Chapter

Rice: Worldwide Production, Utilization, Problems Occurring Due to Climate Changes and Their Mitigating Strategies

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Abstract

The production of rice is least in Pakistan and quite low as compared with other countries. Proper crop management techniques such as intercropping and combining organic manures are useful for better productivity and eco-friendly environment. Whereas studies are needed to evaluate the efficiency of intercrops and incorporation of certain nutrients with these plants. To examine results of intercropping experiment was carried out research by combining nutrient management practices. Five methods were taken including, sole rice, sole Green gram, rice + Green gram (drill), rice + green gram (Ridges), rice + green gram (bed) in the main plot moreover sub-plot included treatments of organic and inorganic supplement. The results show that sole rice followed by intercropping rice along green gram (poultry manure) has better characteristics of growth and yield, higher yield. by changing irrigation methods and farming methods, managing organic additives and fertilizer inputs, and choosing appropriate varieties and planting methods. CH_4 decreased by 75% and N2O increased by 58%. The overall rice production of Rice + green gram(ridges) is 2285 kg ha^{-1} followed by rice + green gram(drill) (2060 kg ha^{-1}). Rice + green gram(ridges) intercropping and (25 percent Urea+25 percent FYM+ 50 percent PM) were also correlated with better N usage performance and post-harvest soil usable N, phosphorus (P) and potassium (K) Benefit: cost (BC) ratios were also higher in the same treatment. From these results it is obvious that the integration of intercropping and induction of organic manures has a substantial impact on the outcome of rice.

Keywords: intercropping, F.M(farmyard manure), P.M(poultry manure), N:P: K, Rice, CH_4

1. Introduction

As the world population is increasing, the demand of the food supply is also increasing [1]. Estimating the future food demand, it can be considered that the food requirements will increase approximately 100 to 110% in regard to feed the world's growing inhabitants by 2050 [2]. Cereal crops have been utilized as a main component of the human diet for start of life in world. Rice (*Oryza sativa*) belongs to one of the major cereal crops. It is grown for >7000 years in all over the world [3]. The annual production recorded in 2014 > 740Mt. It is consumed as a staple food in many countries of the world [4]. Furthermore, Various components of rice crop such as rice husk, rice brans etc. are being used for the manufacturing of the different products such as rice bran is utilized to obtain the oil and rice husks are being used in manufacturing of different bakery products as a nutrition enhancing element. Rice is inimitable crop in term of its growth, it can be grown in various conditions either these are wet or dry, different kinds of soils, wide range of hydrological circumstances and different climatic conditions. But it is grown mostly in tropics, sub tropic, humid and sub humid areas. Irrigated rice gives average yield of 5 tons/ha globally, but this estimate varies widely in according to seasons, nations and regions. In tropic regions, well expert farmers can get the yield of 5 to 6 tons/ha and 7 to 8 tons/ha in wet and dry seasons accordingly. The decrease in the yield of rice in wet season may be due to the less quantity of solar radiations reaching to the earth [5].

2. Classification of rice

Kingdom	*Plantae*
Sub kingdom	*Tracheobionta*
Division	*Magnoliophyta*
Class	*Liliopsida*
Sub class	*Commelinidae*
Order	*Poales*
Family	*Poacaeae*
Sub family	*Oryzoideae*
Tribe	*Oryceae*
Genus	*Oryza*
Specie	22 species including *Oryza sativa, Oryza barthii, Oryza glaberrima, Oryza latifolia, Oryza longistaminata, Oryza punctate, Oryza rufipogon*

2.1 Origin

The most grown and utilizing species of rice are glaberrima (known as African rice) and *Oryza sativa* (known as Asian rice). These are considered as a progenitor of the Oryza species. It is estimated that *Oryza sativa* is grown approximately on the area of 1200 km belt including the areas of Himalaya mountains, areas near the Gangs river of India, Bangladesh, Bhutan, northern Burma, crossing the areas of Thailand, passing through Laos and Vietnam, it covers the some area of china as well. The Asian rice is mostly cultivated in south east Asia and south region. Due to the large belt of rice cultivation, the exact origin of domestication and evolution of related species and intermediates of the rice could not find. The domestication of Asian rice took place at many places in various times in south Asian regions [6]. On other hand, O glaberrima was known to be originated from the Niger river areas in west Africa, almost 3000 years before. The wild crop *Oryza barthi* is considered as its progenitor. After that *Oryza glaberrima* was grown in Liberia [7].

