World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(Review Article)

Status report on greenhouse gas emissions in lowland rice farming in Ivory Coast

Karamoko OUATTARA [1,*], Brahima André SOUMAHORO [2], Tchoa KONE [1] and Mongomake KONE [1]

[1] *Department of Natural Sciences, Biology and Improvement of Plant Production Laboratory; NANGUI ABROGOUA University, 02 BP 801 Abidjan 02, Ivory Coast.*
[2] *Section of Life and Earth Sciences, Department of Science and Technology, Ecole Normale Supérieure d'Abidjan, 08 BP 10 Abidjan 08, Ivory Coast.*

World Journal of Advanced Research and Reviews, 2024, 23(03), 2329–2336

Publication history: Received on 03 June 2024; revised on 18 September 2024; accepted on 21 September 2024

Article DOI: https://doi.org/10.30574/wjarr.2024.23.3.2046

Abstract

Rice production is a major source of global methane and nitrous oxide emissions. Numerous studies have been conducted to quantify the flux rates of these gases in rice fields in many developed countries. However, in Africa and particularly in West Africa, where this culture is experiencing considerable growth, very few studies have focused on this aspect. Thus, the objective of this review was to evaluate the studies and study methodologies already carried out on greenhouse gases in rice cultivation. It appears that several countries have quantified greenhouse gases emitted in rice cultivation. Several methods have been developed such as the gas chromatograph, the spectroscopic method and the calculation using the IPCC guidelines for the quantification of greenhouse gases in rice cultivation. The gases retained are methane and nitrous oxide. And the quantities of gas emitted vary depending on the country. Emissions in Asia are higher than those on other continents. Several emission mitigation solutions have been proposed for rice cultivation with less environmental destruction. However, most of these methods have not yet been applied.

Keywords: GHG; Rice cultivation; Gas chromatograph; Method spectroscopic; IPCC

1. Introduction

The increase in world population coupled with changes in diets will lead to an increase of around 70% in food availability (FAO, 2009). Thus, greenhouse gas emissions from the agricultural sector could increase from 24% to 75% in 2050. To continue to feed the population and reduce the effects of climate change, we will therefore have to think about reducing emissions. Globally, agriculture is directly responsible for 24% of annual greenhouse gas emissions and induces 17% additional emissions through deforestation for additional agricultural land; mainly in developing countries (FAO, 2017). Developing countries currently account for about three-quarters of direct emissions and are expected to be the fastest-growing sources of emissions in the future (Leytem *et al.,* 2011).

Among the agricultural activities often stated as particularly emitting, rice cultivation holds a particular place, in particular due to the production of methane by flooded soils, this representing 92% of the overall warming power of rice (Faraco *et al.,* 2010). According to estimates from the Institute of Research for Development (IRD), to feed the world population, rice production must increase by 60% over the next 30 years. This data is particularly worrying in view of the significant emissions methane (CH_4) and nitrous oxide (N_2O) from rice fields Greenhouse gas (GHG) emissions caused by rice cultivation are significant, around 16% (IPCC, 2014).

Rice is grown in a wide variety of climatic, soil and hydrological conditions. Lowland rice fields, whether irrigated or not, are considered one of the most significant sources of CH4 and N2O emissions. Thus, these practices have attracted considerable attention due to their contribution to global warming. climatic (Bouwman *et al* ., 200 2) . According to Yao

* Corresponding author: OUATTARA Karamoko

et al . (2012), agricultural soils fertilized with nitrogen represent approximately 81% of anthropogenic N_2O emissions into the atmosphere, even though this gas has a warming power 300 times greater than CO_2.

In recent years, the States of developing countries have included in their governance program the objective of reducing greenhouse gas emissions by 2030, although it is not possible to stop to feed. This initiative necessarily involves supporting research on the different levels of emissions in the rice-growing basins of these countries in order to propose solutions to reduce this GHG emission. Due to the complexity and variability of agricultural systems, uncertainties persist in the assessment of GHG emissions, making a research effort in this area necessary. Studies on GHG emissions from rice fields have been carried out for more than two decades in developed countries. The available database of published articles contains hundreds of articles describing field measurements in various rice growing regions around the world. These evaluation methodologies have been adapted according to the conditions and realities of each system. This review focuses on the different places where GHG emissions have been evaluated, the methodological approaches, their evolution, the constraints linked to each of them as well as the possible solutions envisaged to reduce GHGs. The objectives of this study are:

- Examine the levels of GHG emissions from rice fields on different continents and the methodological approaches employed.
- Identify the different mitigation solutions adopted for emissions in rice fields

