the absence of heat that dispersed the gas whenever the sun is shining. Conrad (2002) and Chakraborty *et al.* (2000) underscored the role of temperature in achieving most reliable measurements since the gases are extremely sensitive to heat. Similarly from the Table 1, the CH_4 was not detected during the harvesting stage which perhaps was due to the non-flooding condition of the paddy field at that stage. Mosier *et al.* (2004) and Matthews *et al.* (2000) reported that methane production during under upland rice cultivation or in periods when lowland was not flooded would almost be zero since the water level is zero meaning there was no water at all in the field. Akinbile and Yusoff (2011b) made similar observations in their study using different crop.

During the sowing stage, the field was flooded by water two weeks before the seedlings were sown. This was for the land preparation purposes and also, insecticides had been applied to the field one week before sowing. Also, from the results presented in Fig. 2, there was negligible methane

Table 1: Gases measurement and associated information

Stage/period	Sampling date	Days after sowing	Water level (cm)	CH_4 (%)	CO_2 (%)	O_2 (%)	Balance (%)
Harvesting	12/01/11	111	0	0	1	19	80
	19/01/11	118	0	0	3	17	80
	26/01/11	125	0	0	1.2	18.6	80.2
Sowing	23/02/11	0	6	0	0.1	20	78.9
	10/03/11	4	6	0	0	19	81
	16/03/11	10	6	0	0.1	20	79.9
Emergence	24/03/11	18	6	0	0.1	20	79.9
	30/03/11	24	6	0	0.1	20	79.9
	05/04/11	30	6	0	0	19.8	80.2
Tillering	13/04/11	38	6	0	0	19.9	80.1
	20/04/11	45	6	0	0	20	80
	27/04/11	52	6	0	0	20	80

