How realistic is the prospect of low-carbon rice production? Lessons from China

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Agricultural practices worldwide have come under growing scrutiny for their contributions to environmental problems including climate change and water pollution. The process of rice production is a major cause of methane emissions and high water consumption. The production, oxidation, and transport of methane in rice fields are influenced by many factors, including the cultivation system, rice cultivar, water regime practiced, and types of fertiliser. Simultaneously, soil carbon sequestration in rice fields is a key potential approach for turning rice fields from being a source of greenhouse gas emissions to being a sink. This article summarises some realistic methods for reducing methane emission in rice production. Some case studies are presented regarding methane mitigation in rice fields, such as management of irrigation, the use of suitable rice cultivars (e.g., water-saving and drought-resistant rice, WDR), and combination of different fertilisers. Future perspectives on low-carbon rice production are also discussed.

The challenge

According to the Intergovernmental Panel on Climate Change (IPCC) of the United Nations, the global average surface temperature rose by 0.65 degrees from 1956 to 2005, double the gain that occurred over the previous 100 years (Solomon *et al.*, 2007). Emissions of greenhouse gases from industry, transportation, agriculture and other human activities lead directly to changes in the planet's carbon cycle. Greenhouse gas emissions from agriculture account for 13.5% of global anthropogenic emissions, consisting mainly of methane emissions from the production of rice and from ruminants, nitrous oxide emissions from fertilisation, and methane and nitrous oxide emissions from waste management processes. The global warming potential of methane and nitrous oxide is 25 and 298 respectively, over a 100-year period (Solomon *et al.*, 2007).

Approximately 150 million hectares of land worldwide are under rice production.

Annual methane emissions from rice paddy fields are 20-60 $\times$ 10^9 kg, accounting for 5-10% of the ~600 $\times$ 10^9 kg of total global greenhouse gas emissions (Kirk, 2004). Thus, rice paddies represent one of the most important anthropogenic sources of atmospheric methane (Cai *et al.*, 1997; Yan *et al.*, 2005). However, in irrigated rice paddies with appropriate water control, nitrous oxide emissions are quite low, except when excessively high rates of nitrogen fertilisers are applied. Nitrous oxide emissions in rice fields occur mainly during and immediately after fallow periods, once soils have been flooded.

How is methane produced in a rice paddy?

Methane flux in rice fields results from the shifting balance between methane production, oxidation and transport mechanisms. Methane production requires the flow of carbon and electrons to microbial populations. Rice plants provide substrates to the anaerobic food chain and ultimately to methanogenic bacteria, as root exudates or root autolysis products. Methane consumption in the troposphere happens mainly as oxidation, via either chemical reaction or microbial action, which occurs in the aerobic zone of methanogenic soils (i.e., methanotrophy) and in upland soils. All such processes are influenced by environmental factors such as temperature, carbon source, soil redox potential, pH, microbial diversity, along with the choice of rice cultivar, and they are further affected by the management practices applied to rice fields.

How much methane is emitted from a paddy?

Methane is emitted from the soils in which rice is grown to the atmosphere by three pathways: ebullition, diffusion and transport through the rice plant (Dubey *et al.*, 2005). Rice plants serve as conduits for gas exchange, allowing methane to bypass oxidizing bacteria that exist at the aerobic/anaerobic interface. In some cases, more than 90% of methane flux to the atmosphere from paddy soils is transported through rice plants (Banker *et al.*, 1995). Normally, the production of 1 kg of rice grains corresponds to the emission of 100 g of methane. According to IPCC guidelines, the default methane baseline emission factor is 1.3 kg CH_4 ha^{-1} day^{-1}, assuming no flooding in the 180 days prior to rice cultivation and continuous flooding during rice cultivation without organic amendments (IPCC, 2006).

However, scaling factors vary greatly with the type and amount of organic amendment applied (e.g., compost, farmyard manure, green manure, and rice straw). On an equal mass basis, more methane is emitted from amendments containing higher amounts of easily decomposable carbon, and emissions also increase as more of each organic amendment is applied. Rice straw is often incorporated into the soil after harvest. Following a long fallow period after incorporation of rice straw, methane emissions in the ensuing rice-growing season will be lower than where rice straw is incorporated just before rice transplant (Fitzgerald *et al.*, 2000). Therefore, the timing of rice straw application matters — good timing can result in soil carbon sequestration, making the rice field a carbon sink.

What mitigation measures can be used for methane emissions from a paddy?

Promising techniques include water management, organic amendments during the growing season, fertilisation, and the use of appropriate rice cultivars, with the first two having the greatest impact (Yan *et al.*, 2005). Mid-season drainage, intermittent irrigation or pre-harvest field drying may also reduce methane fluxes.

