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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 (CH_4) 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

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 CH_4 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, CH_4 emission is very low as compared to rice (Jain *et al.* 2016). However, it could be major source of nitrous oxide (N_2O) emissions due to the larger amounts of nitrogen (N) application (Li *et al.* 2010). N_2O 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 N_2O 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 N_2O emissions from soils (Bhatia *et al.* 2010). 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 N_2O and indirect CO_2 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

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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 (RBD) 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) m^2. The dicyandiamide (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 P_2O_5 kg/ha) and K (@60 K_2O 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 CO_2-eq emissions was estimated considering direct N_2O emissions from soils and indirect CO_2 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)):

$$\text{Net GWP} = 298 \times N_2O\ (\text{kg/ha}) + 8.30 \times \text{N rate (kg/ha)} + 1.30 \times \text{Electricity (kWh/ha)} + 3.93 \times \text{Diesel fuel (kg/ha)} \quad (1)$$

where, 298 is the conversion factor for N_2O to CO_2-eq over a 100-year time period (IPCC 2014); 8.30, 1.30 and 3.93 are the CO_2-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 N_2O was analysed by a Gas Chromatography. The details of cumulative N_2O 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:

$$\text{GHGi (kg } CO_2\text{-eq/kg grain yield)} = \frac{\text{GWP (kg } CO_2 \text{ eq/ha)}}{\text{grain yield (kg/ha)}} \quad (2)$$

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 N_2O mitigation. Total income was calculated by using equation (3). The benefit cost ratio (BCR) was calculated using equation (4)

$$\text{Gross income (₹/ha)} = [\text{Grain yield (kg/ha)} \times \text{MSP of grain ((₹/kg))}] + [\text{Straw yield (kg/ha)} \times \text{market price of straw ((₹/ha))}] + [N_2O \text{ mitigation (kg/ha)} \times \text{cost of climate change ((₹/kg N))}] \quad (3)$$

$$\text{Benefit cost ratio (BCR)} = \text{Gross income (₹)/Total cost (₹)} \quad (4)$$

The minimum support price (MSP) of maize and wheat in the particular year offered by CACP, Government of India was used to calculate the income from grain. The market prices of crop straw were taken from Gupta *et al.* (2016). The monetary values of environmental benefits arise from N_2O mitigation was as per the Qiao *et al.* (2015). The cost of climate change is taken from the Kusiima and Powers (2010). Net income was calculated as the difference between gross income and total cost of cultivation.

Data were analyzed by using SPSS (version 21) software, IBM, USA. The analysis of variance (ANOVA) for Randomized Block Design using with Tukey's test at 5% level of significance was carried out to test whether the differences between treatment means were statistically significant or not.

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

Table 1 Grain yield, global warming potential (GWP) and greenhouse gas intensity (GHGi) of maize-wheat system under different nitrogen treatments

