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Tillage and nutrient management influence net global warming potential and greenhouse gas intensity in soybean-wheat cropping system

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Conservation tillage has proven advantageous in improving soil health and productivity. However, the greenhouse gases (GHGs) emission and intensity from different conservation tillage and nutrient management systems under Indian conditions are less understood. Therefore, here, we compared the effect of tillage and nutrient management on GHGs emissions, net global warming potential (NGWP), and greenhouse gas intensity (GHGI) from a field experiment under five years in a soybean-wheat cropping system in the Vertisols. The tillage treatments comprised of reduced tillage (RT) and no tillage (NT). The three nutrient management treatments included application of 100% NPK (T_1), 100% NPK + 1.0 Mg FYM-C ha^{-1} (T_2), 100% NPK + 2.0 Mg FYM-C ha^{-1} (T_3). The results showed significantly higher SOC sequestration under NT (1388 kg ha^{-1} yr^{-1}) followed by RT (1134 kg ha^{-1} yr^{-1}) with application of FYM (2.0 Mg C ha^{-1}) (T_3) every year. Across tillage, integrated nutrient management (T_2 and T_3) lowered NGWP and GHGI compared to NPK (T_1). The GHGI of NT system was less by 33% compared to RT. The results suggest that GHGs mitigation and sustained food production in the soybean-wheat system can be achieved in NT and RT with integrated use of organic and inorganic fertilizer as the major component of nutrient management.

Keywords: Climate change, Nitrous oxide flux, Methane flux, Soil carbon sequestration, Soil respiration, Vertisol

Climate change is a major threat to the Indian economy[1-2] and agriculture is an important source of GHGs emissions, accounting for approximately 24% of total anthropogenic emissions[3]. Tillage and nutrient management are the two key soil management practices that profoundly influence GHGs emissions[4-7] and soil organic carbon storage (SOC)[8-10]. Soil tillage could significantly influence the emission of nitrous oxide (N_2O) and methane (CH_4) from fertilizer applied soil[6-8], as tillage and nutrient management regulate different microbially mediated soil processes, viz., organic matter mineralization[10], nitrification, and denitrification[11], directly affecting the SOC storage and GHG emissions. Tillage physically alters the placement of crop residue in the soil profile[10]. These alterations in crop residue placement influence the decomposition of residue and nutrient release during mineralization[13,14]. Tillage is the primary mechanism by which soil is exposed to oxidation and thus loss of soil C[15]. Further, the tillage intensity before sowing a crop profoundly affects soil aggregation[16], water-filled pore space[16], and the concentration of oxygen and carbon dioxide in soil air[13,17] which directly affects the quantity of GHG emissions from soil. These changes in soil properties may influence gaseous N loss through denitrification and nitrification.

There are contradictory reports on the effect of tillage on soil carbon storage and GHG fluxes. Wetter soil conditions with crop residue on soil surface due to no-tillage may increase N_2O emissions[6,15]. Some studies have shown lower or no difference between tillage systems, even with higher soil moisture in no tillage[16]. Some studies reported that the increase in SOC is restricted to the topsoil layers (0-15 or 0-30 cm) for NT[17,18]. However, at lower depth, the difference among the tillage systems decreases because RT mixes and distributes residue C inputs and SOC to soil depths throughout the tillage zone[19,20]. The difference in reported results is due to the wide range of soil properties and prevailing diverse agro-climatic conditions in global coverage. Agricultural management systems can be compared using indices like net global warming potential (NGWP) and greenhouse gas intensity (GHGI). Previous studies in India have focused on measuring GHG emissions and nutrient management strategies to reduce GHG emissions from rice-wheat cropping systems[21-27].

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However, the studies on the response of GHG emission and soil carbon storage in soybean-wheat cropping systems, particularly in aerobic ecosystems of India, are still scarce[21,27]. Thus, detailed studies are needed to investigate the impact of tillage and nutrient management on SOC sequestration, NGWP, and GHGI. Soybean-wheat system is commonly practiced in the semi-arid to sub-humid tropical Malwa and Vindhyan plateau regions of Madhya Pradesh state in a land area of 2.30 million ha[27]. This belt contributes nearly 80% of the total soybean produced in India. In this study, we quantified the effect of tillage combined with different nutrient management practices on (i) GHGs flux; (ii) NGWP; and (iii) GHGI in the soybean-wheat cropping system.