2.2 Domestication and diversification

There were two ways used for the domestication of the rice cultivation in China and India. In Yangtze japonica, the traits for the domestication were utilized in the beginning and this process was accomplished in China 6,000 to 6,500 years ago. But it was completed approximately after 20,000 years in India. At that time, the Chinese rice was hybridized. When farming trends increase then the growing of rice also moved to the nearby areas among the populations. In this way the rice, the spreading of the rice take place from china to its south regions such as Austronesian and Sino-Tibetan groups. On other hand, In south regions of Asia the distribution of the rice take place after Dravidian and Indo-Aryan have gotten the whole quantity of rice from the northern India [8]. Rice Diversification and domestication processes were exposed to with the help of archaeology, ecology and genetics. Archaeology discovers the evolutionary dates of rice were 4000 BC in india and 5000 BC in china. First detailed study was conducted in Hastinapur city of India on carbonized grains of rice at 1100–750 BC. The samples were taken from Atranjikera a city of Uttar Pradesh almost 1500–1000 BC. After that the cultivation of rice started spreading in different countries of the words such as its cultivation was introduced to the Japan 100-300 BC, west areas of India at 2000 BC, and Philippines and Malaysia by 1400 BC [9].

2.3 Distribution of rice

Paddy rice are those rice which do not contain husk on their surface and brown rice are those which contained any outer surface on it. This can be removed by the milling. After that the rice are polished to obtain the white rice. Rice are mostly grown on the flat lands, delta areas and near the rivers, but it is very difficult to describe the specific environmental conditions and areas for its growth. The countries containing the warm temperatures or subtropical climates give the maximum yields of the rice. The rice yield varies in all over the world according to the latitudes such as 50°N, 45°N and 39°S for China, Japan and Australia accordingly. The areas present at the latitude of 40°S and 45°N are considered as extensive rice cultivating areas. Highest yield is observed in between 30°N to 45°N of equators. It is also being grown in those areas which are present at the below levels of sea i.e., Kerala. In Jammu and Kashmir, the rice is also cultivated at 1979 m altitudes. It can also be cultivated in the deep and shallow water while rainy season is on peak [10]. The rice cultivation in widely range is due to its various varieties according to their origin. Rice can be grown in all kinds of environments depending on the nature of the cultivars. Mostly varieties can be grown in the areas where irrigation waters are available. Furthermore, some varieties of rice are also available, which grow in specific season and at specific lands.

2.4 Civilization due to rice

Rice play an important role in the human diet from the beginning. It has enhanced the civilization and boosted the national economy in each country growing the rice by exporting it to the rest of countries. It plays important role to fulfill the dietary requirements in increasing population, their culture and civilizations. Rice was swamp grass of the semitropical areas, before its cultivation on large levels in agriculture sectors. Then it became the additional food to the peoples of the tribes, who were dependent on the fishing, hunting and other wild foods. Its yield is less on the local level, but the implementation of the management practices like conservation of nutrients and water, and application of soil fertilizers, weeding and tillage practices, and selection of good varieties of the rice has boosted its yield on greater extend. The maximum rice crop can be yielded by utilization and managements of good practices, which are helpful to mitigate the problems of rice growth. Hence after these adaptations, there was great influence in rice yield per acre, rice growing areas and different cropping systems were developed. In this way, civilization was started flourishing throughout the Asia sub-continent. Now, Asian countries are contributing in their economy and meeting the surplus requirements of the population [11].

3. Status of climate change

3.1 Crop management

Various methods to reduce greenhouse gas emissions from rice fields can reduce greenhouse gas emissions from rice fields by changing irrigation methods and farming methods, managing organic additives and fertilizer inputs, and choosing appropriate varieties and planting methods. The following section will discuss all these details with suitable options and possibilities in different agro-conditions.

3.2 Changing irrigation pattern

Irrigation in rice production process is one of the vital features in regulatory greenhouse gas emissions. According to reports, compared with traditional flooded rice, several water managements schemes (such as different drainage periods in the season, alternating wet and dry soil, recurrent irrigation and controlled irrigation) can minimize GHG emissions, Can be used as an option. Practice under different soil and climate conditions without reducing crop yields. Mid-season drainage Mid-season drainage includes a significant period of interruption of irrigation during crop growth. Usually, a short-term drainage (5–20 days) is performed before the maximum sub-till number stage to prevent grade growth and reduce the number of invalid sub-tills, and the duration is adjusted by the conventional method of regional determination. At the beginning of soil aeration, CH_4 emissions may increase in a short time due to the release of CH_4 entrained in the soil, and its emissions will continue to decrease even when the field is submerged again. Since additional water can be used to displace the paddy soil, there is also a difference in the efficiency of mid-season drainage in reducing CH_4 (15–59%) [12]. Drainage in the spring increases the oxidative conditions of the soil and the uptake of nitrogen [13].