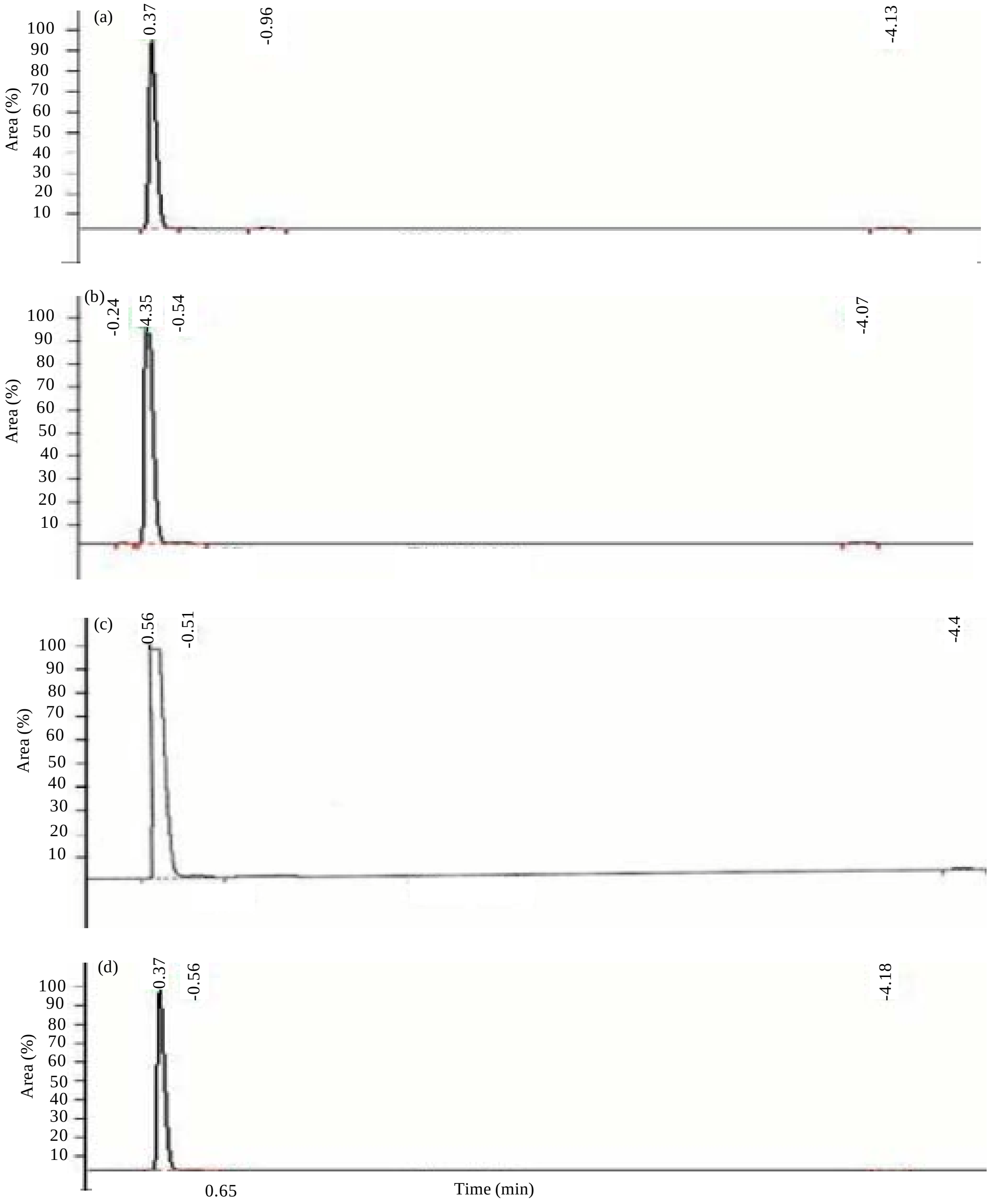

Fig. 2 (a-d): Methane gas measurement during (a) Harvesting (b) Sowing (c) Emergence and (d) Tillering stage on KAS paddy field

detection during this stage. This might be correct theoretically as 90% of the methane gas was transported via rice stalks as reported by Kyuma (2004) and Kern *et al.* (1997). Apart from this, ebullition and diffusion only contributed a small amount of methane emissions from paddy field. Since it was just the sowing stage without any well-developed rice stalks, methane production would naturally be low and this view was supported by Wassmann *et al.* (2000) and Schimel (2000). On the whole, no methane gas was detected in all the four stages and several reasons were given for this situation one of which is the soil factor which is clay. Kyuma (2004)

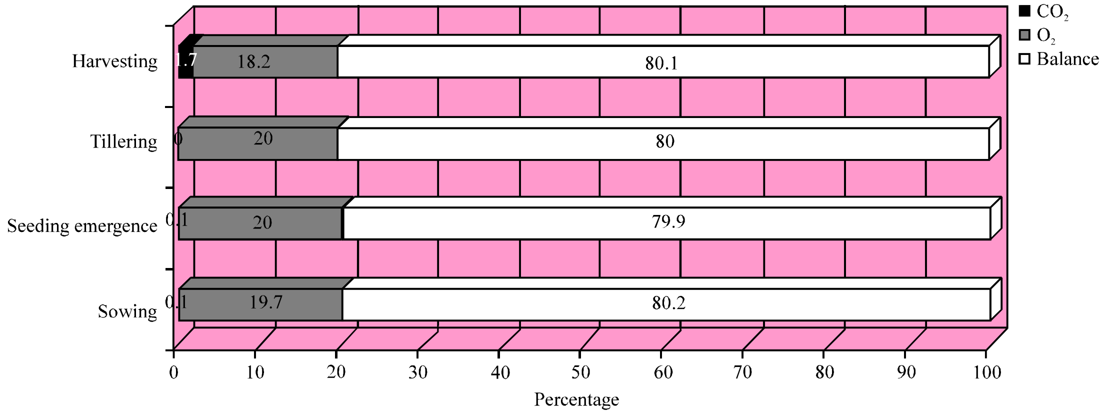

Fig. 3: Percentage composition of CO_2, O_2 and unknown gases on paddy field according to growing stage