Materials and Methods

The study was conducted at the research farm of the ICAR-Central Institute of Agricultural Engineering, Bhopal, Madhya Pradesh, India situated at 23^o 18’N latitude, 77^o 24’E longitude, and at 485 m above mean sea level. The region has a hot sub-humid climate with 920 mm of mean annual rainfall. The maximum temperature is greatest in May, with an average monthly maximum of 37.1°C (May), and the minimum temperature is lowest during January (10.4°C) (Fig. 1). Soils of the experimental area are non-calcareous Vertisol (Isohyperthermic Typic Haplustert), and predominately clay in texture (52% clay), neutral to alkaline in reaction (pH = 7.85), low in soluble salt content (0.50 dS m^{-1} in electrical conductivity), and Ca is the dominant exchangeable cation in the Ap horizon. Initial SOC content determined in the elemental analyzer was between 0.99 and 0.92% at the 0-15 and 15-30 cm soil depths. The cation exchange capacity of surface soil was 44.5 cmol (p^+) kg^{-1}. The NH_4^+ and NO_3^--N content in the surface soil was 5.25 and 5.60 ppm, respectively[9]. The soil bulk density (0-15 cm) was 1.34 mg m^{-3} at 0.27 g g^{-1} soil water content.

Flux measurement was performed during June 2012 to May 2013 in soybean (*Glycine max* L.) – wheat (*Triticum aestivum* L.) cropping system in the long-term tillage experiment initiated in July 2008[9]. The experimental treatment consisted of two tillage and three nutrient management practices, with three replications. Tillage treatment was taken as the main plot, and nutrient application as subplot. The two tillage treatments were no-tillage (NT, direct sowing by no till slit drill) and reduced tillage (RT, one pass rotavator and sowing by seed cum fertilizer drill) for both soybean and wheat. The three nutrient treatments were (1) 100% NPK only (T_1), (2) 100% NPK + FYM @ 1.0 Mg C ha^{-1} (T_2), and (3) 100% NPK + FYM @ 2.0 Mg C ha^{-1} (T_3). The FYM was analyzed for C content in the TOC analyzer every year before application and applied on dry weight basis two weeks before soybean sowing. The recommended doses of fertilizer applied were 30:60:30 kg in soybean and 100:60:30 kg N-P_2O_5-K_2O per ha in wheat to all the treatments. The N fertilizer was applied in split dose while 100% P and K was applied as basal. Recommended agronomic practices were carried out for both the crops. No major disease was observed in both the crops.

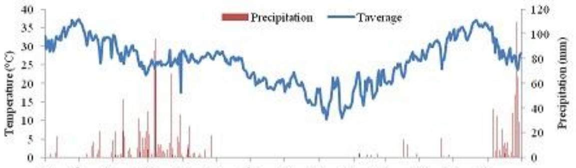

Fig. 1 — Mean daily air temperature and precipitation from May 2012 to June 2013

The static chamber technique was adopted for sampling methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2) using vented polyacrylic chambers of 71 × 46 × 15 cm (length × width × height) placed between crop rows[27]. The chambers were equipped with sampling port. The chamber base was embedded 5 cm into the soil for the duration of the study except during farm operations (tillage, soybean planting, and harvest). The gas in the chamber was drawn off using a syringe and immediately transferred into a 20 mL vacuum glass container. Gas samples were collected synchronously at 0, 30 and 60 min after sealing the chamber into the frame base. Sampling was done during noon to 2:00 pm on the sampling days.

The first gas sampling was made 1-2 days after basal fertilization and consecutively at frequent intervals throughout the growing seasons of soybean, wheat and also during the fallow period. From each plot, five samples were drawn which were considered as replicates and the average was taken as the representative value for that plot. The CO_2, CH_4 and N_2O concentrations were measured using a thermal conductivity detector, a flame ionization detector and an electron capture detector, respectively in a Gas Chromatograph (CIC, Vadodara)[23,27]. The gas emission flux was calculated from the difference in gas concentration according to the equation[27]:

