Contribution of Nitrous oxide in Life Cycle Greenhouse Gas Emissions of Novel and Conventional Rice Production Technologies

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Abstract
Nitrous oxide (N_2O) production and emission under wetland rice (*Oryza sativa* L.) is difficult to predict due to the trade-off between methane (CH_4) and N_2O emissions for different establishment and management practices. Any novel technology with the potential to reduce the emissions of both CH_4 and N_2O under wetland rice could make a significant contribution to total agricultural global warming mitigation. A streamlined life cycle assessment (LCA) approach to quantify the C footprint of rice production process in the Eastern Gangetic Plains (EGP) was adopted. The GHG emissions from one tonne of rice production were studied for the following cropping practices: a) conventional puddled transplanting with low residue retention (CTLR); b) conventional puddled transplanting with high residue retention (CTHR); c) unpuddled transplanting following strip tillage with low residue retention (UTLR) and; d) unpuddled transplanting with high residue retention (UTHR). Total pre–farm and on–farm emissions for 1 tonne of rice production amounted to 1.11, 1.19, 1.33 and 1.57 tonne CO_2–eq for UTLR, UTHR, CTLR and CTHR, respectively, in the 100-year time horizon. For all four treatments, the predominant GHG emission was soil CH_4 (comprising 60-67% of the total) followed by emission from on-farm machinery use. The UTLR was the most effective GHG mitigation option (it saved 29% of the total GHG emissions in comparison with CTHR) in wetland rice production. N_2O emission contributed 2–3.5% to the total on–farm GHG emitted for rice production of which the lowest portion was shared by UTLR and UTHR. The UTLR reduced both CH_4 and N_2O emissions simultaneously. The novel minimum tillage establishment approach for rice followed by UT has potential to increase global warming mitigation of wetland rice in the EGP, but further research is needed to assess the contributions of N_2O in the LCA of rice production in other similar rice growing areas.

Key words: Barind area, Global warming mitigation potential, Puddling, Rice based cropping systems, Unpuddled transplanting

Introduction
In flooded paddy soils, N_2O can be produced via nitrification in the oxidised layer just below the soil surface; N_2O can also be produced via denitrification in the lower reduced layer (Patrick et al. 1985). Wassmann et al. (2004) found that measures to reduce CH_4 emissions often lead to increases in N_2O emissions, and this compromise between CH_4 and N_2O is a major impediment in reducing GWP of wetland rice. Ideal strategies would reduce emissions of both CH_4 and N_2O simultaneously. The recent development of UT of rice (Haque et al. 2016) together with residue retention using bed planting, or strip tillage, as a form of conservation agriculture (CA) for rice establishment (Malik et al., 2009), need to be assessed in terms of relative effects on emissions of CH_4 and N_2O and on GWP mitigation.
The foremost source of N_2O are those that add nitrogen to soils, such as crop establishment practices, increased organic and synthetic fertilizer use, residue and water management. These activities increase the amount of nitrogen (N) available for nitrification and denitrification, and ultimately an amount of N_2O emits (IPCC, 2013). Direct and indirect emissions from agricultural systems are now thought to contribute approximately 35% of the total global source strength (17.7 Tg N_2O-N yr^{-1}; Kroeze et al., 1999). Some studies have attempted to quantify N_2O emissions induced by crop establishment practices, water and fertilizer management (Zou et al. 2009) in comparison with background N_2O emissions from rice paddies; however, they exhibit wide variations (Zheng et al., 2004). Some studies suggested that crop establishment practices with increased residue retention increased CH_4 and N_2O emissions, while others reported that CH_4 and N_2O emissions decreased with them (Zou et al. 2005), so further study is recommended.
Integration of CA into rice–based triple cropping systems in the EGP face challenges. The recently developed UT of rice, which is suitable for CA, has performed well in yield, financial returns, soil quality) and fuel consumption (2 to 3 times lower) (Haque et al., 2016), but has not been examined for its effects on GWP. A LCA analysis of the new UT rice production technology can estimate its potential contribution to GWP (Blengini and Busto, 2009). The present study was carried out to: assess the contributions of N_2O to life cycle GHG emissions for CT and UT with crop residue retention levels; determine the hotspots contributing

significantly to the GHG emissions within the system boundaries by a LCA study, and identify the causes for the predominant GHG emissions during the pre– and on–farm stages of rice production.