found out that west Malaysian soil taken from coastal lowlands are clayey and contain moderate amount of silts. Thus, oxidation of methane might occur as reported by Le Mer and Roger (2001) that clay soils might have entrapped more methane which increased the probability of oxidation and in that circumstance, low methane emissions would be experienced. Since, low methane gas was produced, there was a probability that the little produced may have been oxidized before its emission to the atmosphere took place which must have led to reduction in the methane flux. Boeckx *et al.* (2005) reported that production rate would be higher than emission rate because it was most unlikely that all the CH_4 produced would be emitted into the atmosphere. Some would be oxidized by the reaction of methanotrophic bacteria or oxygen in the atmosphere and also by the photosynthesis activities of benthic organisms. In the case of India, Purkait *et al.* (2007) remarked that irrigated areas in India were subjected to Alternate Wetting and Drying (AWD) cycles and most of the methane gas were oxidized before reaching the soil-air interface resulting in lower methane flux and uptake by the rice soil. Similar observations were observed by Salam and Kato-Noguchi (2010) in Bangladesh during the study similar to this. Akinbile *et al.* (2012) also reported on Bangladesh rice that apart GHG, Arsenic contamination was very prevalent and inhibit tremendously growth and yield.

Apart from these, factors which control methane gas emissions such as temperature, pH and sulphate concentrations were prone to make its emissions to fluctuate tremendously for *in-situ* study and may have affected the flux as well (Neue *et al.*, 1997). These factors were assumed to have affected methane gas emissions resulting in its sinks in this study, due to unstable control factors and soil disturbances during the in-situ measurements.

The percentage composition of other gases detected by the GA 2000 such as CO_2, O_2 and unknown gases were as shown in Fig. 3. There was gas emission in all the stages except during the tillering stage and the highest CO_2 emission was recorded during the harvesting stage when the field has been drained, preparatory for harvest. The CO_2 value of 1.2% was recorded. Conventionally, rice respires by producing CO_2 in the day before sunrise and O_2 at night after sunset. The measurements at the strength of sunshine might be responsible for the very low quantity of CO_2 recorded during the experiment. The effect of water level on the CO_2 emission was not visible as there were emissions during harvest when the water level was zero as well as in sowing when the water level was at maximum however; the growing stage had measurable impact

Table 2: Hydrogen sulphide (H_2S) gas detected in the gas chamber

Days after sowing	H_2S (ppm)
0	5
4	14
10	13
18	13
24	14
25	13
30	13
38	13
45	13

on the gas emission as CO_2 was not detected only during tillering stage. Pathak *et al.* (2005) reported that CO_2 and CH_4 could only increase considerably if more roots and shoots growth of rice with more N fertilizer application would produce more amounts of root exudates larger amounts of root debris which supplied C as substrate heterotrophic microbes resulting in larger emissions of these gases. This was supported by Tiwari *et al.* (2011), Philips and Podrebarac (2009), corroborating the observations recorded from this study. Oxygen was present in detectable quantities at all the different growing stages and this was due to the electric fan installed to circulate the air within the gas chamber before taking the measurements. It ranged between 18.2 to 20% in all the stages. The largest portions of the gas within the chamber were unknown, with the exception of hydrogen sulphide, due to the inability of the GA 2000 to detect it. It ranged between 79.9 to 80.2% in all the growing stages and the probability that the unknown gas was inert was high due to its low reactivity.