$$F=\Delta C\left(\frac{V}{At}\right)\rho$$

where 'F' is the gas emission flux (mg m^{-2} h^{-1}), 'ρ' is the gas density at the standard temperature and pressure, ΔC is the change in concentration of gas (ppm in CO_2 and CH_4 and ppb in N_2O) inside the chamber, 't' is the time conversion factor. The negative fluxes of GHG indicate the uptake of a given gas by soil, and positive fluxes indicate the net emissions from soil. The weather data on daily rainfall and daily average temperature used for this study were recorded at the weather station of Central Institute of Agricultural Engineering farm, Bhopal. Soybean and wheat yields were determined from crop cutting of $1m^2$ area from two spots in each plot. The grains were separated from the panicle/pod, dried, and weighed. Grain moisture was determined immediately after weighing and subsamples were dried in an oven at 65°C for 48 h. After five years of experiment, at harvest of wheat in 2013 soil samples from each experimental plot were collected using a core sampler from 0-5, 5-15 and 15-30, 30-45 cm soil depth. The entire volume of soil was weighed and mixed thoroughly and a subsample was taken to determine dry weight. The fresh soil was air-dried for 7 days, sieved through a 0.5 mm sieve, mixed, and stored in sealed plastic jars for analyses. Soil samples were analyzed for soil organic carbon in TOC analyzer (Analytik Jena Inc.). From the analyzed data change in soil carbon (ΔSOC) was determined by using equation[9,19].

$$\Delta\, Soil\ Organic\ Carbon\ \left(\frac{\frac{Mg}{ha}}{yr}\right)=\frac{\text{Final} - \text{initial SOC storage}}{\text{Number of intervening years}}$$

where, SOC storage (Mg/ha) = SOC (%) × B.D. (Mg m^{-3}) × depth (cm)

Calculation of the NGWP was based on considering soil C sequestration (Δ soil C), emissions of GHG from soil (soil N_2O flux + soil CH_4 flux)[27].

NGWP = 28 × CH_4 + 265 × N_2O− (44/12) × SOC change (Mg CO_2eq ha^{-1})

GHGI is related to grain yield, as described in:
GHGI = NGWP/ yield (Mg CO_2eq Mg^{-1} grain yield)

The daily flux of CO_2, CH_4, and N_2O for each sampling date was analyzed using the GLM procedure available in SAS 9.2 for Windows (SAS Institute Inc., Cary, NC, USA) to detect the interactive effects of tillage and nutrient. Means were separated using Duncan's Multiple Range Test (DMRT). Unless indicated otherwise, differences were considered only when significant at P <0.05.

Results

Nitrous oxide (N_2O) fluxes

During the measurement period, N_2O flux was observed in all the treatments. Also, the temporal trend of N_2O flux in different treatments in the soybean crop season was similar to the corresponding flux pattern in the wheat growing season (Fig. 2). As compared to the initial period, the N_2O emission was 45-75% higher in the late growth period (after flowering) of soybean crop (Fig. 2). The peak of the N_2O flux was mostly observed in the fallow period after harvest of soybean and before sowing of wheat (Fig. 2). The two-way ANOVA indicated that seasonal cumulative N_2O emission was not significantly affected by tillage method (NT and RT) and the interaction of tillage and nutrient. However, integrated use of organic and inorganic fertilizer (T_2 and T_3) resulted in significantly higher N_2O emissions compared to inorganic fertilizer (T_1). Similar patterns of N_2O emissions were observed in wheat growing season except for few pronounced fluxes during fertilizer and irrigation application.

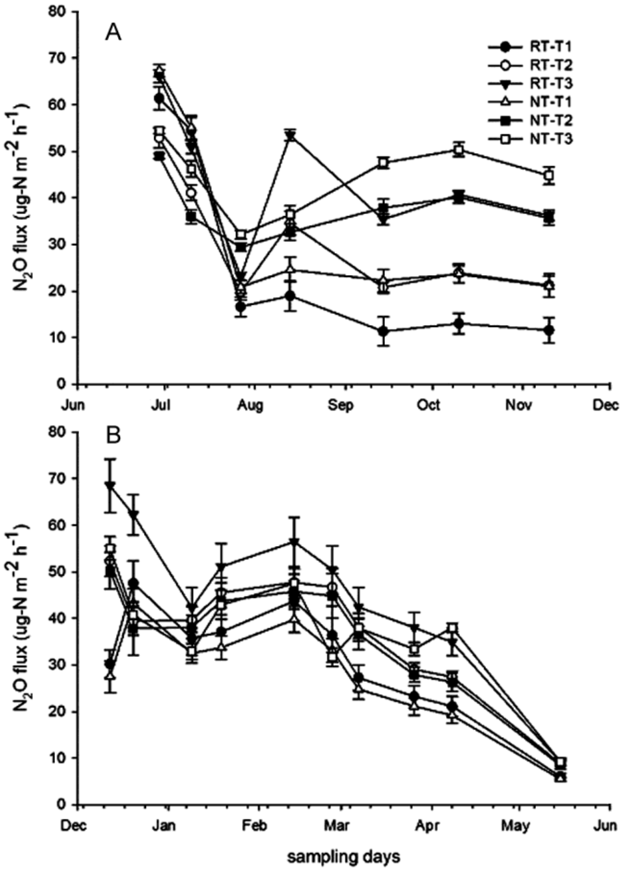

Fig. 2 — Effect of tillage and nutrient on soil N_2O emission in soybean and wheat after five years of experiment