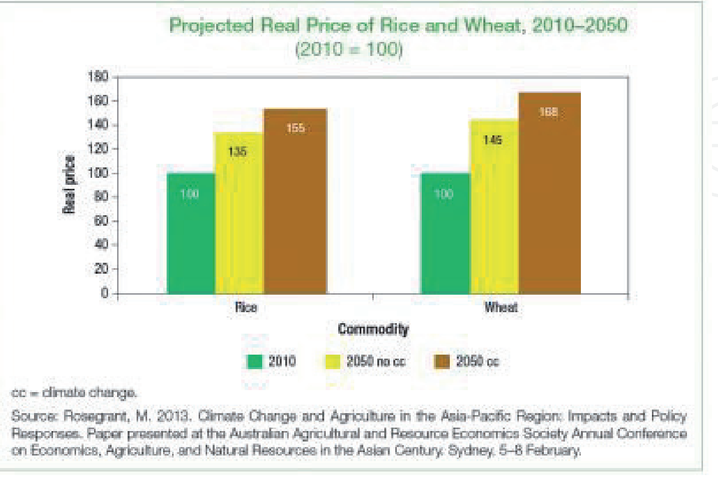
Therefore, this can be achieved by reducing the amount of water applied, because the net reduction in water will ultimately reduce CH_4 emissions. Wassmann et al. [14] reported that the aerobic conditions generated by the flux of oxygen discharged into the soil are not conducive to the activities of methanogenic bacteria, therefore, in the medium term, drainage can reduce CH_4 emissions by 43%. Timely mid-season drainage management seems to be an important way to obtain net benefits from greenhouse gas emissions [15]. So far, many studies have confirmed its applicability in rice fields based on overall greenhouse gas emissions. Zou et al. [16] recommended mid-season drainage as the best option to reduce greenhouse gas emissions, because they pointed out that the GWP of mid-season drainage was reduced by 27% compared with traditional CH_4 and N_2O-based floods [17]. Wassmann et al. [18] also reported that the GWP (CH_4 and N_2O) of the mid-season drainage was reduced by 42% and 72%, respectively, compared with the traditional flood. Since greenhouse gas emissions are greatly affected by the length and time of sewage discharge.

3.3 Alternate wetting and drying

Alternating wetting and drying are the periodic drying and re-oil flooding of the rice field. Compared with mid-season drainage, the time interval between wet and dry conditions seems too short to promote the transition from aerobic soil conditions to anaerobic soil conditions [19]. Alternating wetting and drying can significantly reduce CH_4 emissions, but the N_2O emissions of this system vary greatly. Drainage and the resulting aerobic soil conditions will oxidize CH_4 and avoid CH_4 production. Song and Fujiyama [20] reported that compared with traditional flooded rice, alternating wetting and drying may reduce CH_4 emissions by 73%. Yagi et al. [21] proposed that optimal irrigation according to the physiological characteristics of crops at different growth stages can limit the frequency of alternating wet and dry conditions, thereby reducing the production and emission of N_2O. However, further research is needed in this practice to solve the problem of offsetting N_2O emissions.

3.4 Intermittent drainage

Intermittent drainage involves repeated free drainage and irrigation. It has the advantage of improving soil oxidation conditions by enhancing root activity, increasing soil carrying capacity and ultimately reducing water input that leads to anaerobic conditions. It enhances the diffusion of oxygen into the soil, increases the aerobic area and reduces the production of CH_4 [22] pointed out that compared with traditional floods, intermittent drainage can reduce CH_4 emissions by 44%. Hardy [23] also showed that, compared with permanent floods, intermittent drainage can reduce CH_4 emissions by 15%. N_2O emission during intermittent irrigation strongly depends on the flooding conditions of the field. Different water regimes in rice fields lead to sensitive changes in N_2O emissions [17]. Nevertheless [24, 25] reported that compared with traditional floods, the global warming potential (CH_4 and N_2O) of intermittent irrigation was reduced by 34% and 54%, respectively.