2. The different countries having carried out GHG measurements

Most major rice producing countries have determined the level of methane (CH_4) and nitrous oxide (NO_2) emissions. Figure **1** below shows countries on different continents that have carried out work to quantify GHG emissions. During our exploratory study, we were able to count seven countries on the Asian continent, namely: China, Taiwan, Burma, South Korea, India, Japan and Vietnam. With regard to Europe, we selected France and Spain and only the United States has quantified the emissions linked to rice cultivation on the American continent. In Africa, the documents we were able to obtain are those from three countries such as: Kenya, Egypt, Zimbabwe and Tanzania. It should be noted that no West African country is among them.

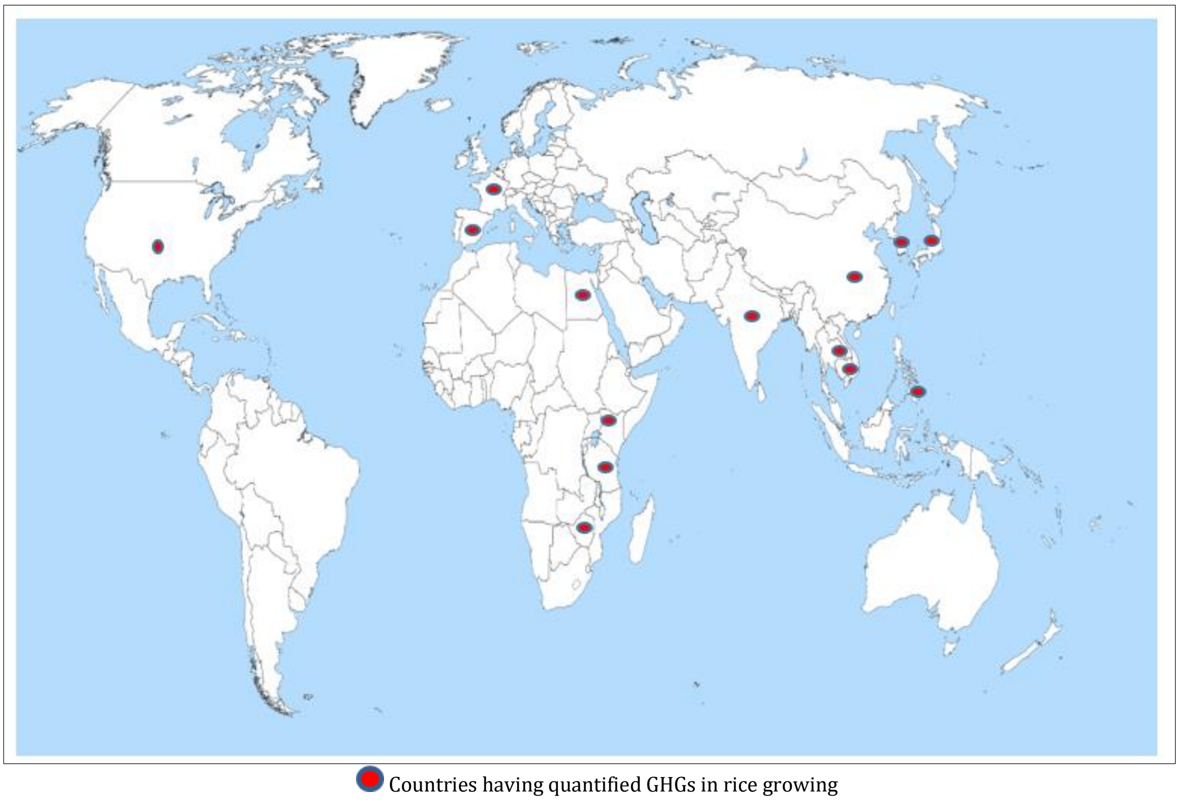

Figure 1 World map representing the countries having estimated GHGs in rice cultivation (Google; 2024)

3. The different methodological approaches used for GHG quantification

3.1. Gas chromatography (GC)

The measurement technique involves an enclosure called a manual or automated chamber. Chambers are usually placed on "bases" permanently fixed into the ground. The rooms are constructed from polyvinyl chloride (PVC) to avoid oxidation (Rochette and Ericksen -Hamel, 2008; Parkin And Venterea , 2010). Sampling is carried out by inserting a polypropylene syringe into the septa of the chamber and slowly drawing a sample of gases which are transferred to glass vials previously evacuated and sealed with a butyl rubber septum for storage (Christiansen, 2011 Butterbach - Bahl *et al.,* 2013). Various studies have identified that exetainers with pre-evacuated butyl rubber septa as a gas storage tool are the most suitable (Glatzel & Well , 2008 ; Spötl , 2004). Rochette and Bertrand (2003) found that storage in polypropylene syringes led to a loss of 16% of N2O over 24 hours. The gas chromatography (GC) is equipped with an electron capture detector (ECD) for N_2O, an ionizing flame detector (FID) for methane and carbon dioxide and a thermal conductivity detector (TCD) for oxygen and high carbon dioxide concentrations (Rochette and Bertrand, 2005; Leytem *et al* 2011).