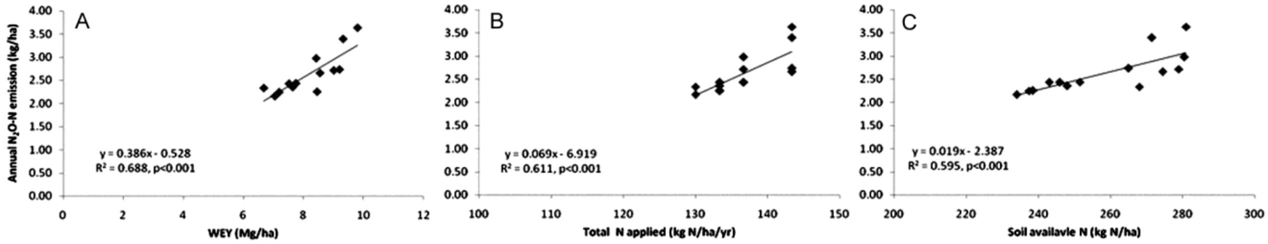

Fig. 3 — Correlation of annual N_2O emission to (A) wheat equivalent yield (WEY); (B) total N applied; and (C) soil available N

Table 1 — Effect of tillage and nutrient on cumulative seasonal and annual soil respiration (CO_2), GHG flux (N_2O, CH_4), and GWP in the soybean-wheat system after five years of experiment

Treat-ments	Soil resp. CO_2-C	CH_4-C flux	N_2O-N flux	Soil resp. CO_2	CH_4-C flux	N_2O-N flux	Annual soil resp. CO_2-C	Annual CH_4-C flux	Annual N_2O-N flux	GWP
	Soybean-fallow				Wheat- fallow		(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha/yr)
	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)				
RT-T1	1009c	–0.09a	0.85c	2614c	–0.18b	1.31c	3623cd	–0.27b	2.16c	890c
RT-T2	1360b	–0.10a	1.11b	3514b	–0.26b	1.61b	4875b	–0.36b	2.72b	1118b
RT-T3	1596a	–0.12a	1.66a	3989a	–0.40a	1.97a	5585a	–0.52a	3.63a	1493a
NT-T1	813c	–0.10a	1.15b	2454c	–0.31b	1.19c	3267d	–0.41ab	2.34bc	957c
NT-T2	946c	–0.10a	1.43a	3130b	–0.44a	1.54b	4076c	–0.54a	2.98b	1219b
NT-T3	1296b	–0.10a	1.73a	3481b	–0.46a	1.66b	4777b	–56a	3.39a	1392a

[Overall means followed by the same letter in each observation are not significantly different from each other (P <0.05; n=3). T1, 100% NPK; T2, 100% NPK+1.0 Mg FYM-C ha^{-1}; T3, 100% NPK+2.0 Mg FYM-C ha^{-1}; RT, reduced tillage; and NT, no tillage]

Table 2 — Effect of tillage and nutrient management on soybean, wheat, wheat equivalent yield, change in SOC, NGWP, and GHGI in the soybean-wheat system after five years of experiment

Treat-ments	Soybean yield (kg/ha)	Wheat yield (kg/ha)	Wheat equivalent yield (kg/ha)	Δ SOC (0-45 cm soil depth) (kg/ha/yr)	NGWP CO_2 eq. (kg/ha/yr)	GHGI (kg CO_2 eq. per kg yield)
RT-T1	1537b	4548c	7052bc	519.1d	–1013.1a	–143.7a
RT-T2	2163ab	5491b	9017a	616.7c	–1143.1a	–126.8a
RT-T3	2500a	5732a	9806a	1134.5ab	–2666.9c	–272.0b
NT-T1	1067c	4943bc	6682c	661.3c	–1467.3b	–219.6b
NT-T2	1757b	5566b	8428b	1047.8b	–2623.1c	–311.2c
NT-T3	2113a	5881a	9325a	1388.4a	–3699.2d	–396.7c

[Overall means followed by the same letter in each observation are not significantly different from each other (P <0.05; n=3). T1, 100% NPK; T2, 100% NPK+1.0 Mg FYM-C ha^{-1}; T3, 100% NPK+2.0 Mg FYM-C ha^{-1}; RT, reduced tillage; and NT, no tillage]

Basal fertilizer application together with first N top dressing resulted in a peak flux of N_2O in all the treatments. Overall, the annual total N_2O emissions ranged from 2.16 kg N ha^{-1} under RT-T_1 to 3.63 kg N ha^{-1} under RT-T_3 (Table 1).