Treatment	Grain yield (t/ha)					
	Wheat		Maize		Maize-wheat system	
	2012–13	2013–14	2013	2014	2012–13	2013–14
NO	1.8±0.3b*	1.5±0.1d	1.6±0.2d	1.5±0.3b	3.3±0.3c	3.0±0.3c
Urea	3.4±0.6a	3.2±0.1a	3.9±0.1a	3.7±0.2a	7.1±0.5a	6.8±0.1a
Urea + FYM	3.1±0.3a	3.0±0.1b	3.4±0.2b	3.3±0.5a	7.1±0.5a	6.2±0.1a
FYM	2.2±0.3b	2.3±0.1c	2.0±0.1c	2.0±0.2b	5.9±0.2b	4.3±0.1b
Urea + NI	3.5±0.3a	3.2±0.1a	4.0±0.3a	3.8±0.1a	7.2±0.3a	6.7±0.8a
NOCU	3.5±0.1a	3.2±0.1a	3.9±0.2a	3.7±0.4a	7.3±0.1a	6.9±0.4a
			GWP (kg CO_2-eq/ha)			
NO	440±10e*	441±6e	260±118e	261±9f	700±10f	702±5f
Urea	1727± 19a	1730±8a	1535±15a	1556±19a	3262±15a	3286±18a
Urea + FYM	1233±12c	1222±13c	1043±14c	1045±20d	2276±18d	2268±21d
FYM	729±15d	723±29d	527±21d	529±14e	1256±10e	1253±42e
Urea + NI	1622±19b	1614±16b	1459±15b	1456±13c	3082±32c	3070±29c
NOCU	1653±13b	1642±14b	1493±7b	1492±11b	3147±13b	3134±5b
			GHGi (kg CO_2/kg grain)			
NO	0.25±0.05c*	0.29±0.02d	0.16±0.05d	0.18±0.04b	0.21±0.02c	0.24±0.03d
Urea	0.52±0.08a	0.55±0.02a	0.39±0.02a	0.42±0.03a	0.46±0.04a	0.49±0.02a
Urea + FYM	0.40±0.04ab	0.41±0.01c	0.31±0.02b	0.34±0.05a	0.33±0.02b	0.37±0.06bc
FYM	0.33±0.04bc	0.31±0.01d	0.26±0.01c	0.27±0.03b	0.21±0.01c	0.30±0.02cd
Urea + NI	0.47±0.04a	0.51±0.01b	0.37±0.02a	0.38±0.01a	0.43±0.02a	0.46±0.01ab
NOCU	0.47±0.02b	0.50±0.01b	0.38±0.02a	0.40±0.05a	0.43±0.01a	0.46±0.03ab

Mean with different letter (s) in a column are significantly different ($P<0.05$) (Tukey's). * Mean ± SD.

system productivity could be at par or higher than chemical fertilizers (Kundu *et al*. 2006).

Global warming potential: 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_2O 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 GWPs 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: 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_2O and indirect CO_2 emission. However, in earlier estimates authors used GWP of N_2O 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 13–16%, respectively 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

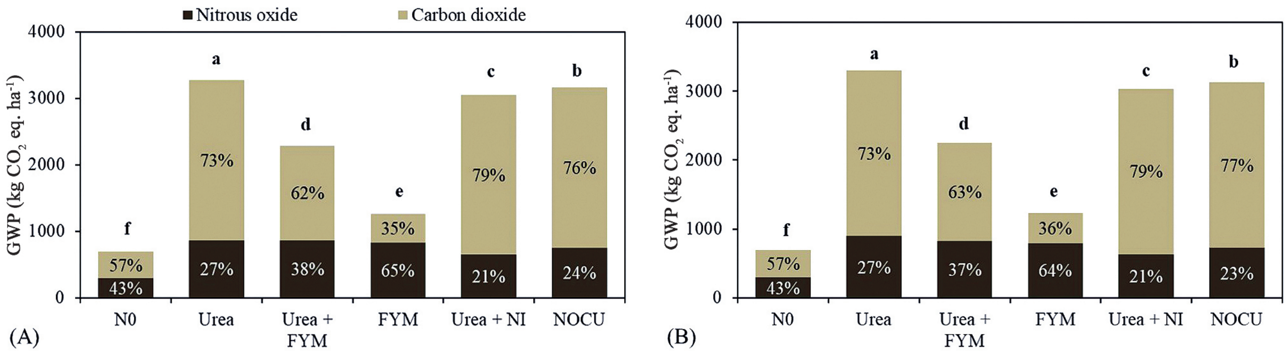

Fig 1 Share of direct N_2O and indirect CO_2 emission to GWP of maize-wheat system. a) 2012–13 and b) 2013–14. Mean with different letter (s) in a column are significantly different (P<0.05) (Tukey's).