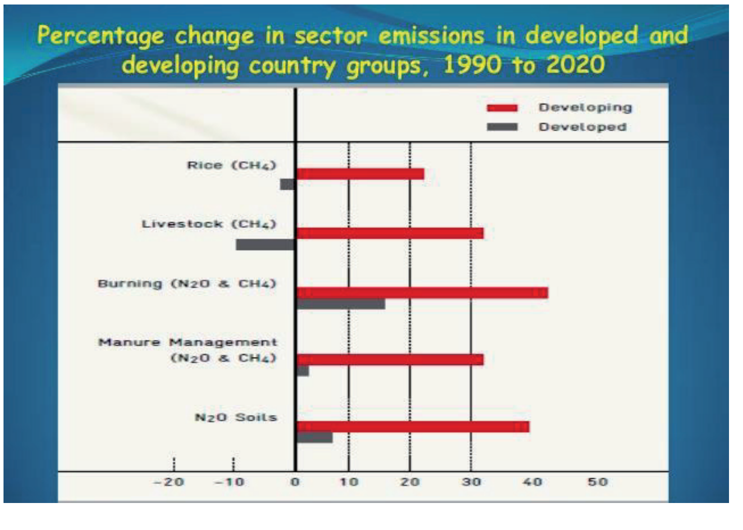


3.5 Controlled irrigation

According to reports, compared with irrigated rice, controlled irrigation can minimize the net emissions of greenhouse gases [26, 27]. During the rice growing season, the soil in the controlled irrigated rice field is kept dry (60–80%), but there is no flooding after the rice seedlings are regreened [28], similar to the water in the rice intensive system (Sato) [26] reported that, compared with traditional flooded rice, CH_4 emissions from controlled irrigation rice fields were reduced by 79%, and N_2O emissions increased by 10%. The GWP of controlled irrigation was much smaller than that of traditional flooded rice (67%). Peng et al. [27] also reported that the global warming potential (CH_4 and N_2O) of the irrigation system was reduced by 27% compared to conventional floods. In addition, some authors report that deep-water irrigation (water depth of 10 cm) and permanent humidification, humidification irrigation and water-saving irrigation can also reduce greenhouse gas emissions from rice fields, especially CH_4 [29, 30] can be used as a tool to reduce greenhouse gas emissions.

3.6 Straw/residues management

Crop production inevitably leads to the production of large amounts of straw/residue that are usually left in the field [31]. With the gradual decrease in the amount of organic fertilizers, the rice soil relies heavily on the recycling of straw to overcome the carbon loss caused by soil cultivation and crop harvesting. Although burning straw can ensure rapid seedbed preparation for farmers and avoid the risk of nitrogen immobilization during the decomposition of residues, carbon and nitrogen are relatively large, but incomplete carbon combustion will produce a large amount of greenhouse gases and affect air quality. Produce adverse effects [31, 32]. In addition, N oxides and other fire-source organic compounds can cause the formation of tropospheric ozone. Rice straw is composed of a variety of organic components, such as cellulose, hemicellulose, lipids, protein, lignin, etc., each component's contribution to the improvement of CH_4 emission rate is variable. CH_4 The discharge rate is very sensitive to the management method of straw entering the soil. Ali et al. [33] reported that the CH_4 emission rate of fresh rice straw is higher compared to the non-crop season in rice fields. In a field survey conducted in Zhejiang Province, China, [34] found that the recorded greenhouse gas emissions of early straw incorporation at the beginning of the fallow period in winter were 11% less than the traditional straw incorporation method in spring. Similarly, [35] showed that in the fallow period (60 days before rice planting), the incorporation of residues is beneficial in terms of greenhouse gas emissions and grain yield, compared to the usual application before transplantation. Abandoning rice straw can also be an effective measure, because compared with the combined use of straw, straw removal reduces the emissions of these three gases [36].



3.7 Application of biochar

Biochar is a carbon-rich material produced by pyrolyzing waste biomass under anoxic conditions and high temperatures [37]. The highly porous structure and the increased surface area of carbon-rich fine-grained biochar makes it an ideal soil amendment for carbon sequestration [38, 39]. Galloway et al. [40] pointed out that compared with the plots without biochar, biochar produced by pyrolysis of crop straw can increase carbon sequestration by 22% and reduce N_2O emissions by 35%. Higher levels of biochar are more effective in reducing N_2O emissions from rice fields [41, 42]. Huang et al. [43] observed that the application of biochar at 10 and 40 ha^{-1} reduced N_2O emissions by 58% and 74%, respectively. Jin et al. and Lehmann [44, 45] also recorded that the use of biochar can significantly reduce N_2O emissions. The application of biochar may have a positive impact on soil organic carbon and significantly reduce N_2O emissions, which may be a way to reduce greenhouse gas emissions. However, the long-term effects of biochar on the physical and chemical properties of soil and the rate of soil organic carbon sequestration require further studies to draw reliable conclusions.