Relationship between N_2O emission and Wheat equivalent yield (WEY)

The wheat equivalent yield (WEY) ranged from 6682 to 9806 kg/ha (Table 2). The N addition from inorganic fertilizer and FYM significantly increased the WEY. The annual N_2O emission was regressed with WEY by the relationship ‘y=0.386x-0.528’ (Fig. 3A). Thus, grain yield can be a sensitive predictor for N_2O emissions from soil under soybean and wheat crops when different management practices are considered. Annual N_2O emissions (y) increased linearly with amount of N (x) applied to soil through fertilizer and/or organic manures, according to the relationship y = 0.069x - 6.919 (r^2=0.611, P <0.001) (Fig. 3B). Increase in availability of soil N (x) also linearly increased annual N_2O emission (y), which was statistically significant (r^2=0.595, P <0.001) (Fig. 3C).

Methane (CH_4) production and consumption

The data showed soybean-wheat system in the Vertisol was a net sink of CH_4 (Fig. 4 and Table 1). All the treatments showed similar temporal patterns in the CH_4 fluxes in soybean and wheat growing seasons. Effect of tillage on CH_4 uptake was not significant in the soybean crop season, however, in wheat season, the NT system showed significantly higher CH_4 uptake than RT. Among the nutrient management treatments, the FYM treated plots (T_2 and T_3) had significantly higher CH_4 uptake than inorganic treatment (T_1) in wheat. The cumulative seasonal CH_4 uptake during soybean-fallow was the

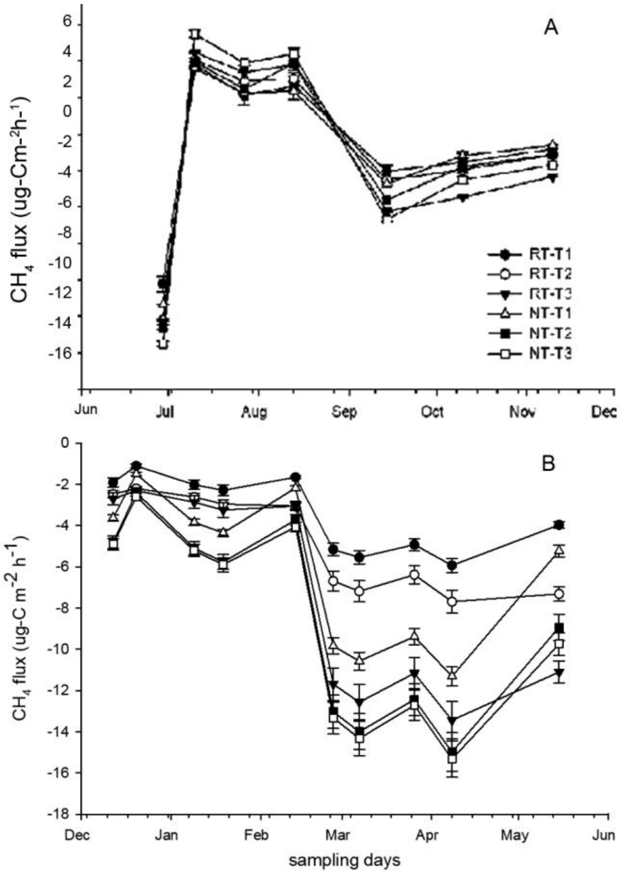

Fig. 4 — Effect of tillage and nutrients on soil CH_4 production and oxidation in soybean and wheat after five years of experiment.

highest in RT-T_3 (–0.12 kg ha^{-1}) and the lowest in RT-T_1 (–0.09 kg ha^{-1}) (Table 1). In wheat-fallow the cumulative seasonal CH_4 uptake was in the range of –0.18 (RT-T_1) to –0.46 (NT-T_3). Annual cumulative CH_4 uptake was significantly different between studied nutrient and tillage management treatments.

Ecosystem respiration during the two cycles of annual soybean-wheat rotation

The average soil CO_2 flux measured by the static chamber method is the total respiration, which includes the respiration of plant roots and soil microbes. The emission of CO_2, as expressed in terms of CO_2-C in the soybean crop, was significantly higher (Fig. 5) in RT as compared to NT plots across nutrient treatments. In the present study, the CO_2 flux of plots receiving FYM and chemical fertilizer (T_2 and T_3) was higher than the inorganic treatment (T_1) in both soybean and wheat crop periods. The cumulative seasonal CO_2 emission during soybean-fallow was the highest in RT-T_3 (1596 kg ha^{-1}) and the lowest in NT-T_1 (813 kg ha^{-1}) (Table 1). Similar pattern was also observed in wheat-fallow season.