3.2. Spectroscopic methods (PAS)

Spectroscopic instruments are also substitutes for the chromatographic technique. This is due to their portability, low maintenance and ease of use (Iqbal *et al* ., 2012). These devices are suitable for direct use in the field by allowing direct measurements of the fluxes emitted in the rooms (Leytem *et al* ., 2011) .

3.3. The calculation method according to the IPCC guideline

This method is based on calculations defined by the guidelines of the Intergovernmental Panel on Climate Change (IPCC) in 2006. These calculations are based on software or GHG calculators such as SECTOR, EXACT and Cool Farm Tool (Hillier *et al* ., 2011 , 2013 ; Grewer *et al* ., 2018 ; Vetter *et al* ., 2018 ; Wassmann *et al* ., 2019 ; Lai *et al* ., 2021). The SECTOR tool is one of the greenhouse gas (GHG) calculators for croplands. This calculation is based on the values obtained from the methodology approved by the Tier 2 approach of the Intergovernmental Panel on Climate Change in 2006 and refined in 2019 (IPO, 2006 ; IPCC, 2019 ; Wassmann *et al* ., 2019). This calculator was developed by the GHG mitigation platform in the rice sector of the International Rice Research Institute (IRRI). This tool is available in Excel and its use requires information on the cultivated area, yield and management practices (Primitiva *et al* ., 2022).

4. Results obtained for greenhouse gas emissions in rice growing

Using different evaluation methods, several authors were able to determine the quantities of CH4, NO_2 and CO_2 emitted in rice fields. It appears that N_2O and CH_4 emissions depended more on fertilization and the level of irrigation for rice fields subject to normal water management and a nitrogen fertilizer application rate (Wang and *al.,* 1999, Hou *et al* ., 2000 and Sun *et al* ., 2016). Studies carried out in an irrigated rice field have shown that the use of urea and ammonium sulfate as fertilizers is an important factor in greenhouse gas emissions (Sabyasachi *et al* ., 2002). Table **1** below shows the quantities of greenhouse gases determined by country. Gas emissions vary from one continent to another. Methane emissions in Asia range from 13 to 4370 kg CO2 CO2eq. ha −1 and those of nitrous oxide is 0.10 to 473.0 kg CO2 eq . ha −1. Rice cultivation for the European countries selected emits between 0.38 kg to 0.11 Mt CO2eq for methane and 6.03 kg/ha to 46.74 Mt CO2eq for nitrous oxide. In Africa, methane emissions vary by 0.35 kg·ha $^{-1}$ to 630.70 kg CO2-eq ha-1 and 0.2 kg·ha $^{-1}$ to 53.64 kg CO2-eq ha-1 for nitrous oxide There is a chronic lack of data on rice cultivation in relation to GHG emissions in Côte d'Ivoire.

Table 1 Quantities of greenhouse gases determined by country

Country	Greenhouse gas	Quantities	Authors
France	CH_4	0.11 Mt CO2e	CITEPA, 2012
	N_2O	46.74 Mt CO2e	
India	CH_4	24.5 to 37.2 kg ha $^{-1}$ day $^{-1}$	Sabyasachi *et al* .,2002;
	N_2O	0.037 to 0.186 kg ha−1 day $^{-1}$	
China	CH_4	1633.8 kg CO2eq. ha−1	