3.8 Fermentation of manure

The greenhouse gas emission potential of fermented manure in the soil is low because the SOM reservoir will be quickly depleted during the fermentation process. Compared with fresh organic modifiers and a combination of urea and organic modifiers, the application of fermentation residues can reduce CH_4 emissions by approximately 60% and 52%, respectively [46]. Several field studies have evaluated various organic corrections for greenhouse gas emissions (especially methane). The difference between fresh materials (straw or fertilizer) is relatively small; however, it has been reported that there is a huge difference between the greenhouse gas emissions triggered by preferred and fresh materials [47, 48]. Using fermented biogas residues can only increase CH_4 emissions by 42%, while unfermented manure can increase CH_4 emissions by 112–138% [49]. Other carbon benefits obtained by substituting biogas for conventional fossil fuel energy, the use of biogas residues in rice fields can provide soil fertility while reducing CH_4 emissions. Nayak et al. [50] concluded that the application of livestock manure in rice fields can greatly reduce N_2O emissions, while increasing CH_4 emissions and soil organic carbon sequestration. Patrick and Reddy [51] reported that the application of compost in the rice field reduced N_2O emissions by 50% compared to the application of urea. However, the CH_4 emissions during anaerobic composting can offset the output obtained after mixing into the soil, and aerobic composting technology can minimize such emissions. Nayak et al. [50] observed that compared with fresh straw, the emissions of organic amendments produced by aerobic composting of straw were significantly reduced, indicating that it can be used as an environmentally friendly method.

3.9 Fertilizer management

Fertilizer management is an important part of reducing the environmental impact of rice fields. Soil fertilizers applied to crops are not always effective [52, 53]. Improving the efficiency of fertilizer use can reduce greenhouse gas emissions, especially N_2O emissions, and indirectly reduce the carbon dioxide emissions of nitrogen fertilizers [54]. Measures to improve fertilizer utilization and reduce greenhouse gas emissions include: accurately adjusting the amount of fertilizer according to crop needs [55–57] and using nitrification inhibitors or slow-release fertilizers [58, 59] adjust the timing of application and select the appropriate source, accurately locate the fertilizer in the soil, avoid excessive application or eliminate the application of nitrogen fertilizer [60].

3.10 Adjusting fertilization and matching N supply with demand

Adjusting the nitrogen and phosphorus content to meet crop demand is conducive to crop yields while controlling greenhouse gas emissions. Even in best fertilization practices, large amounts of nitrogen will be released into the atmosphere. In irrigated rice, nearly 48% of applied nitrogen is lost in gaseous form [60]. The responsible mechanism for nitrogen loss is ammonia volatilization, nitrification and denitrification. The specific meaning of all these processes may vary according to natural conditions and crop management practices [45]. The rate of fertilizer controls the emission of greenhouse gases. In general, the emission of greenhouse gases, especially N_2O, increases with the increase of nitrogen input [34, 55]. The general strategy for minimizing N loss and reducing N_2O emissions is to avoid excessive use of N in space and time. Reducing the amount of nitrogen fertilizer application to a level that does not reduce crop yields can also reduce the demand for nitrogen fertilizer, and ultimately reduce the indirect emissions of carbon dioxide during the nitrogen fertilizer production process. IPCC (1997) estimated that regardless of the source of N, 1.25% of the applied N would be lost as N_2O. Several studies have documented the instantaneous increase in N_2O emissions from rice fields due to the application of nitrogen fertilizers. [25]. It was observed that the application of urea will increase N_2O emissions by 54% compared with no nitrogen fertilizer. Lu et al. [49] reported that N_2O emissions in rice fields increased with the application of nitrogen fertilizer, especially at higher rates. Reducing nitrogen fertilizer has no significant impact on CH_4 emissions, while the current average nitrogen fertilizer application for rice can be reduced by 33%, which can reduce N_2O emissions by 27%. Recent field studies report that high nitrogen content can reduce net CH_4 emissions from rice systems by roughly 30–50% [59, 60].

Aulakh et al. [34] reported that the increase in nitrogen application reduced CH_4 emissions and increased N_2O emissions compared with the control without nitrogen application. Zou et al. [16] also recorded that when the nitrogen application rate increased from 150 kg to 400 kg N ha^{-1}, CH_4 decreased by 75% and N_2O increased by 58%. A recent meta-analysis showed that the response of CH_4 emissions may be related to the N rate, where the addition of N at a low rate tends to stimulate CH_4 emissions, but it may alleviate CH_4 emissions at high N rates [35, 47]. However, further research is inevitably needed to deal with the compromise between nitrogenous fertilizers and CH_4 and N_2O. Applying nitrogen fertilizer to the soil near the active root absorption zone can reduce the loss of surface nitrogen and increase plant nitrogen use efficiency, thereby reducing N_2O emissions. Khaliq et al. [30] pointed out that placing chemical fertilizers in a 6–10 cm soil layer can significantly increase nitrogen use efficiency and reduce N_2O emissions. In addition, distributing nitrogen fertilizer at different growth stages of crops can also increase nitrogen use efficiency and reduce nitrogen loss.

