Global warming potential and its cost of mitigation from maize (Zea mays) - wheat (Triticum aestivum) cropping system

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ABSTRACT

The maize (Zea mays L.) - wheat (Triticum aestivum L.) cropping system (MWCS) could be better alternative to rice-wheat cropping system (RWCS), due to its lower water requirement, methane (CH4) emission and soil degradation. However, the global warming potential (GWP), greenhouse gas intensity (GHGi) and benefit cost ratio (BCR) of the MWCS need to be quantified in order to propose management practices for GWP mitigation. To achieve the objective of the study a field experiment was conducted at the ICAR-IARI, New Delhi during 2012–14. The experiment consisted of six treatments, viz. N0 (control), Urea, Urea+FYM, FYM, Urea+NI (nitrification inhibitor) and NOCU (neem oil coated urea). Two-year average results showed that as compared to urea treatment, GWP of MWCS lowered by 6, 16, 31 and 62% in urea+NI, NOCU, Urea+FYM and FYM, respectively. GHGi lowered by 6, 6, 24 and 46% in urea+NI, NOCU, Urea+FYM and FYM, respectively. The BCR was higher in NOCU and Urea+NI as compared to urea treatment; however, it was lower in FYM and urea+FYM. Thus, NOCU is capable for mitigating GWP and lowering GHGi with higher BCR from MWCS.

Key words: Cost benefit analysis, Global warming potential, GHG intensity, Maize-wheat cropping system

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The rice (Oryza sativa L.) - wheat (Triticum aestivum L.) cropping system (RWCS) is covering 10.5 (53%) mha area in Indo-Gangetic Plains (IGP) (Panigrahy et al. 2010) and produces 50% of the total food grain of the country (Dhillon et al. 2010). Recently, the sustainability of RWCS is questionable due to productivity stagnation, water table depletion and higher global warming potential (GWP) (Ladha et al. 2003). Rice had higher GWP with CH4 being the major contributing GHG (Sapkota et al. 2018). Therefore, the need is felt to diversify the RWCS to reduce its adverse impacts. The maize (Zea mays L.) - wheat cropping system (MWCS) could be a better alternative which is 3rd most important system after rice-wheat and rice-rice systems in India. Maize appears to be better alternative to rice. It is grown in aerobic condition and, therefore, CH4 emission is very low as compared to rice (Jain et al. 2016). However, it could be major source of nitrous oxide (N2O) emissions due to the larger amounts of nitrogen (N) application (Li et al. 2010). N2O is major contributor to the total GWP of wheat and maize cultivation in the region (Sapkota et al. 2018).

The higher N use and low N use efficiency (NUE) causing higher N2O emission from soils (Pathak et al. 2002, Fagodiya et al. 2017). The balanced N use, use of nitrification inhibitors (NIs), neem oil coated urea (NOCU) and farm yard manure (FYM) can mitigate the N2O emissions from soils (Bhatia et al. 2017). Most of the mitigation studies have largely focussed on the RWCS in the region (Jain et al. 2016, Gupta et al. 2016, Malyan et al. 2019). The economic analyses of many of these studies are lacking. Therefore, the study is required to quantify the GWP of the MWCS considering direct N2O and indirect CO2 emissions and to identify the management practices leading to its mitigation. The present study was conducted to assess the impacts of alternative N management on GWP, greenhouse gas intensity (GHGi) and benefit cost ratio (BCR) of MWCS in upper IGP of India.

MATERIALS AND METHODS

A field experiment was conducted at the ICAR-IARI, New Delhi for two years (2012–14). It comes under alluvial tract of the IGP and located at 28°38′ N lat., 77°09′ E long. The climate of the region is sub-humid and sub-tropical type with cold winter and hot dry summer. The average
rainfall of the region is about 750 mm, most of which occurs during monsoon. The details of the experimental weather condition and soil parameters are given in Fagodiya et al. (2019). The experiment was carried out in randomized block design (RBDD) with six treatments and three replications. The treatments were: (1) control (N0), i.e. without nitrogen, (2) urea (120 kg N/ha); (3) urea (60 kg N/ha) + FYM (60 kg N/ha); (4) FYM (120 kg N/ha); (5) Urea (108 kg N/ha) + NI (nitrification inhibitor) (12 kg N/ha); and (6) neem oil coated urea (NOCU) (120 kg N/ha). The size of the individual plot was 25 (5 × 5) m². The dicymometrine (DCD) is used as a NI. The FYM (0.52% N) was applied 10 days before sowing of each crop. Total 58 and 29 kg/plot FYM was applied in FYM, and urea + FYM treatments, respectively.