The quantities of hydrogen sulphide, H_2S as detected by GA 2000 during some growing stages in the KAS rice fields were as presented in Table 2. A sudden increase was recorded from first to fourth day after sowing, i.e., from 5 to 14 ppm and that was sustained through to tillering and for the next six weeks of experiment, though with a very marginal fluctuation of 13 ppm (Table 2). The amount of H_2S was quite high after sowing and application of pesticides to control mollusk until the tillering stage and H_2S toxicity might have occurred in soils due to low active iron and in parts of fields which had been enriched by organic substrates. Such scenario agreed with the findings of Jackel and Schnell (2000). The H_2S is a type of gas that emits bad odour and promotes corrosion produced from the reduction of SO_4^{2-}. The severity of H_2S toxicity is common in coastal peats which dry-out seasons between periods of flooding (Neue *et al.*, 1997). Other toxic substances produced during the decomposition of organic matter at low redox potentials are thiols, organic sulphides, H_2S and C_2H_4 and there was a relationship between sulfate concentration in soil and CH_4 production rate. The higher sulphate concentration would result in lower CH_4 production since H_2S was produced on reduction of sulphate with oxidation of CH_4 during the process. There was the likelihood of competition between methanogenesis micro-organisms and sulphate-reducing bacteria. Normally in these conditions sulphate-reducers win which would result in less methane (Mukherjee *et al.*, 2009) because CH_4 was oxidized during the sulphate reduction by the bacteria (Meijide *et al.*, 2010). Although, $NH_4^+SO_4^{2-}$ caused root rot in rice by producing hydrogen sulphide, it might effectively affect rice production and subsequently CH_4 emission (Minamikawa *et al.*, 2005). It was reported by Le Mer and Roger (2001) and Fukushima and Chen (2009) that $NH_{4+}SO_4^{2-}$ was the substrate which was suitable to control CH_4 emissions from rice soil. Most of the trace gases from rice fields were unknown gases, which could be inert gases. It covered 80% of the overall air contents in the chamber and might also contained some of the greenhouse gases that retard rice yields but were not detected due to the timing of measurement. One thing that is however abundantly clear is that the effect of these GHG emissions from KAS rice fields negatively affected production and yield under any given circumstances.

CONCLUSION

An attempt was made to determine methane emissions on rice fields at KAS, Perak, Malaysia. Besides, the effect of two other greenhouse gases namely carbon dioxide and hydrogen sulphide were determined from the same field. From the study, there was no detection of methane emission during the four growing stages of paddy rice development. Previous studies confirmed low methane detection during those four stages, resulting in low emissions, however, it was reported that significant CH_4 might be detected during heading and ripening stages of rice production which was not considered during this study. Similarly, the timing of measurement was reported to have a direct effect on the CH_4 readings. In the same manner, the water level, soil type and type of fertilizer applied had been proved to have considerable effect towards emission of CH_4 and other gases from the rice fields. While methanogenesis formation reduced soil with very low Eh condition to produce methane, this occurred only during flooding period, clayey soil promotes methane oxidation which resulted in lower methane emission. It has been established that soil is the main source for methane production and emission and also good methane sink medium. Similarly, while nitrogen fertilizer promotes methane emission, sulphate fertilizer promotes methane oxidation which reduces methane emission. This is also an important control factor for methane emission in the rice fields. Other GHGs such as CO_2 and H_2S were also detected in small quantities indicating their low emissions from KAS rice field under flooded conditions. The CO_2 ranged from 0.1 to 3% while H_2S was between 5 and 14 ppm throughout the entire experimentation. Further research on methane emissions is crucial in other to develop the significant databank on methane emissions from rice fields in Malaysia. Moreover, further research to comprise all the planting stages is needed to be able to observe the actual trend of methane emissions in the selected sites. It was also suggested that different fertilization's plot experimentation might be an alternative to evaluate the effects of chemical fertilizers on the emissions of methane and other GHGs. Finally, the need to consider another important GHG, nitrous oxide (N_2O) and GHG emissions under different irrigation management scenarios with respect to yield is also proposed.

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REFERENCES

Akinbile, C.O. and M.S. Yusoff, 2011a. Effect of tillage methods and fertilizer applications on *Amaranthus currentus* in Nigeria. Int. J. Agric. Res., 6: 280-289.

Akinbile, C.O. and M.S. Yusoff, 2011b. Growth, yield and water use pattern of chilli pepper under different irrigation scheduling and management. Asian J. Agric. Res., 5: 154-163.

Akinbile, C.O., A.M.M. Haque and H. A. Aziz, 2012. Arsenic contamination in irrigation water for rice production in Bangladesh: A review. Trends Applied Sci. Res. (In Press).

Akinbile, C.O., K.M. Abd El-Latif, R. Abdullah and M.S. Yusoff, 2011. Rice production and water use efficiency for self-sufficiency in Malaysia: A review. Trends Appl. Sci. Res., 6: 1127-1140.

Boeckx, P., X. Xu and V. Cleemput, 2005. Mitigation of N_2O and CH_4 emission from rice and wheat cropping systems using dicyandiamide and hydroquinone. Nutr. Cycling Agroecosyst., 72: 41-49.