4. Conclusion

From above all discussion it may concluded that nitrogen have positive impact on rice yield greenhouse gas emissions from rice fields can reduce greenhouse gas emissions from rice fields by changing irrigation methods and farming methods, managing organic additives and fertilizer inputs, and choosing appropriate varieties and planting methods. CH_4 decreased by 75% and N_2O increased by 58%. CH_4 emissions may be related to the N rate, where the addition of N at a low rate tends to stimulate CH_4 emissions.

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References

[1] Petersen LK. Impact of Climate Change on Twenty-First Century Crop Yields in the US. Climate, 2019;7(3):40.

[2] Kontgis C, Schneider A, Ozdogan M, Kucharik C, Duc NH, Schatz J.Climate change impacts on rice productivity in the Mekong River Delta. Appl Geogr.2019; 102:71-83.

[3] Takeshi I, Shimamoto Ko. Perspectives of becoming a model plant: The importance of rice to plant science. Science Direct.1996; 1:9599.

[4] FAOSTAT (2016) http://faostat3.fao.org/download/Q/QC/E. Accessed 13 Feb 2016

[5] Dobermann A, Fairhurst T.Rice: nutritional disorders and nutrient management. Singapore:Potash and Phosphate Institute of Canada. International Rice Research Institute, Los Baños.2000.

[6] Nayar NM. Origins and phylogeny of rices. Elsevier.2014.

[7] Linares OF. African rice (Oryza glaberrima): history and future potential. Proceedings of the National Academy of Sciences.2002; 99(25): 16360-16365.

[8] Fuller DQ. Pathways to Asian civilizations: Tracing the origins and spread of rice and rice cultures. *Rice*.2011;4(3):78-92.

[9] Smith CW. Crop production: evolution, history, and technology. John Wiley and Sons.1995.

[10] Chang TT. The impact of rice on human civilization and population expansion. Interdisciplinary Science Reviews.1987; *12*(1):63-69.

[11] Bloom A, Swisher M. Emissions from rice production. Encyclopedia of Earth.2010; Accessed at 15(6);2011.

[12] Inubushi K. Characteristics and improvements of the poor paddy soils. Paddy fields soils. Introduction to Soil Science.2001

[13] Colton D, Giebermann K, Monk P. The linear sampling method for three-dimensional inverse scattering problems. ANZIAM Journal.2000; 42:434-460.

[14] Wassmann R, Neue HU, Lantin RS, Makarim K, Chareonsilp N, Buendia LV, Rennenberg H. Characterization of methane emissions from rice fields in Asia. II. Differences among irrigated, rainfed, and deepwater rice. In Methane Emissions from Major Rice Ecosystems in Asia.2000;(pp. 13-22). Springer, Dordrecht

[15] Towprayoon S, Smakgahn K, Poonkaew S. Mitigation of methane and nitrous oxide emissions from drained irrigated rice fields. Chemosphere.2005:59(11), 1547-1556.

[16] Zou J, Huang Y, Jiang J, Zheng X, Sass R L.A 3-year field measurement of methane and nitrous oxide emissions from rice paddies in China: Effects of water regime, crop residue, and fertilizer application. Global Biogeochemical Cycles.2005; 19(2).

[17] Osugi A, Itoh H, Ikeda-Kawakatsu K, Takano M, Izawa T. Molecular dissection of the roles of phytochrome in photoperiodic flowering in rice. Plant physiology.2011;157(3): 1128-1137.

[18] Wassmann R, Lantin RS, Neue HU, Buendia LV, Corton TM, Lu Y. Characterization of methane emissions from rice fields in Asia. III. Mitigation options and future research needs. Nutrient Cycling in Agroecosystems. 2000;*58*(1-3):23-36.

[19] Katayanagi N, Furukawa Y, Fumoto T, Hosen Y. Validation of the

DNDC-rice model by using CH_4 and N2O flux data from rice cultivated in pots under alternate wetting and drying irrigation management. Soil science and plant nutrition.2012; *58*(3):360-372.

[20] Song JQ, Fujiyama H.Difference in-response of rice and tomato subjected to sodium salinization to the addition of calcium. Soil Science and Plant Nutrition.1996;*42*(3):503-510.