The experiment was started with sowing of wheat (WR-544) on 08 December, 2012 followed by maize (Pusa Composite-3) on 26 July, 2013 during 2012–13. During 2013–14, the sowing of wheat and maize was done on 07 December, 2013 and 7 July, 2014, respectively. Wheat sowing was done with 20 cm row spacing. While, maize sowing was done at 60 cm row spacing. The half nitrogen (60 kg N/ha) was applied as basal dose. The remaining half nitrogen was top dressed twice in equal amount. Top dressing was done at crown root initiation (CRI) and maximum tillering stage in wheat, and at knee height and tasselling stage in maize. The single superphosphate (SSP) and muriate of potash (MOP) were applied at the time of sowing for P (@60 P2O5 kg/ha) and K (@60 K2O kg/ha) requirement. Irrigation was done as and when required. The need-based hand weeding was also done. Crops were manually harvested from total plot area at physiological maturity stages. Wheat was harvested on 09 April 2013 and 2014, while maize was harvested on 23 and 7 October in 2013 and 2014 respectively. The grains were separated manually from the straw and air dried, and weighed for estimation of grain yield.

The net global warming potential (GWP) in terms of CO2-eq emissions was estimated considering direct N2O emissions from soils and indirect CO2 emissions from manufacturing and transportation of N fertilizers, electricity/diesel consumption for pumping of groundwater for irrigation, diesel fuel consumption for farm operations and transportation of bulky FYM. The GWP was calculated as (Gao et al. (2015) and Guardia et al. (2016)):

\[
\text{Net GWP} = 298 \times \text{N}_2\text{O} (=\text{kg/ha}) + 8.30 \times \text{N rate (kg/ha)} + 1.30 \times \text{Electricity (kWh/ha)} + 3.93 \times \text{Diesel fuel (kg/ha)}
\]

where, 298 is the conversion factor for N2O to CO2-eq over a 100-year time period (IPCC 2014); 8.30, 1.30 and 3.93 are the CO2-eq emissions coefficients related to N fertilizer manufacturing and transportation (Zhang et al. 2013), generation of electricity used for pumping of ground water (Zhang et al. 2013), and diesel fuel consumption for farm operations and transportation of bulky FYM (Huang et al. 2013), respectively. The gas samples were collected using close chamber techniques (Pathak et al. 2002) and N2O was analysed by a Gas Chromatography. The details of cumulative N2O emissions for every treatment for both the crops during both the years were published as Fagodiya et al. (2019). The greenhouse gas intensity (GHGI), related to grain yield and GWP was calculated by GWP divided by grain yield as:

\[
\text{GHGI (kg CO}_2\text{-eq/kg grain yield)} = \frac{\text{GWP (kg CO}_2\text{eq/ha)}}{\text{grain yield (kg/ha)}}
\]

The cost of cultivation was estimated considering the cost of seed, fertilizers, energy and the hired human labour. The cost of cultivation and energy were calculated as per Gupta et al. (2016). Total gross income was calculated by totaling the income from selling of grains, crop residues and the environmental benefits arising from N2O mitigation. Total income was calculated by using equation (3). The benefit cost ratio (BCR) was calculated using equation (4)

\[
\text{Benefit cost ratio (BCR)} = \frac{\text{Gross income (₹/ha)}}{\text{Total cost (₹/ha)}}
\]

RESULTS AND DISCUSSION

Grain yield: Two-year average productivity of MWCS ranged from 3.3±0.3–7.3±0.1 t/ha and 3.0±0.3–6.9±0.4 t/ha during the 2012–13 and 2013–14, respectively (Table 1). As compared to urea treatment higher productivity was reported in Urea+NI and NOCU. This might be due to slow release of nitrogen (Bhatia et al. 2010). The system productivity of Urea+FYM was at par with the urea treatment which might be due to immediate release and availability of nutrients. The system productivity was significantly lowered by 17 and 37% in FYM during 2012–13 and 2013–14, respectively. It has been due to slow release of nutrient during the initial periods of FYM application (Mahmood et al. 2017, Fagodiya et al. 2017). It represents that the FYM alone cannot be substitute for chemical fertilizers (Meena et al. 2018). However, in the long-term FYM studies the
Global warming potential (GWP) of MWCS varied from 700–3262 and 702–3286 kg CO$_2$-eq/ha during 2012–13 and 2013–14, respectively (Table 1). In NOCU and Urea+NI treatments, GWP lowered by 4–5% and 6–7%, respectively as compared to urea treatment. However, in FYM+Urea and FYM, the GWP lowered by 30–31% and 61–62%. The share of direct N$_2$O and indirect CO$_2$ in GWP varied from 21–43% and 57–79%, respectively (Fig 1). In urea, NOCU and urea+NI, the indirect CO$_2$ contributed 73, 76 and 79% respectively which is mainly due to indirect CO$_2$ emission during the fertilizer manufacture and transportation (Zhang et al. 2013). The GWP of MWCS was in the order of NO < FYM < Urea+FYM < Urea+NI < NOCU < Urea. It indicates that the application of FYM along with fertilizers could be a highly efficient low carbon emission technology.