	N_2O	473.0 kg CO2 eq . ha−1	Yan *et al* ., 2009; Yan *et al* ., 2003; Chen *et al* ., 2013; Zhang *et al* ., 2023; Feng *et al* ., 2013
Japan	CH_4	2185 to 4370 kg CO2 ha−1	Harada *et al* ., 2007; Minamikawa *et al* ., 2006
	N_2O	47 to 83 kg CO2 ha−1	
Burma	CH_4	13 to 55 kg CH4 ha $^{-1}$	Win and Kyaw Win, 2020
	N_2O	0.10 to 0.27 kg NO2 ha $^{-1}$	
Vietnam	CH_4	34.6 to 749.1 Kg/ha	Tariq *et al* ., 2017
	N_2O	0.1 to 2 Kg/ha	
Etats-Unis	CH_4	308 to 6126 kg CO2 eq ha-1	Advent-Borbe *et al* ., 2013 ; Pittelkow *et al* ., 2013
	N_2O	490 à 1 915 kg CO2 eq ha-1	
Kenya	CH_4	630.70 kg CO2-eq ha-1	Jane, 2020
	N_2O	53.64 kg CO2-eq ha-1	
Egypte	CH_4	390 kg CO2-eq ha-1	Farag *et al* ., 2013
	N_2O	3.56 kg CO2-eq ha-1	
Zimbabwe	CH_4	0.35 to 1.4 kg·ha $^{-1}$	George *et al* ., 2013
	N_2O	0.2 to 0.6 kg·ha $^{-1}$	
Tanzania	CH_4	88.7 and 220.6 kg ha $^{-1}$	Primitive *et al* ., 2022
	No. $_2$O	Not detected	
Taiwan	CH_4	163 to 728 t	Shang- Shyng , 2009 Yang and Chang, 2001
	No. $_2$O	29493 to 61471 t	
Spain	CH_4	0.38 to 125 Kg/ha	Swamp *et al* ., 2017
	N_2O	6.03 to 14.24 Kg/ha	
South Korea	CH_4	706 to 2328 kg CO2-eq ha-1	Ahn *et al* ., 2014; Berger *et al* ., 2013
	N_2O	0.02 to 0.88 kg CO2-eq ha-1	

5. Possible solutions considered

The literature reveals several proposals made for the mitigation of different gases emitted in rice cultivation. Indeed, the promotion of the use of organic manure and urea by micro dose of N_2O is approximately 30% (Kuikman *et al* ., 2003). Also, intermittent irrigation and application of fertilizers deep in the soil would reduce greenhouse gas emissions in irrigated rice cultivation (Uprety *et al* ., 2012). Thus, adequate fertilizer management practices can sequester 0.3 tonnes C ha $^{-1}$ year $^{-1}$ and irrigation would sequester approximately 0.2 tonnes C ha $^{-1}$ year $^{-1}$ (Conant *et al* ., 2001). Organic fertilizers based on cattle manure further reduce N_2O emissions from the field. Applying fertilizer in small doses reduces N_2O emissions from the field. Fractional application of fertilizers reduces N_2O and CH_4 emissions and promotes the promotion of organic farming (Uprety *et al* ., 2012). Studies have shown that the application of nitrification inhibitors will significantly delay methane emissions (Keerthisinghe *et al* ., 1993). Likewise, straw burning and the incorporation of rice straw before cultivation leads to a significant reduction in greenhouse gas emissions. This significantly reduces methane emissions (Wassmann and Pathak , 2007).

Furthermore, the association of mycorrhizas with rice cultivation facilitates access to nutrients by the plant by improving yield. Mycorrhizae lead to an improvement in carbon storage in the soil and thus reduce CO_2 emissions (Lal *et al* ., 1998; Smith *et al* ., 2008).

6. Conclusion

There is no data on rice cultivation in relation to GHG emissions in Côte d'Ivoire. In most countries in the sub-Saharan region, and even other African countries, the net effects of emissions are not known. Due to the lack of information on the level of GHG emissions in Africa, and the diversity of lowland rice farming systems, the quantification of GHG emissions is necessary to identify and propose sustainable management practices that offer opportunities to reduce GHG emissions. This makes it difficult to design mitigation measures adapted to local conditions. In the current state of cultivation practices such as the use of mineral fertilizers, water management practices, the variety of types of development, and the type of fertilizer would be interdependent to explain the factors influencing the level of greenhouse gas emissions in the rice-growing lowlands of the Ivory Coast. Research into sustainable agriculture specifically in rice cultivation must be on the agenda as we fight climate change in our countries. And research would benefit from focusing on this area which remains little known to farmers. This will provide knowledge on the level of emissions of these gases from our rice fields in order to develop potential methods that could help to intensify rice cultivation and reduce greenhouse gas emissions.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Adviento-Borbe MA, Pittelkow CM, Van Kessel C, Hill JE, Six J, and Linquist BA (2013). Optimal fertilizer nitrogen levels and global warming on the yield scale Potential of rice sown in seedlings. J. Approx. Qual . 42:1623–1634 .