Bounphanousay, C. P. Jaisil, J. Sanitchon, M. Fitzgerald, N.R.S. Hamilton and J. Sanitchon, 2008. Chemical and molecular characterization of fragrance in black glutinous rice from Lao PDR. Asian J. Plant Sci., 7: 1-7.

Chakraborty, N., G.M. Sarkar and S.C. Lahiri, 2000. Methane emission from rice paddy soils, aerotolerance of methanogens and global thermal warming. Environmentalist, 20: 343-350.

Conrad, R., 2002. Control of microbial methane production in wetland rice fields. Nutr. Cycling Agroecosyst., 64: 59-69.

Fukushima, Y. and S. Chen, 2009. A decision support tool for modifications in crop cultivation method based on life cycle assessment: A case study on greenhouse gas emission reduction in Taiwanese sugarcane cultivation. Int. J. Life Cycle Assess., 14: 639-655.

Jackel, U. and S. Schnell, 2000. Suppression of methane emission from rice paddies by ferric iron fertilization. Soil Biol. Biochem., 32: 1811-1814.

Jiao, Z., A. Hou, Y. Shi, G. Huang, Y. Wang and X. Chen, 2006. Water management influencing methane and nitrous oxide emissions from rice field in relation to soil redox and microbial community. Commun. Soil Sci. Plant Anal., 37: 1889-1903.

Kern, J.S., Z. Gong, G. Zhang, H. Zhuo and G. Luo, 1997. Spatial analysis of methane emissions from paddy soils in China and the potential for emissions reduction. Nutr. Cycling Agroecosyst., 49: 181-195.

Khalil, M.A.K., R.A. Rasmussen, L. Reu, MX. Wang, M.J. Shearer, R.W. Dalluge and C.L. Duan, 2000. Seasonal production and emission of methane from rice fields: Final report. U.S. Department of Energy, Germantown, MD., USA., pp: 20.

Kyuma, K., 2004. Paddy Soil Science. Kyoto University Press and Trans Pacific Press Melbourne, ISBN: 9781920901004, Pages: 280.

Le Mer, J. and P. Roger, 2001. Production, oxidation, emission and consumption of methane by soils: A review. Eur. J. Soil Biol., 37: 25-50.

Li, C., A. Mosier, R. Wassmann, Z. Cai and X. Zheng *et al.*, 2004. Modeling greenhouse gas emissions from rice-based production systems: Sensitivity and upscaling. Global Biogeochem. Cycles, Vol. 18 10.1029/2003GB002045.

Li, C.S., 2000. Modeling trace gas emissions from agricultural ecosystems. Nutr. Cycling Agroecosyst., 58: 259-276.

MAEP, 2010. Tanaman padi. Paddy Information Center, Malaysian Agro Exposition Park, Serdang, Malaysia.

Ma, J., E. Ma, H. Xu, K. Yagi and Z. Cai, 2009. Wheat straw management affects CH_4 and N_2O emissions from rice fields. Soil Biol. Biochem., 41: 1022-1028.

Matthews, R.B., R. Wassmann and J. Arah, 2000. Using a crop soil simulation model and GIS techniques to assess methane emissions from rice fields in Asia. I. Model development. Nutr. Cycl. Agroecosyst., 58: 141-159.

McCarl, B.A., R.M. Adams and B.H. Hurd, 2001. Global climate change and its impact on agriculture. http://agecon2.tamu.edu/people/faculty/mccarl-bruce/papers/879.pdf

Meijide, A., L.M. Cardenas, L. Sanchez-Martin and A. Vallejo, 2010. Carbon dioxide and methane fluxes from a barley field amended with organic fertilizers under Mediterranean climatic conditions. Plant Soil, 328: 353-367.

Minamikawa, K., N. Sakai and H. Hayashi, 2005. The effects of ammonium sulfate application on methane emission and soil carbon content of a paddy field in Japan. Agric. Ecosyst. Environ., 107: 371-379.

Mosier, A., R. Wassmann, L. Verchot, J. King and C. Palm, 2004. Methane and nitrogen oxides fluxes in tropical agricultural soils: Source, sinks and mechanism. Environ. Dev. Sustainability, 6: 11-49.