Greenhouse gas intensity (GHGi) ranged from 0.25–0.55 and 0.16–0.42 kg CO$_2$-eq/kg grain in wheat and maize (Table 1). The GHGi in this study lowered than the earlier estimates (Jain et al. 2016, Gupta et al. 2016). It is because we considered the GWP of direct N$_2$O and indirect CO$_2$ emission. However, in earlier estimates authors used GWP of N$_2$O and CH$_4$ emissions. The GHGi of wheat was higher than maize and this may be attributed to higher crop growth duration and lower yield of wheat as compared to maize. The GHGi lowered significantly in FYM and Urea+FYM treatments as compared to urea and varied from 0.21–0.30 and 0.33–0.37, respectively. It indicates that the use of FYM can significantly reduce the GHGi. The use of NI and NOCU can also reduce the GHGi.

Cost-benefit analysis: In both wheat and maize, the cost for hiring human labour were highest followed by cost of tractor operations, and cost of fertilizers and FYM (Fig 2). During 2012–13, hiring human labour, tractor operations, and fertilizer and FYM contributions in total cost ranged from 34–36%, 11–20% and 13–16%, respectively in wheat, and 44–49% 11–19% and 13–15% in maize. During 2013–14, it ranged from 34–37%, 11–19% and 13–15% in wheat, and 43–48%, 11–20% and 13–15% in maize.

In wheat crop, cost of cultivation in Urea+NI, Urea+FYM and FYM treatments was higher by 6%, 10% and 16% during 2012–13 and 4%, 7% and 13% in 2013–14 as compared to urea treatment (Table 2). In maize crop the cost of cultivation was higher by 6%, 13% and 21% during 2013 and 6%, 12% and 19% during 2013 in Urea+NI, Urea+FYM and FYM treatments, respectively. These differences in Urea+FYM and FYM treatments may
be attributed to more human labour and tractor operations during handling of the bulky FYM, while in Urea+NI was due to higher price of NI. The benefit cost ratio (BCR) of the maize-wheat systems ranged from 0.86–1.53 during 2012–13, and 0.77–1.48 during 2013–14. In Urea+FYM, FYM and Urea+NI the BCR lowered significantly. The lower BCR in FYM was due to higher cost of labour and tractor operations, and lower crop productivity. The BCR of different treatments were in order of FYM < NO < Urea+FYM < Urea+NI < Urea = NOCU during 2012–13 and NO < FYM < Urea+FYM < Urea+NI < Urea < NOCU.

The complete replacement of urea with NOCU can reduce both the GWP and GHGi of the MWCS. Application of NOCU is helpful in reducing the cost of cultivation with

Fig 1 Share of direct N\textsubscript{2}O and indirect CO\textsubscript{2} emission to GWP of maize-wheat system. a) 2012–13 and b) 2013–14. Mean with different letter(s) in a column are significantly different (P<0.05) (Tukey’s).

Fig 2 Share of different factors in total cost of cultivation of maize-wheat system. a) wheat and b) maize crop.
higher income which ultimately enhances the BCR. Use of NI with urea application, 50% and 100% replacement of urea with FYM can also reduce the GWP and GHGi of the MWCS. However, the 50 and 100% replacement of urea may not be economical viable during the initial years of the FYM application. However, in long term it may also enhance the crop yield. Thus, the application of NOCU and use of NIs with urea are capable for mitigating the GWP and GHGi of the MWCS with the immediate effect. In long-term approach the 50 and 100% replacement of urea with FYM may also be better option for mitigating the GWP and GHGi with higher BCR.

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