[2] Ahn , J.-H. ; Choi, M.Y.; Kim, B.-Y. ; Lee, J.-S.; Song, J.; Kim, G.-Y. ; Weon , H.-Y. (2014). Effects of water-efficient irrigation on greenhouse gas emissions and prokaryotic communities in rice field soil. Microbe. School . 68:271-283

[3] Arias-Navarro C, Díaz -Pinés E, Kiese R, Rosenstock RS, Rufino MC, Stern D, Neufeldt H, Verchot LS, Butterbach-Bahl K (2013) Gas pooling: A sampling technique to overcome the spatial heterogeneity of soil carbon dioxide and nitrous oxide flux. Soil Biol Biochem 67:20-23 .

[4] Björn Ole Sander & Reiner Wassmann . (2014). Common practices for manual sampling of greenhouse gases in rice production: a literature review on closed chamber method sampling arrangements. Vol 4, (1) 1-13.

[5] Bouwman , AF, Boumans , LJM and Batjes , NH (2002). N2O and NO emissions from fertilized fields: summary of available measurement data. Global Biogeochem . 16 , (4), 1058 .

[6] Butterbach-Bahl K, Kiese R, Liu C. (2011) . Biosphere-atmosphere exchange of CH4 in terrestrial systems. In: Rosenzweig AC and Ragsdale SW (eds) Methods in Enzymology , Vol. 49. Academic Press, pp 271-287 . Berger, S.; Jang, me; Seo , J.; Kang, H.; Gebauer, G. 2013. A record of NO and CH emissions and underlying soil processes from Korean rice fields affected by different water management practices. Biogeochemistry , 115, 317-332.

[7] Cameron M. Pittelkow , Maria A. Advent-Borbe , James E. Hill, Johan Six, Chris van Kessel, Bruce A. Linquist . (2013). Yield-scale global warming potential of annual nitrogen oxide and methane emissions from continuously flooded rice in response to nitrogen input. Agriculture, Ecosystems and Environment 177: 10–20.

[8] Chikowo R, Zingore S, Snapp S, Johnston A. (2014) . Farm typologies, soil fertility variability and nutrient management in smallholder agriculture in sub-Saharan Africa. Nutr Cycle Agroecosys 100: 1-18 .

[9] Chen, H.; Zhu, Q.; Peng, C.; Wu, N.; Wang, Y.; Fang, X.; Jiang, H.; Xiang, W.; Chang, J.; Deng, X. (2013). Methane emissions from rice paddies natural wetlands, and lakes in China: Synthesis and new estimate. Glob. Chang. Biol., 19, 19–32.

[10] Christiansen, J.R., Korhonen , J.F.J., Juszczak , R., Giebels , M., and Pihlation , M. (2011). Evaluating the effects of chamber placement, manual sampling, and headspace mixing on CH4 fluxes in a laboratory experiment. Plant Soil, 343: 171–185.

[11] Conant , RT, Paustia K., and Elliott ET (2001): Grassland management and conversion into grassland : Effects on soil carbon . Ecological Applications, 11, pp. 343-355.

[12] De Klein, CAM, Barton, L., Sherlock, RR, Li, Z. and Littlejohn , RP (2003). Estimation of a nitrous oxide emission factor for animal urine from selected New Zealand pastoral soils. Soil Res., 41:381–399.

[13] Ei Phyu W, and Kyaw Kyaw Wi. (2020). Greenhouse gas emissions, grain yield and water productivity: a case study of a paddy rice field based in Burma, C 2020 The Authors. Greenhouse Gases: Science and Technology, Society of Chemical Industry and John Wiley , Greenhouse Gas Science Technology. 10:884-897.

[14] Fangueiro , D.; Becerra , D.; Albarran , Á.; Rocher, D.; Sánchez-Llerena , J.; Souris-Nunes, JM; Lopez- Piñeiro , A. (2017). Effect of tillage and water management on GHG emissions from Mediterranean rice ecosystems. Atmosphere. Approximately, 150, 303–312.

[15] Farag , A.A; Radwan H.A; Abdrabbo MA A; Heggi MA M; McCarl BA (2013). Carbon Footprint for Paddy Rice Production in Egypt. Nature and Science; 11,(12):36-45.

[16] FAO (2017) Greenhouse Gas Emissions from Agriculture, Forestry and Other Land Use. Retrieved from http://www.fao.org/resources/infographics/infographicsdetails/en/c/218650/ .).

[17] Feng J, Changqing C, Yi Z, Song Z, Deng A, Zheng C, and Zhanga W. (2013). Impacts of agricultural practices on greenhouse gas emissions from rice fields in China: a meta-analysis. Agriculture, Ecosystems and Environment 164: 220-228.