[21] Yagi K, Tsuruta H, Kanda KI, Minami K. Effect of water management on methane emission from a Japanese rice paddy field: Automated methane monitoring. Global Biogeochemical Cycles.1996; 10(2):255-267.

[22] Adhya TK, Bharati K, Mohanty SR, Ramakrishnan B, Rao VR, Sethunathan N, Wassmann R.Methane emission from rice fields at Cuttack, India. Nutrient Cycling in Agroecosystems.2000; 58(1-3):95-105.

[23] HardyBL. Climatic variability and plant food distribution in Pleistocene Europe: Implications for Neanderthal diet and subsistence. Quaternary Science Reviews.2010; *29*(5-6):662-679.

[24] Feng T, Ye R, Zhuang H, Rong Z, Fang Z, Wang Y, Jin Z.Physicochemical properties and sensory evaluation of Mesona Blumes gum/rice starch mixed gels as fat-substitutes in Chinese Cantonese-style sausage. Food Research International.2013;*50*(1):85-93.

[25] Yang N, Zhang H, Chen M, Shao LM, He PJ.Greenhouse gas emissions from MSW incineration in China: Impacts of waste characteristics and energy recovery. Waste management.2012;32(12):2552-2560.

[26] Hou H, Peng S, Xu J, Yang S, Mao Z.Seasonal variations of CH_4 and N_2O emissions in response to water management of paddy fields located in Southeast China. Chemosphere.2012; 89(7):884-892.

[27] Peng S, Yang S, Xu J, Gao H. Field experiments on greenhouse gas emissions and nitrogen and phosphorus losses from rice paddy with efficient irrigation and drainage management. Science China Technological Sciences.2011;*54*(6):1581.

[28] Yu S, Ma Y, Menager L, Sun DW. Physicochemical properties of starch and flour from different rice cultivars. Food and bioprocess technology.2012; *5*(2):626-637.

[29] Liu XY, Qu JJ, Li LQ, Zhang AF, Jufeng Z, Zheng JW, Pan GX.Can biochar amendment be an ecological engineering technology to depress N2O emission in rice paddies?—A cross site field experiment from South China. Ecological Engineering.2012; *42*:168-173.

[30] Khaliq A, Shakeel M, Matloob A, Hussain S, Tanveer A, Murtaza G.Influence of tillage and weed control practices on growth and yield of wheat. Philippine Journal of Crop Science (PJCS).2013;*38*(3): 00-00.

[31] Beri V, Sidhu BS, Bahl GS, Bhat AK. Nitrogen and phosphorus transformations as affected by crop residue management practices and their influence on crop yield. Soil Use and Management.1995; 11(2):51-54.

[32] Watanabe A, Katoh K, Kimura M. Effect of rice straw application on CH_4 emission from paddy fields: II. Contribution of organic constituents in rice straw. Soil science and plant nutrition.1993;39(4):707-712.

[33] Ali RI, Awan TH, Ahmad M, Saleem MU, Akhtar M. Diversification of rice-based cropping systems to improve soil fertility, sustainable productivity and economics. Journal of Animal and plant sciences.2012; 22(1):108-12.

[34] Aulakh MS, Wassmann R, Bueno C, Kreuzwieser J, Rennenberg H.

Characterization of root exudates at different growth stages of ten rice (*Oryza sativa L.*) cultivars. Plant biology.2001;3(2):139-148.

[35] Banger K, Tian H, Lu Nitrogen fertilizers stimulate or inhibit methane emissions from rice fields. Global Change Biology,2012;18(10):3259-3267.

[36] Canavesi F. ICAR 2006.

[37] Cassman KG, Dobermann A, Walters DT, Yang H. Meeting cereal demand while protecting natural resources and improving environmental quality. Annual Review of Environment and Resources. 2003; 28(1):315-358 Corton TM, Bajita JB, Grospe FS, Pamplona RR, Assis CA, Wassmann R, Lantin RS, Buendia LV. Methane emission from irrigated and intensively managed rice fields in Central Luzon (Philippines). Nutr Cycl Agroecosyst. 2000; 58:37-53.

[38] Dong X, Gong M, Shen J, Wu J.Experimental measurement of vapor–liquid equilibrium for (trans-1, 3, 3, 3-tetrafluoropropene (R1234ze (E))+ propane (R290)). International journal of refrigeration.2011; 34(5):1238-1243.

[39] Freney JR. Emission of nitrous oxide from soils used for agriculture. Nutrient Cycling in Agroecosystems. 1997;49(1-3):1-6.