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

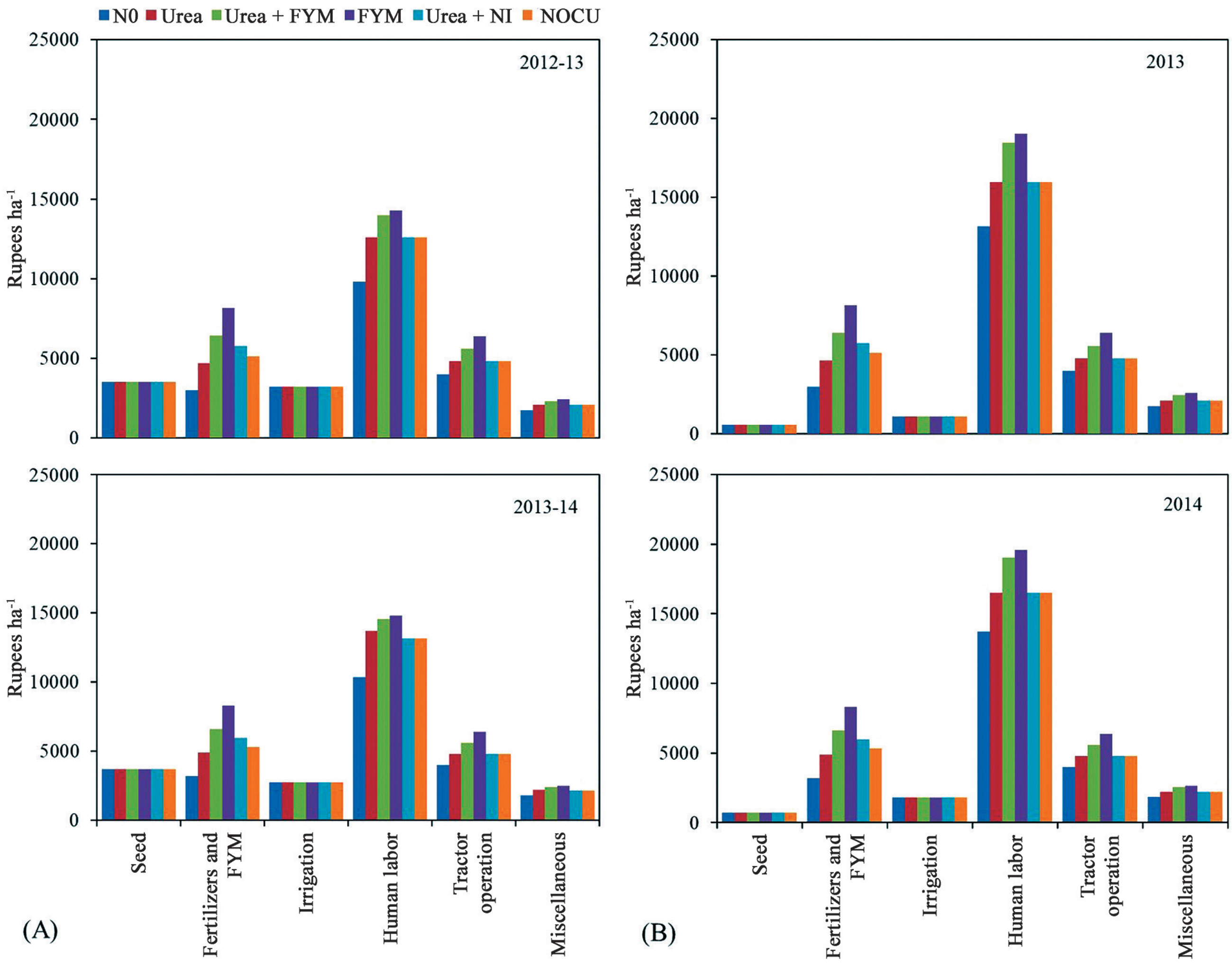

Fig 2 Share of different factors in total cost of cultivation of maize-wheat system. a) wheat and b) maize crop.

Table 2 Cost of cultivation, total income and benefit cost ratio of maize-wheat system under different nitrogen treatments

Treatment	Cost (₹/ha)				Total income (₹/ha)			
	Wheat		Maize		Wheat		Maize	
	2012–13	2013–14	2013	2014	2012–13	2013–14	2013	2014
NO	27624±450e*	28982±720d	26648±623e	28467±456e	28264±455c	25184±689c	23127±795d	18894±450f
N120	34923±465d	36950±435c	33947±650d	35818±678d	51149±650a	49364±725a	54207±650a	54067±950d
Urea + FYM	38245±790b	39629±700b	38500±798b	40346±750b	51086±789a	49296±730a	47734±830b	60568±830a
FYM	40335±650a	41693±500a	40898±689a	42718±550	38402±329b	41972±356b	31140±570c	30187±570e
Urea + NI	36989±900b	38395±940bc	36013±578c	37879±329	52208±370a	50140±453a	55532±970a	55946±970c
NOCU	35810±700d	37221±723c	34834±829cd	36705±630	52638±825a	50772±623a	55319±650a	58536±650b