[18] George N, Menas W, Ngonidzashe C, Lizzie M, Jeffrey L S. (2013) Greenhouse gas emissions from intermittently flooded Dambo rice (Dambo rice) under different tillage practices in the small-scale zone Chiota Farms in Zimbabwe, Atmospheric and Climate Sciences; Vol.3 No.4A,: 38838, 8 p.

[19] Glatzel, S., & Well, R. (2008). Evaluation of septum-capped vials for storage of gas samples during air transport. Environmental Monitoring and Assessment, 136(1–3), 307–11.

[20] IPCC. (2021). Climate change 2021: the basis of physical science. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change ; Cambridge University Press : Cambridge, United Kingdom; New York, NY, USA, 2391 pp.

[21] Grewer , U., Bockel , L., and Bernoux, M. (2013). EX-ACT quick guidance Estimating and Targeting GHG Mitigation in Agriculture. (Rome: Food and Agriculture Organization of the United Nations).

[22] Grewer, U., Bockel, L., Galford, G., Gurwick, N., Nash, J., Pirolli, G., et al., (2016). A methodology for greenhouse gas emission and carbon sequestration assessments in agriculture: supplemental materials for info note series analysing low emissions agricultural practices in USAID development projects CCAFS Working paper No. 187. (Copenhagen, Cali and Rome: CGIAR Research Program on Climate Change, Agriculture and Food Security, International Center for Tropical Agriculture and Food and Agriculture Organization of the United Nations).

[23] Grewer, U., Nash, J., Gurwick, N., Bockel, L., Galford, G., Richards, M., et al., (2018). Analyzing the greenhouse gas impact potential of smallholder development actions across a global food security program. Environ. Res. Lett. 13, 044003.

[24] Hisatomi H, Kobayashi H and Shindo H. 2007. Reduction of greenhouse gas emissions from no-till rice cultivation in the Hachirogata polder , northern Japan: Life cycle inventory analysis, Soil Science and Plant Nutrition, 53: 5, 668-677.

[25] Hillier, J., Smith, P., and Bandel, T. (2013). "Farm-scale greenhouse gas emissions using the Cool Farm Tool: application of a generic farming emissions calculator in developing countries," in Climate Change Mitigation and Agriculture, (Routledge), 245–254 p. doi: 10.4324/9780203144510-29.

[26] Hillier, J., Walter, C., Malin, D., Garcia-Suarez, T., Mila-i-Canals, L., and Smith. (2011). A farm-focused calculator for emissions from crop and livestock production. Environ. Model. Softw. 26, 1070–1078. doi: 10.1016/j.envsoft.2011.03.014.

[27] I. P. O. (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Hayama; Kanagawa: Institute for Global Environmental Strategies 2 p.

[28] Iqbal J, Castellano MJ, Parkin TB (2012) Evaluation of photoacoustic infrared spectroscopy for simultaneous measurement of N2O and CO2 gas concentrations and fluxes at the soil surface. Global Change Biol 19: 327-336.

[29] Jiao, Z., Hou, A., Shi, Y., Huang, G., Wang, Y., & Chen, X. (2006). Water management influencing methane and nitrous oxide emissions from rice field in relation to soil redox and microbial community. Communications in Soil Science and Plant Analysis, 37, 1889–1903.

[30] Keerthisinghe, D.G., Freney, J.R. and Mosier, A.R., (1993) : Effect of wax-coated calcium carbide and nitrapyrin on nitrogen loss and methane émissions from dry-seeded flooded rice Biol Fertil Soils 16 :71-75.

[31] Kelliher , FM, Sherlock, RR, Clough, TJ, Premarante , M., Laughlin, RJ, McGeough, KL, Harvey, MJ, McMillan, AMS, Reid, A., & Saggar, S. (2012). Air Sample Collection, Storage and Analysis, In: Nitrous Oxide Chamber Methodology Guidelines 5p.

[32] Kofi K. Boateng, George Y. Obeng, and Ebenezer Mensah (2017). Rice cultivation and greenhouse gas emissions: a review and conceptual framework with reference to Ghana. Agriculture , 7 (1), 7 ; https://doi.org/10.3390/agriculture7010007 .

[33] Kuikman PJ, Groot W, Hendriks R, Verhagen J and de Vries F (2003) : Stocks of C in soils and émissions of CO from agricultural soils in The Netherlands. Wageningen, Alterra. Alterra-report 561, 37p.