[40] Galloway JN, Aber JD, Erisman JW, Seitzinger SP, Howarth RW, Cowling EB, Cosby BJ. The nitrogen cascade. Bioscience.2003; 53(4):341-356.

[41] Ghosh S, Majumdar D, Jain MC. Methane and nitrous oxide emissions from an irrigated rice of North India. Chemosphere.2003;51(3):181-195.

[42] Gregorich EG, Rochette P, Vanden B, Ygaart AJ, Angers DA. Greenhouse gas contributions of agricultural soils and potential mitigation practices in Eastern Canada. Soil and Tillage Research.2005; 83(1):53-72.

[43] Huang YC, Simmons C, Kaigler D, Rice KG,Mooney DJ.Bone regeneration in a rat cranial defect with delivery of PEI-condensed plasmid DNA encoding for bone morphogenetic protein-4 (BMP-4). Gene therapy.2005; 12(5):418-426.

[44] Jin H, Li S, Cheng G, Shaoling W, Li X.Permafrost and climatic change in China. Global and Planetary Change.2000; 26(4):387-404.

[45] Lehmann J. A handful of carbon. Nature.2007; 447(7141): 143-144.

[46] Liang W, Yi SHI, Zhang H, Jin YUE, Huang GH. Greenhouse gas emissions from northeast China rice fields in fallow season. Pedosphere.2007; 17(5): 630-638.

[47] Linquist BA, Adviento-Borbe MA, Pittelkow CM,Van Kessel C,Van Groenigen KJ. Fertilizer management practices and greenhouse gas emissions from rice systems: a quantitative review and analysis. Field Crops Research.2012;135:10-21

[48] Liu Y, Guo Y, Gao W, Wang Z, Ma Y, Wang Z.Simultaneous preparation of silica and activated carbon from rice husk ash. Journal of Cleaner Production.2012;32:204-209.

[49] Lu Y, Wassmann R, Neue HU, Huang C. Dynamics of dissolved organic carbon and methane emissions in a flooded rice soil. Soil Science Society of America Journal.2000 64(6); 2011-2017.

[50] Nayak AK,Pal D,Das S.Calcium pectinate-fenugreek seed mucilage mucoadhesive beads for controlled delivery of metformin HCl. Carbohydrate polymers.2013; 96(1):349-357.

[51] Patrick Jr WH, Reddy KR. Nitrification-denitrification reactions in flooded soils and water bottoms: Dependence on oxygen supply and ammonium diffusion. Journal of environmental quality.1976; 5(4):469-472.

[52] Pittelkow CM, Adviento-Borbe MA,Hill J E,Six J,van Kessel C, Linquist BA.Yield-scaled global warming potential of annual nitrous oxide and methane emissions from continuously flooded rice in response to nitrogen input. Agriculture, Ecosystems & Environment.2013;177:10-20.

[53] Schlesinger W H.Carbon sequestration in soils.1999.

[54] Shang Q, Yang X, Gao C, Wu P, Liu J, Xu Y, Guo S. Net annual global warming potential and greenhouse gas intensity in Chinese double rice-cropping systems: a 3-year field measurement in long-term fertilizer experiments. Global Change Biology.2011;17(6): 2196-2210.

[55] Wassmann R, Papen H, Rennenberg H.Methane emission from rice paddies and possible mitigation strategies. Chemosphere. 1993;*26*(1-4):201-217.

[56] Yang H, Du T, Qiu R. Chen J, Wang F, Li Y, Kang S. Improved water use efficiency and fruit quality of greenhouse crops under regulated deficit irrigation in northwest China. Agricultural Water Management. 2017;179:193-20

[57] Yao F, Huang J, Cui K, Nie L, Xiang J, Liu X, Peng S. Agronomic performance of high-yielding rice variety grown under alternate wetting and drying irrigation. Field crops research.2012;126, 16-22

[58] Zhang A, Cui L, Pan G, Li L, Hussain Q, Zhang X, Crowley D. Effect of biochar amendment on yield and methane and nitrous oxide emissions from a rice paddy from Tai Lake plain, China. Agriculture, ecosystems & environment.2010;139(4):469-475.

[59] Zhang W, Hendrix PF, Dame LE, Burke RA, Wu J, Neher DA, Fu S. Earthworms facilitate carbon sequestration through unequal amplification of carbon stabilization compared with mineralization. Nature communications.2013;4: 2576.

[60] Zheng X, Wang M, Wang Y, Shen R, Gou J, Li J, Li L. Impacts of soil moisture on nitrous oxide emission from croplands: a case study on the rice-based agro-ecosystem in Southeast China. Chemosphere-Global Change Science.2000; 2(2):207-224.