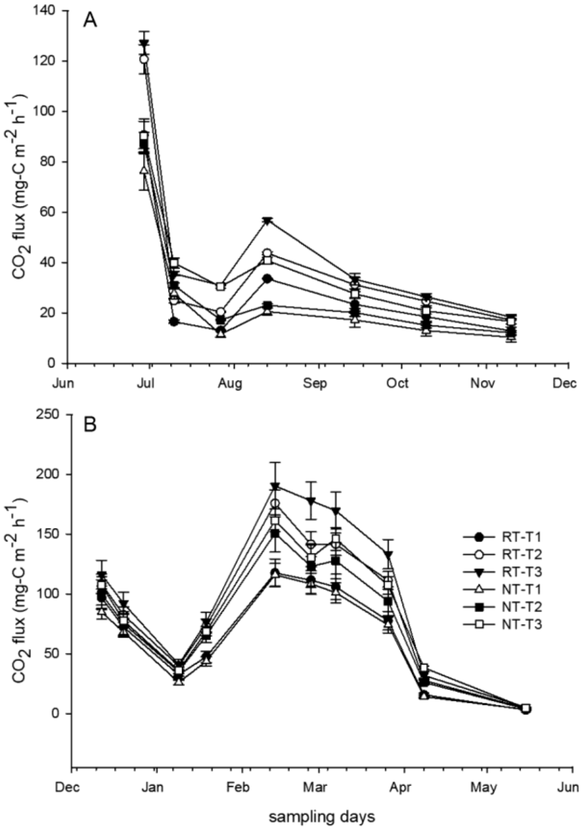

Fig. 5 — Effect of tillage and nutrients on soil CO_2 emission in soybean and wheat after 5 years of experiment.

Changes in soil organic carbon (SOC) storage and relationship with WEY

The effects of tillage and nutrient management were significant on SOC storage in the 0-45 cm soil depth (Table 1). As compared to inorganic treatment (T_1), the application of FYM with inorganic fertilizer (T_2 and T_3) significantly ($P < 0.05$) increased topsoil SOC (Table 2). After five years of experiment, the change in SOC stock (ΔSOC) rate in the topsoil followed the order, NT (1032.5 kg $ha^{-1}yr^{-1}$) > RT (756.8 kg $ha^{-1}yr^{-1}$). The ΔSOC rate in the topsoil of NT-T_3 was the highest and was significantly higher than the RT-T_3 treatments (Table 2). Changes in soil organic carbon (y) significantly correlated with net primary productivity, i.e. WEY (x) and the relationship worked out as ‘y=0.203x-0.862’ (r^2=0.534, P <0.01) (Fig. 6).

Net global warming potential (NGWP) and greenhouse gas intensity (GHGI)

The NGWP was estimated by net exchange of gases (i.e., N_2O and CH_4) and SOC changes (Table 1). Greenhouse gas intensity was computed to express the relationship between net GWP and wheat grain equivalent yield. The positive values expressed as kg CO_2 equivalents per kg of WEY indicate a net source

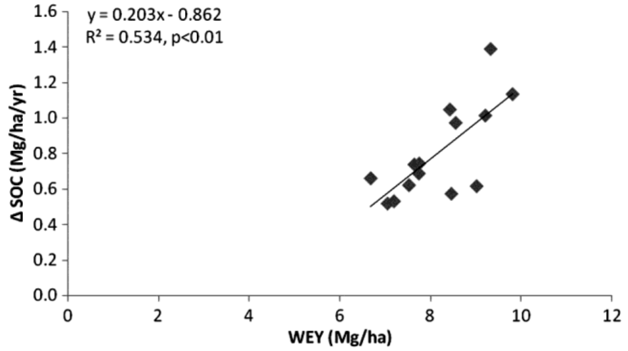

Fig. 6 — Correlation between change in soil organic carbon (ΔSOC) storage to wheat equivalent yield (WEY)