[34] Lai, L., Wassmann, R., and Sander, B. O. (2021). Policy framework for myanmar rice production and in-depth study on greenhouse gas emissions. J. Earth Environ. Sci. Res. 185, 159. doi: 10.47363/JEESR/2021

[35] Lal, R., Kimble, J.M., Follett, R.F. and Stewart, B.A., (1998). Management of carbon sequestration in soil, CRC Press LLC.

[36] Leytem AB, Dungan RS, Bjorneberg DL, Koehn AC (2011) Emissions of ammonia, methane, carbon dioxide, and nitrous oxide from dairy cattle housing and manure management systems. J Environm Qual 40: 1383–1394.

[37] Lu, WF , Chen, W. , Duan, BW, Guo, W. M., Lu, Y., Lantin, R. S., ... Neue, H. U. (2000). Methane emissions and mitigation options in irrigated rice fields in southeast China. Nutrient Cycling in Agroecosystems, 58, 65–73.

[38] Minamikawa K., Sakai N and Yagi K. (2006). Methane Emission from Rice Fields and Its Mitigation Options on a Field Scale. Microbes Environment. Flight. 21, no. 3, 135-147.

[39] Minamikawa, K., Yagi, Tokida K., Sander T. B. O., et Wassmann, R. (2012). Appropriate frequency and time of day to measure methane emissions from an irrigated rice paddy in Japan using the manual closed chamber method. Greenhouse Gas Measurement and Management, 2(2–3), 118–128.

[40] Parkin , T.B. (2006). Effect of sampling frequency on estimates of cumulative nitrous oxide emissions. J. Approx. Qual., 37:1390–5.

[41] Pedersen, AR, Petersen, SO and Schelde , K., (2010). A comprehensive approach to estimating soil-atmosphere trace gas flux with static chambers. EUR. J. Sol Sci ., 61: 888–902.

[42] Primitiva A.M , Kibebew K , Peter M , and Abebe A. (2022). Greenhouse gas emissions in irrigated paddy rice influenced by crop management practices and nitrogen fertilization rates in eastern Tanzania; Food Syst ., Sec. Climate-Smart Food Systems, Vol 6, 2 p.

[43] Qin, Y., Liu, S., Guo, Y., Liu, Q., & Zou, J. (2010). Methane and nitrous oxide emissions from organic and conventional rice cropping systems in Southeast China. Biology and Fertility of Soils, 46(8), 825–834.

[44] Rakesh Tiwari , K. Kritee , Tapan K. Adhya , Terry Loecke , Joe Rudek and Drishya Nair . (2015). Sampling guidelines and analytical optimization for direct greenhouse gas emissions from tropical rice and rainfed cropping systems. 6(3) 169-184.

[45] Rochette, P. and Bertrand, N. (2003). Storage and handling of soil air samples using polypropylene syringes and glass vials. Can. J. sol Sci ., 83: 631–637.

[46] Rochette P. and Bertrand N., (2005). Soil -surface gas emissions . In M. Carter ed . Soil Sampling and Methods of Analysis. CRC press, Boca Rotan. 63:1207-1213.

[47] Rochette P and Eriksen-Hamel NS (2008). Chamber measurements of soil nitrous oxide flux: are absolute values reliable? Soil Sci . Soc. A m. J. 72(2), 331 to 342 .

[48] Rochette, P. (2011). Towards a standard non-steady-state chamber methodology for measuring soil N2O emissions. Anim. Feed Sci . Technol ., 167:141–146.

[49] Rochette, P., Chadwick, DR, de Klein, CAM and Cameron, K. (2012). Deployment protocol, in: de Klein, CAM, Harvey, M. (Eds .), Nitrous Oxide Chamber Methodology Guidelines.

[50] Sapkota , TB, Rai, M., Singh, LK, Gathala , MK, Jat, ML, Sutaliya , JM, Bijarniya , D., Jat, MK, Jat, RK, Parihar , CM, Kapoor, P., Jat, HS , Dadarwal , RS, Sharma, PC and Sharma, DK (2014). Greenhouse gas measurement of smallholder production systems : guidelines for the static chamber method. International Maize and Wheat Improvement Center (CIMMYT) and Indian Council of Agricultural Research (ICAR), New Delhi, India. p. 18.

[51] Sass, R. L., & Fisher, F. M. (1995). Methane emissions from Texas rice fields: A five year study. In S. Peng, K. T. Ingram, H.-U. Neue, & L. H. Ziska (Eds.), Climate change and rice (pp. 46–59).