Mukherjee, R., A. Barua, U. Sarkar, B.K. De and A.K. Mandal, 2009. Role of Alternative Electron Acceptors (AEA) to control methane flux from waterlogged paddy fields: Case studies in the Southern part of West Bengal, India. Int. J. Greenhouse Gas Control, 3: 664-672.

Naser, H.M., O. Nagata, S. Tamura and R. Hatano, 2007. Methane emissions from five paddy fields with different amounts of rice straw application in central Hokkaido, Japan. Soil Sci. Plant Nutr., 53: 95-101.

Neue, H.U., R. Wassmann, H.K. Kludze, B. Wang and R.S. Lantin, 1997. Factors and processes controlling methane emissions from rice field. Nutr. Cycling Agroecosyst., 49: 111-117.

Pathak, H., C. Li and R. Wassmann, 2005. Greenhouse gas emissions from Indian rice fields: Calibration and upscaling using the DNDC model. Biogeosci. Discuss., 2: 113-123.

Philips, R.L. and F. Podrebarac, 2009. Net fluxes of CO_2, but not N_2O or CH_4, are affected following agronomic-scale additions of urea to prairie and arable soils. Soil Biol. Biochem., 41: 2011-2013.

Purkait, N.N., A.K. Saha and S. De, 2007. Behaviour of methane emission from a paddy field of high carbon content. Indian J. Radio Space Phys., 36: 52-58.

Salam, M.A. and H. Kato-Noguchi, 2010. Allelopathic potential of methanol extract of Bangladesh rice seedlings. Asian J. Crop Sci., 2: 70-77.

Schimel, J., 2000. Global change: Rice, microbes and methane. Nature, 403: 375-377.

Singh, B., D. Katiyar, D.V. Singh, A.K. Kashyap and A.M. Lall, 2011. Impact of urea on spatio-temporal distribution of methanotrophic bacteria in rainfed rice agro ecosystem. Int. J. Agric. Res., 6: 699-706.

Singh, J.S. and S. Singh, 1995. Methanogenic bacteria, methanogenesis and methane emission from rice paddies. Trop. Ecol., 36: 145-165.

Streese-Kleeberg, J., I. Rachor and R. Stegmann, 2009. *In-situ* measurement of methane oxidation activity in landfill covers by gas pushpull tests. Proceedings of the 12th International Waste Management and Landfill Symposium, October 5-9, 2009, Cagliari, Italy, pp: 1-12.

Tiwari, D.K., P. Pandey, S.P. Giri and J.L. Dwivedi, 2011. Effect of GA_3 and other plant growth regulators on hybrid rice seed production. Asian J. Plant Sci., 10: 133-139.

Towprayoon, S., K. Smakgahn and S. Poonkaew, 2005. Mitigation of methane and nitrous oxide emissions from drained irrigated rice fields. Chemosphere, 59: 1547-1556.

Tsuruta, H., 2002. Methane and nitrous oxide emissions from rice paddy fields. Proceedings of the 17th World Congress of Soil Science, August 14-21, 2002, Thailand, pp: 1-10.

Tyagi, L., A. Verma and S.N. Singh, 2004. Investigation on temporal variation in methane emission from different rice cultivars under the influence of weeds. Environ. Monitor. Assess., 93: 91-101.

Vaghefi, N., M.N. Shamsudin, A. Makmom and M. Bagheri, 2011. The economic impacts of climate change on the rice production in Malaysia. Int. J. Agric. Res., 6: 67-74.

Wassmann, R., R.S. Lantin, H.U. Neue, L.V. Buendia, T.M. Corton and Y. Lu, 2000. Characterization of methane emissions from rice fields in Asia. III. Mitigation options and future research needs. Nutr. Cycling Agroecosyst., 58: 23-36.

Yue, J., W. Liang, J. Wu, Y. Shi and G. Huang, 2010. Methane and nitrous oxide emissions from rice field soil in phaeozem and mitigative measures. http://www.coalinfo.net.cn/coalbed/meeting/2203/papers/agriculture/AG034.pdf