Materials and methods

A detailed description can be found in Alam et al. (2016). The study was conducted in Northwest Bangladesh at Alipur village, Durgapur upazilla, Rajshahi division on the Eastern Gangetic plain (EGP). Greenhouse gas emissions from a rice crop were calculated (in carbon dioxide equivalents; CO_2-eq) for four farming practices in the EGP: 1. Conventional puddled transplanting (CT) with low residue retention (LR- current farmer practice for this region which involves keeping about 20% of the standing rice crop residue in the field during harvesting of crops); 2. Conventional puddled transplanting (CT) with high residue retention (HR- retention of 50% of standing rice residue and all residues of other crops after harvesting); 3. Un-puddled transplanting (UT) with low residue retention (LR); and 4. Un-puddled transplanting (UT) with high residue retention (HR). A streamlined LCA approach was adopted, considering cradle-to-farm gate GHG emissions. The system boundary consists of pre–farm and on–farm life cycle stages. The input and output data of these life cycle stages for producing one tonne of rice are then quantified to form life cycle inventories for CT and UT with LR and HR retention. Pre-farm GHG emissions include all activities for producing farm inputs (chemicals, energy and machinery) and the emissions from the transportation of inputs to the rice field. Emission factors for all inputs and their transportation to field and for on-farm emissions were calculated. Soil emissions of CO_2, CH_4 and N_2O were quantified at the experimental site using closed chambers. Global warming impact values were expressed over 100-year time horizons. Individual GHG (CO_2, CH_4 and N_2O) emissions from each production stage were converted to CO_2-eq using established conversion factors. All data regarding CO_2–eq emissions were statistically analysed with SPSS software package version 21 a two–factor analysis of variance.

Results and discussion

The total GHG emissions from 1 tonne of rice production followed the ascending order: CTHR<UTHR<CTLR<UTLR ($p<0.05$) (Figure 1). For all four treatments, the on-farm stage contributed 89–93% of the total greenhouse gas emissions due to farm machinery use and soil emissions during wetland rice production (Figure 2). The CH_4 emission from paddy fields was the most predominant portion of GHG emissions in all treatments/practices, comprising 60 (UTLR practice)–67% (CTHR practice). The farm machinery use made up the second largest emission (13–16% of total) followed by soil CO_2 emissions (9–10%), input productions (6–9%) and transportation (2–3%) (Figure 2). The greenhouse gas emissions varied from 1.11-1.57 tonne CO_2-eq in the 100-year horizon (Figure 1). The CTHR practice emitted about 1.4 times more GHG emissions for 1 tonne of rice production than the best mitigation option, the unpuddled method (UTLR) due to emission of the least CH_4. Although UTLR performed better in terms of total GHG emissions per tonne of rice, higher CH_4 emissions under UTHR outbalanced the yield benefits with the practice.

The soil N_2O emissions comprised only 2–3% of total emissions for different treatments (Figure 2). The UTLR emitted the lowest N_2O under on-farm conditions which was followed by UTHR, CTHR and CTLR, respectively (Figure 1). However, the present value (0.2 in CTLR to 0.1 in UTHR) is lower than the default value (1%) of N_2O loss from mineral N applied as fertilizer used by the IPCC (2013). The N use efficiency was expected to be high due to well-controlled continuous flooding of soil to minimise N loss through leaching and volatilization (Bandyopadhyay et al., 2009). Previous measurements of soil strength at this site (M. A. Islam, personal communication) indicate the presence of a plough-pan that would restrict N leaching to deeper soil layers (Patil and Das, 2013). Little of the fertilizer-derived NH_4^+-N would be oxidised biologically to NO_3-N under the prevailing anaerobic soil conditions which would lower the risk of NO_3-N leaching and N_2O production due to denitrification (Savant and de Datta, 1982). These rice soils also contain clay minerals such as illite or vermiculite (Moslehuddin et al., 2009) which immobilise NH_4^+-N through fixation (Allison et al., 1953) leading to low rates of NH_3 volatilisation.

Conclusions

In the EGP, applying UTLR in the wetland rice system can reduce GHG emissions by 1.11 tonne CO_2-eq per tonne rice production (100-year time horizon). The on–farm stage contributed 89– 93% in 100 years of the total GHG emissions due mostly to high GHGs emission and to farm machinery use. Irrespective of tillage or residue retention, CH_4 was the predominant GHG emitted from the production of 1 tonne of rice with N_2O contributing only 2-3 % of the total. The novel UT has, therefore, potential to decrease global warming emissions of wetland rice grown in the EGP. We recommend carrying out additional streamlined LCA for all crops in the rice-based cropping system to understand the contributions of N_2O in LCA GHGs of agriculture production practices in diversified rice growing areas.

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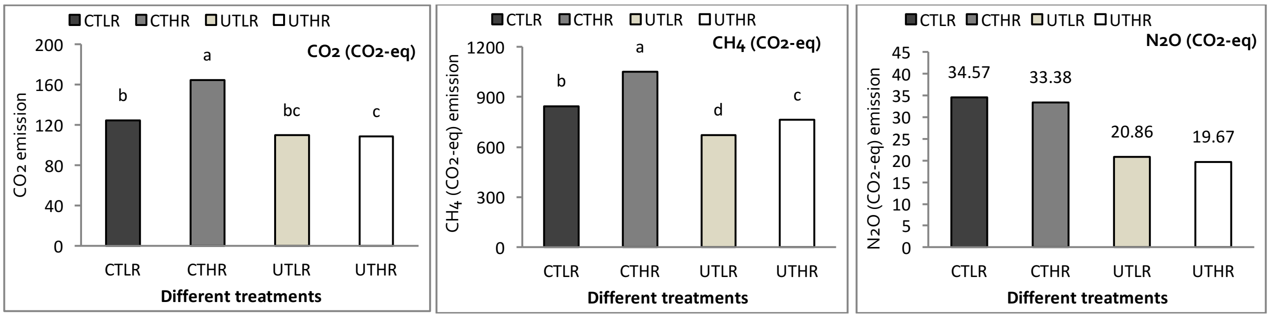