[52] Sass, R. L., Andrews, J. A., Ding, A., & Fisher, F. M. (2002). Spatial and temporal variability in methane emissions from rice paddies: Implications for assessing regional methane budgets. Nutrient Cycling in Agroecosystems, 64(1–2), 3–7.

[53] Shang-Shyng Y, Chao-Ming L, Hsiu-Lan C, Ed-Huan C et Chia-Bei W. (2009). Estimation of methane and nitrous oxide emissions from paddy fields in Taiwan, renewable energy, vol 34, Issue 8,1916-1922 p.

[54] Smith P, Martino D, Cai Z, Gwary D, Janzen HH, Kumar P, Mccarl B, Ogle S, O'Mara F, Rice C, Scholes RJ, Sirotenko O, Howden M, Mcallister T, Pan G, Romanenkov V, Schneider U, Towprayoon S, Wattenbach M and Smith JU gas mitigation in agriculture. Philosophical Transactions of the Royal Society B 363 :789–813.

[55] Spötl , C. (2004). A simple method of soil gas stable carbon isotope analysis . Rapid Communications in Mass Spectrometry , 18 (11), 1239 – 1242 .

[56] Tariq A, Vu QD, Jensen LS, De Tourdonnet S, Sander BO, Wassmann R, Mai TV, De Neergaard A. (2016). Mitigation of CH 4 and N 2 O emissions from intensive rice production systems in northern Vietnam: effectiveness of drainage schemes in combination with incorporation of rice residues. Agricultural. Ecosystem. Approximately, 249:101-111.

[57] Uprety DC, Subash D, Dong H; Bruce A. K, Amit G, and Jigeesha U. (2012). Technologies for Mitigating the Effects of Climate Change: Agriculture Sector, 35-54 p.

[58] Venterea , RT, Parkin, TB, Cardenas, L., Petersen, SO and Pedersen, AR (2012). Considerations on data analysis, in: de Klein, CAM, Harvey, MJ (Eds .), Nitrous Oxide Chamber Methodology Guidelines 15p.

[59] Vetter, S. H., Malin, D., and Smith, Hillier, J. (2018). The potential to reduce GHG emissions in egg production using a GHG calculator–A Cool Farm Tool case study. *J. Cleaner Prod.* 202, 1068–1076. doi: 10.1016/j.jclepro.2018.08.199

[60] Wang, M. X., & Shangguan, X. J. (1995). Methane emissions from rice fields in China. In S. Peng, K. T. Ingram, H.-U. Neue, & L. H. Ziska (Eds.), *Climate change and rice*.pp. 69–79.

[61] Wassmann R and Pathak H. (2007) : Introducing greenhouse gas mitigation as a development objective in rice-based agriculture : II. Cost- benefit assessment for different technologies, regions and scales. Agricultural Systems 94 :826-840**.**

[62] Wassmann R., Pasco R., Zerrudo J., Ngo D. M., Vo T. B. T., and Sander, B. O. (2019). Introducing a new tool for greenhouse gas calculation tailored for cropland: rationale, operational framework and potential application. *Carbon Manage.* 10, 79–92. doi: 10.1080/17583004.2018.1553436**.**

[63] Yan, X.Y. ; Akiyama, H. ; Yagi, K. ; Akimoto, H. (2009**).** Global estimations of the inventory and mitigation potential of methane emissions from rice cultivation conducted using the 2006 Intergovernmental Panel on Climate Change Guidelines. *Glob. Biogeochem. Cycles*, *23 p*.

[64] Yang, SS and HL Chang. (2001). Methane emissions from rice fields in Taiwan. Biol. Fertilizer. Soils 33: 157-165.

[65] Yan, X.Y. ; Ohara, T. ; Akimoto, H. (2003**).** Development of region-specific emission factors and estimation of methane emission from rice fields in the East, Southeast and South Asian countries. *Glob. Chang. Biol.*, *9*, 237–254.

[66] Zhan, M., Cao, C., Wang, J., Jiang, Y., Cai, M., Yue, L., & Shahrear, A. (2011). Dynamics of methane emission, active soil organic carbon and their relationships in wetland integrated rice-duck systems in Southern China. Nutrient Cycling in Agroecosystems, 89(1), 1–13.

[67] Zhang Z, Fan J, Wan Y, Wang J, Liao Y, Lu Y, Qin X. (2023). Evaluation of Methane Emission Reduction Potential of Water Management and Chinese Milk Vetch Planting in Hunan Paddy Rice Fields. Agronomy.; 13(7):1799. https://doi.org/10.3390/agronomy13071799.