of GHGs to the atmosphere, while negative values indicate net sinks of GHG to the soil. The annual N_2O flux was in the range 2.16 (RT-T_1) to 3.63 (RT-T_3) kg N/ha. There was no significant effect of tillage on N_2O emission. Significantly higher SOC sequestration under NT-T_3 (1388 kg ha^{-1} yr^{-1}) followed by RT-T_3 (1134 kg ha^{-1} yr^{-1}) with the application of FYM (2.0 Mg C ha^{-1}) every year resulted in lower NGWP and GHGI under the two treatments compared to NPK fertilization (Table 2). Irrespective of tillage treatments, the application of FYM with inorganic fertilizer reduced the NGWP ranging from 13 to 163%. Averaged across nutrient treatments, NGWP of RT and NT were –1608 and –2597 kg CO_2 equivalent ha^{-1} yr^{-1}. All the treatments were net sinks of GHGs, and thus had negative NGWP (Table 2). The GHGI values varied from –181 to –309 kg CO_2 eq. kg^{-1} wheat equivalent yield in this study.

Discussion

The N_2O flux peak was usually observed in the fallow season after soybean harvest, though no fertilizer was applied in the fallow season before wheat sowing (Fig. 2). This was attributed to the decomposition and senescence of roots and nodules containing N fixed by soybean plant[29]. The N-rich root nodules of soybean plants emit N_2O during the process of degradation and decomposition[29-31]. Secondly, inside the soybean plant's root nodules, the N in organic form is mineralized to NH_4^+-N followed by emission of N_2O due to nitrification and denitrification[29]. Nitrous oxide emissions increased strikingly in the soybean crop growth cycle's late growth period (i.e., the grain-filling stage). The cumulative N_2O flux was higher in wheat than soybean, probably because of the high fertilizer N dose in wheat, which increases soil NO_3^--N availability and N_2O loss by nitrification and denitrification in soil[27,32-34].

The positive correlation between grain yield and N_2O emission indicated grain yield could be a sensitive predictor for N_2O emissions from soil under soybean and wheat crops under different management practices. The results showed grain yield significantly explained 69% of the variation in N_2O emission. In our study, available soil N and N fertilizer application could explain 59 to 61% variation in annual nitrous oxide emissions in soybean-wheat cropping cycle in the Vertisols of central India. However, grain yield explains a more significant variation in N_2O emission (Fig. 3A). Previous studies conducted by McSwiney & Robertson[35] and Chen *et al*.[36] have also addressed the relationship between seasonal N_2O emission and crop yields of maize and wheat, respectively. The cumulative N_2O emission was greater from plots receiving FYM (T_2 and T_3) than inorganic fertilizer (T_1) because FYM could be the source of C and N for the soil nitrifiers and denitrifiers population, which produce N_2O during nitrification and denitrification[11,12,37,38]. Further, the increase in microbial growth increases the consumption of O_2 and creates anaerobic conditions necessary for denitrification[29].

Tillage modifies soil structure, varying soil moisture, aeration, and temperature the major factors for soil respiration[11-13,33]. Our results showed that RT system had relatively higher CO_2 emission compared to NT in the soybean and wheat growing season, which showed that soil with tillage emitted more CO_2 than the same soils with NT systems[4,5]. In the present study, the CO_2 fluxes of plots receiving FYM along with 100% NPK (T_2 and T_3) were higher than 100% NPK (T_1). Higher flux under plots receiving FYM and chemical fertilizer is probably due to better microbial activity and higher soil organic carbon (SOC) content. Compared to chemical treatment, higher CO_2-C fluxes in the integrated nutrient were due to higher availability of organic C, resulting in increased soil respiration[27]. Greater soil respiration observed in wheat than soybean was due to higher root biomass in wheat which enhanced the contribution of root respiration to total respiration[14,39]. Further, the total duration of the wheat-growing season is more than soybean. Also, a congenial soil environment led to greater biological activity during wheat cultivation. The positive correlation between WEY and SOC stock suggested that wheat equivalent yield (WEY) increased with an increase in SOC stock. Soil organic carbon build-up is improved by the increase in net primary productivity of the cultivated crop. There exists a strong relationship between crop yield and SOC stock. The potential of management practices for improving above and below-ground biomass could dictate the relative increase in SOC stock[10,33]. Negative values of NGWP and GHGI indicated mitigation potential under the treatments. Though wheat equivalent yield was higher in RT than NT, the GHGI of NT system was less by 33% compared to RT, which could be attributed to lower NGWP of the NT system.