Fig. 1. Effect of rice establishment techniques and residue retention on on-farm emission of GHG (CO_2 equivalent; $p < 0.05$). Bars with the same letter above them are not significantly different at $p < 0.05$. Comparisons are made among emissions converted to CO_2-eq according to GWPs of CO_2, CH_4 and N_2O over 100-year time horizon. SE (±) for CO_2 emission is 4.7 for CH_4 are 43.5 and for N_2O is 0.2 over 100-year time horizons, respectively. [Legend: CTLR–puddled transplanting with low residue retention; CTHR– puddled transplanting with high residue retention; UTLR–unpuddled transplanting with low residue retention and UTHR–puddled transplanting with high residue retention].

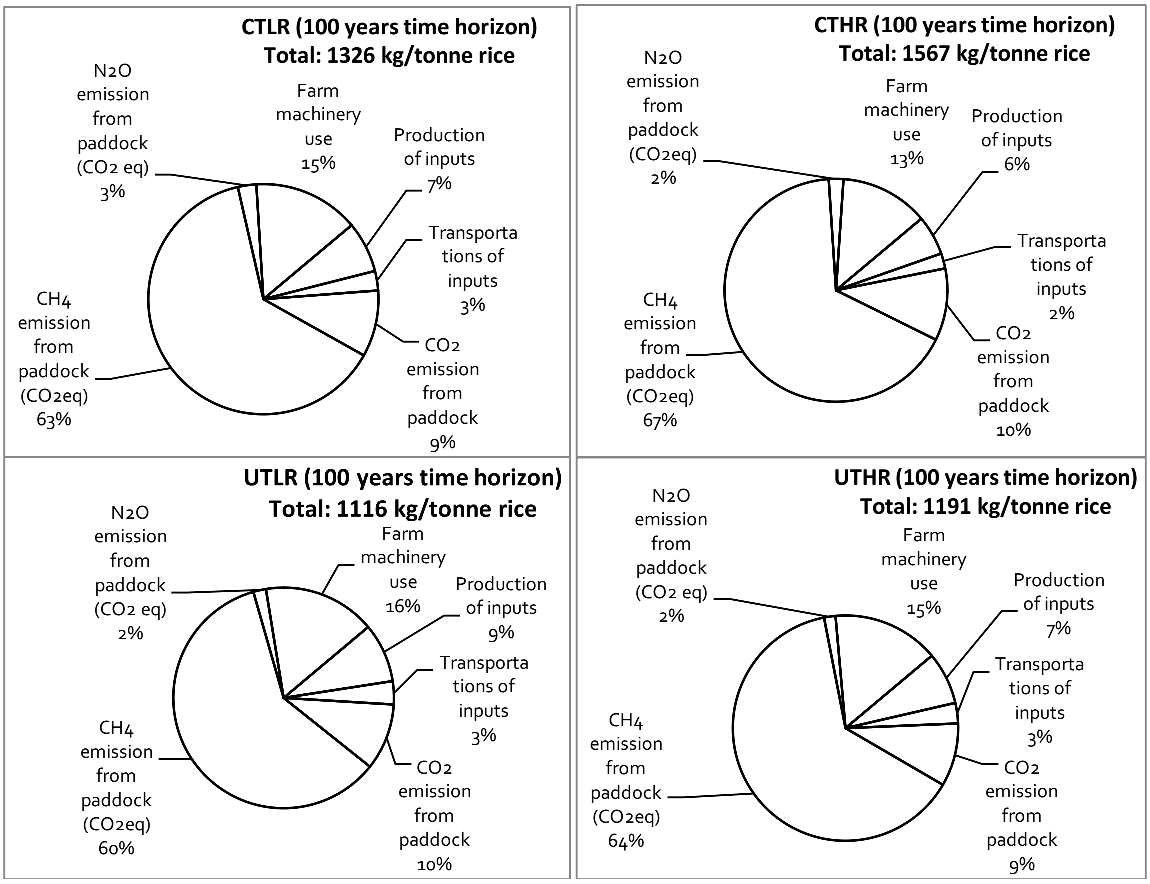

Fig. 2. Percentage contributions to GHG emissions (CO_2 equivalents) in terms of inputs and outputs for one tonne of paddy production as influenced by crop establishment techniques and residue retention. [Legend: CTLR–puddled transplanting with low residue retention; CTHR–puddled transplanting with high residue retention; UTLR–unpuddled transplanting with low residue retention and UTHR–puddled transplanting with high residue retention]