Improved water management acts by potentially altering soil moisture and soil Eh (soil redox potential), and eventually influencing methane emissions during the growing season of rice. Increases in soil Eh and decreases in methane flux are often observed in mid-season drained rice fields, resulting in a marked reduction of total seasonal methane emissions compared to continuously flooded rice fields (Mishra *et al.*, 1997; Jain *et al.*, 2000). Short-term draining practices can also strongly reduce methane emissions from rice paddies, by approximately 45% in intermittently drained fields compared to continuous flooding (Yagi *et al.*, 1996). The average methane fluxes from rice fields with single and multiple drainages were 60% and 52% of the flux from continuously flooded fields (Yan *et al.*, 2005). Methane flux can be reduced by 39% with the use of water-saving, controlled irrigation (5-25 mm standing water) compared to continuous flooding (30-50 mm standing water; Peng *et al.*, 2006). The flux from fields flooded in the previous season was 1.9 times that from fields drained previously for a short season and 2.8 times that from fields drained previously for a long season (Yan *et al.*, 2005).

Rice plants act as a methanogenic substrate, a conduit for methane transport through aerenchyma, and a potential methane-oxidising micro-habitat in the rhizosphere by diffusing oxygen (Dubey *et al.*, 2005). Methane emission is greatly influenced by the genetic characteristics of rice plants, owing to corresponding differences in the development of aerenchyma tissues. High-yielding cultivars with low photosynthate carbon translocation towards the roots result in reduced methane emission. Thus, screening of existing popular varieties, and initiation breeding programmes for new cultivars that have low photosynthate partitioning to the roots and a limited development of aerenchyma tissues offers promising options for methane mitigation.

Case study 1: Mitigation of methane emissions by water management and choice of rice cultivar

A single mid-season drainage for approximately 5-10 days — a common irrigation practice adopted in major rice-growing regions of China and Japan — can greatly reduce methane emissions. In an alternate wetting and drying (AWD) cycle, water is irrigated to create flooded conditions, a certain number of days (ranging from 1 to more than 10) after the disappearance of standing water (Bouman *et al.*, 2007). Most of the methane gas released during the cycle oxidises before reaching the soil/air interface, resulting in a lower methane flux. In addition, high Eh values prevent methane formation by methanogenic bacteria, and hence reduce methane emissions. However, rice yields may decline under conditions of lower irrigation if an unsuitable rice cultivar is selected.

A series of water-saving and drought-resistance rice (WDR) cultivars have been bred to give similar yield potential and grain quality but less water consumption (i.e., 50% of water use), compared to current paddy rice with irrigation. However, in water-limited environments, such cultivars show a higher drought resistance, which minimizes yield loss (Luo, 2010). An experiment involving normal irrigation, NI; 70% of that, NI70%; and 30% or NI30% and two rice varieties (A and B) was conducted (2012-2013) at the Zhuanghang Experimental Station of the Shanghai Academy of Agricultural Sciences, Shanghai, China.

The water regime of the NI70% treatment involved alternate wetting and drying, similar to the AWD cycle. The NI30% treatment simulated a kind of drought condition. Methane emissions were monitored at 9:00-10:00 h once a week throughout the rice growing season with a static chamber method, which consists of a plexiglass base frame (50 cm length × 40 cm width × 20 cm height) and a plexiglass lid (50 cm length × 40 cm width × 50 cm height) equipped with a battery-driven 12 V fan at the centre of its inner top. Additionally, other plexiglass frames were used to extend the lid height (20, 40 or 60 cm), depending on the rice height. The base frames were inserted into the soil approximately 15 cm, and 4 hills of rice plants were transplanted. One base frame was placed in each plot. Four gas samples were collected from each chamber at 6-min intervals using gas auto-sampling equipment attached to 4 plastic gas bags at each sampling time point. The gas samples were taken to the laboratory immediately for the measurement of methane, nitrous oxide and carbon oxide concentrations with a gas chromatographer and emission fluxes were calculated. For the B cultivar, rice yields declined significantly in the NI70% and NI30% treatments compared to yields obtained with NI. Conversely, rice yields were not different in the two irrigation managements for the A cultivar, compared to NI. The results indicated that A rice is more drought-resistant than B, in terms of grain yield. On the other hand, reductions in irrigation significantly decreased soil moisture and increased the soil Eh

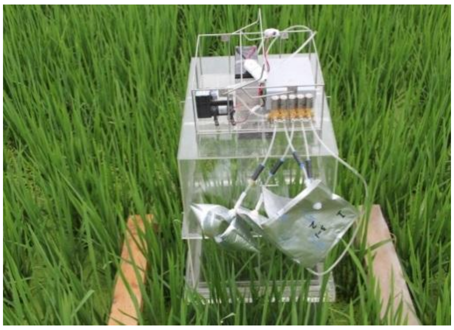
Zhuanghang Experimental Station
(credit: Sheng Zhou, SAAS)

value, which lowered total methane emissions on a seasonal scale: the NI30% treatment reduced methane emissions by 77% for A and 51% for B, compared to emissions observed with NI. The selection of A combined with lower irrigation might enable the maintenance of rice yields while lowering methane emissions and allowing water conservation.

Case study 2: mitigation of methane using a combination of fertilizers

The choice of fertiliser can affect production and emission of methane from rice paddies, by influencing (1) availability of carbon sources in a field, (2) growth rates of rice plants, (3) activity of methanogenic micro-organisms in the soil, and (4) the amount and composition of root exudates from growing rice plants. Adding fresh organic matter to flooded soils would markedly increase methane emissions and should be avoided, while transferring fresh organic matter as compost or biochar will mitigate emissions and increase carbon content.