Treatment	Benefit cost ratio (BCR)					
	Wheat		Maize		Maize-wheat system	
	2012–13	2013–14	2013	2014	2012–13	2012–13
N0	1.02±0.01d*	0.87±0.01e	0.87±0.02c	0.66±0.02c	0.95±0.01e	0.74±0.01e
N120	1.46±0.01a	1.34±0.01a	1.60±0.04a	1.51±0.04b	1.53±0.01a	1.46±0.01b
Urea + FYM	1.33±0.01c	1.24±0.01c	1.24±0.03b	1.50±0.03b	1.29±0.01c	1.34±0.01c
FYM	0.95±0.01e	1.01±0.01d	0.76±0.02d	0.71±0.02c	0.86±0.01d	0.85±0.01d
Urea + NI	1.41±0.02b	1.31±0.02b	1.54±0.04a	1.48±0.02b	1.48±0.02b	1.39±0.01c
NOCU	1.47±0.01	1.36±0.01a	1.59±0.04a	1.59±0.50a	1.53±0.01a	1.48±0.01a

Mean with different letter (s) in a column are significantly different (P<0.05) (Tukey's). * Mean ± SD.

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.

REFERENCES

Bhatia A, Sasmal S, Jain N, Pathak H, Kumar R and Singh A. 2010. Mitigating nitrous oxide emission from soil under conventional and no-tillage in wheat using nitrification inhibitors. *Agriculture, Ecosystems and Environment* **136**: 247–53.

Dhillon B S, Kataria P and Dhillon P K. 2010. National food security vis-à-vis sustainability of agriculture in high crop productivity regions. *Current Science* **98**: 33–6.

Fagodiya R K, Pathak H, Bhatia A, Jain N, Gupta D K, Kumar A, Malyan S K, Dubey R, Radhakrishanan S and Tomer R. 2019. Nitrous oxide emission and mitigation from maize–wheat rotation in the upper Indo-Gangetic Plains. *Carbon Management* **10**(5): 489–99.

Fagodiya R K, Pathak H, Bhatia A, Kumar A, Singh S D, Jain N and Harith R. 2017. Simulation of maize (*Zea mays* L.) yield under alternative nitrogen fertilization using Infocrop-maize model. *Biochemical and Cellular Archives* **17**(1): 65–71.

Fagodiya R K, Pathak H, Kumar A, Bhatia A and Niveta J. 2017. Global temperature change potential of nitrogen use in agriculture: A 50-year assessment. *Scientific Reports* **7**: 44928; doi:10.1038/srep44928.

IPCC. 2014. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Working Group II Contribution to the Fifth Assessment Report. Cambridge University Press, Cambridge, UK and New York, NY USA.

Gao B, Ju X, Meng Q, Cui Z, Christie P, Chen X and Zhang F. 2015. The impact of alternative cropping systems on global warming potential, grain yield and groundwater use. *Agriculture, Ecosystems and Environment* **203**: 46–54.

Guardia G, Tellez-Rio A, Garcia-Marco S, Martin-Lammerding D, Tenorio J L, Ibanez M A and Vallejo A. 2016. Effect of tillage and crop (cereal versus legume) on greenhouse gas emissions and Global Warming Potential in a non-irrigated Mediterranean field. *Agriculture, Ecosystems and Environment* **221**: 187–97.

Gupta D K, Bhatia A, Das T K, Singh P, Kumar A, Jain N and Pathak H. 2016. Economic analysis of different greenhouse gas mitigation technologies in rice–wheat cropping system of the Indo-Gangetic Plains. *Current Science* **110**(5): 867–74.

Gupta D K, Bhatia A, Kumar A, Das T K, Jain, N, Tomar R, Malyan S K, Fagodiya R K, Dubey R and Pathak H. 2016. Mitigation of greenhouse gas emission from rice–wheat system of the Indo-Gangetic plains: Through tillage, irrigation and fertilizer management. *Agriculture, Ecosystems and Environment* **230**: 1–9.