A field experiment at the Zhuanghang Experimental Station (2011-2013) examined the effect of different fertilisers on rice yield and methane emissions from a paddy. The treatments applied to plots were chemical fertiliser (CF), chemical fertiliser with wheat straw (CF-WS), slow-release chemical fertiliser with wheat straw (SCF-WS), chemical fertiliser with biochar (CF-BC), and organic fertiliser with chemical fertiliser (OF-CF), each at rates of 225 kg-total N ha^{-1}, along with no fertiliser (Non-F) on control plots. Rice cultivar was grown in all treatments under a conventional water regime, with one summer mid-drainage.



Gas auto-sampling equipment (credit: Sheng Zhou, SAAS)

Total methane emissions increased significantly, by 40%-165% in CF-WS, SCF-WS, and OF-CF plots compared to the control, demonstrating that organic matter applied with chemical fertilizer would enhance methane emissions. However, the total methane emissions in CF-BC and CF were similar; suggesting that methane emission was inhibited when straw was transferred into biochar before application. Although methane emissions in CF-WS, SCF-WS, and OF-CF plots increased, the total methane emissions were lower than the carbon inputs into soil as organic matter, suggesting that these three treatments could represent a carbon sink. Conversely, no organic matter was added to soils in the CF treatment, and the methane emitted would represent a carbon source.

Future perspectives

Low-carbon rice production requires combining available mitigation options into a comprehensive package. Knowledge of the soil microbe communities associated with the leading rice cultivars is essential for recommending appropriate mitigation strategies. Protocols need to consider the needs of the farming community. Simulation models need to be developed to estimate methane emissions for a range of climate and agricultural management practices.

In addition to greenhouse gases released in rice production, the production and consumption of pesticides, fertilisers and agricultural fuels; the rice grain harvest, processing, packaging and transportation; and the treatment of straw and rice husks after processing also release greenhouse gases. Thus, a comprehensive approach is required to assess such impacts.

References

Banker, B.C., Kludze, H.K., Alford, D.P., DeLaune, R.D. and Lindau, C.W. 1995. Methane sources and sinks in paddy rice soils: relationship to emissions. *Agriculture, Ecosystems & Environment* 53 (3), 243-251.

Bouman, B.A.M., Lampayan, R.M. and Tuong, T.P. 2007. Water Management in Irrigated Rice: Coping with Water Scarcity. International Rice Research Institute, Los Banos, Philippines, http://books.irri.org/9789712202193_content.pdf

Cai, Zucong, Xing Guangxi, Yan, Xiaoyuan, Xu, Hua, Tsuruta, H., Yagi, K. *et al.* 1997. Methane and nitrous oxide emissions from rice paddy fields as affected by nitrogen fertilisers and water management. *Plant and Soil* 196, 7-14.

Dubey, S.K. 2005. Microbial ecology of methane emission in rice agroecosystem: a review. *Applied Ecology and Environmental Research* 3(2), 1-27. http://www.ecology.kee.hu/pdf/0302_001027.pdf

Fitzgerald, G.J., Scow, K.M. and Hill, J.E. 2000. Fallow season straw and water management effects on methane emissions in California rice. *Global Biogeochemical Cycles*, 14: 767-775.

Solomon, S.D., Quin, D., Manning, M., Chen, Z.L., Marquis, M., Averyt, K. *et al.* 2007. IPCC Climate Change 2007: the physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK. http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg1_report_the_physical_science_basis.htm

Jain, M.C., Kumar, S., Wassmann, R., Mitra, S., Singh, S.D., Singh, J.P. *et al.* 2000. Methane emissions from irrigated rice fields in northern India (New Delhi). *Nutrient Cycling in Agroecosystems* 58 (1-3), 75-83.

Kirk, G. 2004. The biochemistry of submerged soils. John Wiley and Sons. Chichester, West Sussex,UK.

Luo, L. 2010. Breeding for water-saving and drought-resistance rice (WDR) in China. *Journal of Experimental Botany* 61, 3509-3517.

Mishra, S., Rath, A.K., Adhya, T.K., Rao, V.R. and Sethunathan, N. 1997. Effect of continuous and alternate water regimes on methane efflux from rice under greenhouse conditions. *Biology and Fertility of Soils* 24 (4), 399-405.

Peng ShiZhang, Li DaoXi, Jiao XiYun, He Yan and Yu JinYuan. 2006. Effect of water-saving irrigation on the seasonal emission of CH_4 from paddy field. *Journal of Zhejiang University (Agriculture and Life Sciences*) 32, 546-50.

Yagi,K, Tsuruta, H., Kanda, K. and Minami, K. 1996. Effect of water management on methane emission from a Japanese rice paddy field: automated methane monitoring. *Global Biogeochemical Cycles* 10 (2), 255-267.

Yan, Xiaoyuan, Yagi, K., Akiyama, H. and Akimoto, H. 2005. Statistical analysis of the major variables controlling methane emission from rice fields. *Global Change Biology* 11, 1131-1141.

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