Huang J X, Chen Y Q, Sui P and Gao W S. 2013. Estimation of net greenhouse gas balance using crop- and soil-based approaches: two case studies. *Science of the Total Environment* **456–457**: 299–306.

Jain N, Arora P, Tomar R, Mishra S V, Bhatia A, Pathak H, Chakraborty D, Kumar V, Dubey D S, Harit R C and Singh J P. 2016. Greenhouse gases emission from soils under major crops in Northwest India. *Science of the Total Environment*

542: 551–61.

Kundu S, Bhattacharyya R, Prakash V, Gupta H S, Pathak H and Ladha J K. 2006. Long-term yield trend and sustainability of rainfed soybean–wheat system through farmyard manure application in a sandy loam soil of the Indian Himalayas. *Biology and Fertility of Soils* **43**(3): 271–80.

Kusiima J M and Powers S E. 2010. Monetary value of the environmental and health externalities associated with production of ethanol from biomass feedstocks. *Energy Policy* **38**: 2785–96.

Ladha J K, Pathak H, Tirol-Padre A, Dawe D and Gupta R K. 2003. Productivity trends in intensive rice–wheat cropping systems in Asia. (In) *Improving the Productivity and Sustainability of Rice–Wheat Systems: Issues and Impacts*, pp 45–76.

Li H, Qiu J, Wang L, Tang J, Li C and Van Ranst E. 2010. Modelling impacts of alternative farming management practices on greenhouse gas emissions from a winter wheat–maize rotation system in China. *Agriculture, Ecosystems and Environment* **135**: 24–33.

Mahmood F, Khan I, Ashraf U, Shahzad T, Hussain S, Shahid M, Abid M and Ullah S. 2017. Effects of organic and inorganic manures on maize and their residual impact on soil physico-chemical properties. *Journal of Soil Science and Plant Nutrition* **17**(1): 22–32.

Malyan S K, Bhatia A, Kumar S S, Fagodiya R K, Pugazhendhi A and Duc P A. 2019. Mitigation of greenhouse gas intensity by supplementing with *Azolla* and moderating the dose of nitrogen fertilizer. *Biocatalysis and Agricultural Biotechnology* **20**: 101266; doi.org/10.1016/j.bcab.2019.101266.

Meena K B, Mohammad A S, Singh H, Mohammad A B, Singh A K, Mishra A K and Thomas T. 2018. Influence of farmyard manure and fertilizers on soil properties and yield and nutrient uptake of wheat. *International Journal of Chemical Studies* **6**(3): 386–90.

Panigrahy S, Upadhyay G, Ray S S and Parihar J S. 2010. Mapping of cropping system for the Indo-Gangetic plain using multi-date SPOT NDVI-VGT data. *Journal of the Indian Society of Remote Sensing* **38**(4): 627–32.

Pathak H, Bhatia A, Prasad S, Singh S, Kumar S, Jain M C and Kumar U. 2002. Emission of nitrous oxide from rice-wheat systems of Indo-Gangetic Plains of India. *Environmental Monitoring and Assessment* **77**: 163–78.

Qiao C, Liu L, Hu S, Compton J E, Greaver T L and Li Q. 2015. How inhibiting nitrification affects nitrogen cycle and reduces environmental impacts of anthropogenic nitrogen input. *Global Change Biology* **21**(3): 1249–57.

Sapkota T B, Aryal J P, Khatri-Chhetri A, Shirsath P B, Arumugam P, and Stirling C M. 2018. Identifying high-yield low-emission pathways for the cereal production in South Asia. *Mitigation and Adaptation Strategies for Global Change* **23**(4): 621–41.

Zhang W F, Dou Z X, He P, Ju X T, Powlson D, Chadwick D, Norse D, Lu Y L, Wu L, Chen X P, Cassman K G and Zhang F S. 2013. New technologies reduce greenhouse gas emissions from nitrogenous fertilizer in China. *Proceedings of the National Academy of Sciences of the United States of America* **110**: 8375–80.