Conclusion

The results from the field study under soybean-wheat cropping system indicated significant influence of tillage and nutrient management on GHGs (CO_2, N_2O, and CH_4) emission, soil carbon storage, and crop yield. In both no-tillage and reduced tillage, soil carbon storage and crop yield were significantly higher under integrated nutrient management than under only inorganic fertilizer treatment. The cumulative CO_2 emission was higher under reduced tillage than no-tillage. Net global warming potential was negative under all treatments indicating conservation tillage combined with integrated nutrient management in the soybean-wheat system was a net sink of greenhouse gases. However, a life cycle assessment of greenhouse gas emission during the crop cycle shall further add information for computing mitigation benefits of the investigated management practices.

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Conflict of interest

Authors declare no competing interests.

References

1 Bhattacharjee S, Das JK, Roy S & Chakrabarti S, Development of a regional climate change perception index based on traditional knowledge base of small-marginal farmers. *Indian J Tradit Knowl*, 21 (2022) 198.

2 Raj A, Chakrabarti B, Pathak H, Singh SD, Mina U & Purakayastha TJ, Growth, yield and nitorgen uptake in rice crop grown under elevated carbon dioxide and different doses of nitrogen fertilizer. *Indian J Expt Biol* 57 (2019) 181.

3 Lenka S, Lenka NK & Pathak H, Reducing Emission of Greenhouse Gases from Fertilizer Use in India. In: *Soil and Fertilizers*, 1st ed., (Ed. Lal R; Taylor & Francis, CRC Press, Place?), 2020, 357.

4 Bilandžija D, Zgorelec Ž & Kisić I, Influence of tillage practices and crop type on soil CO_2 emissions. *Sustainability*, 8 (2016) 1.

5 Chun TU, Li F-D, Yun-Feng Q, Nong Z, Cong-Ke GU & Xin Z, Effect of experimental warming on soil respiration under conventional tillage and no-tillage farmland in the North China Plain. *J Integr Agric*, 16 (2017) 967.

6 Dendooven L, Patiño-Zúñiga L, Verhulst N, Luna-Guido M, Marsch R & Govaerts B, Global warming potential of agricultural systems with contrasting tillage and residue management in the central highlands of Mexico. *Agric Ecosyst Environ*, 152 (2012) 50.

7 Elder JW & Lal R, Tillage effects on gaseous emissions from an intensively farmed organic soil in North Central Ohio. *Soil Tillage Res*, 98 (2008) 45.

8 Krauss M, Ruser R, Müller T, Hansen S, Mäder P & Gattinger A, Impact of reduced tillage on greenhouse gas emissions and soil carbon stocks in an organic grass-clover ley - winter wheat cropping sequence. *Agric Ecosyst Environ*, 239 (2017) 324.

9 Lenka S, Lenka NK, Singh RC, Manna MC, Misra AK & Rautaray SK, Tillage and Manure Induced Changes in Carbon Storage and Carbon Management Index in Soybean–Wheat Cropping System in the Vertisols of Central India. *Natl Acad Sci Lett*, 38 (2015) 461.

10 Singh D, Lenka S, Lenka NK, Trivedi SK, Bhattacharjya S, Sahoo S, Saha JK & Patra AK, Effect of Reversal of Conservation Tillage on Soil Nutrient Availability and Crop Nutrient Uptake in Soybean in the Vertisols of Central India. *Sustainability*, 12 (2020) 6608.

11 Ghimire R, Lamichhane S, Acharya BS, Bista P & Sainju UM, Tillage, crop residue, and nutrient management effects on soil organic carbon in rice-based cropping systems: A review. *J Integr Agric*, 16 (2017) 1.

12 Lenka S, Malviya SK, Lenka NK, Sahoo S, Bhattacharjya S, Saha JK & Patra AK, Manure addition influences the effect of tillage on soil aggregation and aggregate associated carbon in a Vertisol of Central India, *J Environ Biol*, 41 (2020) 1585.

13 Ren X, Zhu B, Bah H & Raza ST, How Tillage and Fertilization Influence Soil N_2O Emissions after Forestland Conversion to Cropland. *Sustainability*, 3 (2020) 8.

14 Zapata D, Rajan N, Mowrer J, Casey K, Schnell R & Hons F, Long-term tillage effect on with-in season variations in soil conditions and respiration from dryland winter wheat and soybean cropping systems. *Sci Rep*, 11 (2021) 1.

15 Piva JT, Dieckow J, Bayer C, Zanatta JA, de Moraes A, Pauletti V, Tomazi M & Pergher M, No-till reduces global warming potential in a subtropical Ferralsol. *Plant Soil*, 361 (2012) 359.

16 Malhi SS, Lemke R, Wang Z & Chhabra BS, Tillage, nitrogen and crop residue effects on crop yield, nutrient uptake, soil quality, and greenhouse gas emissions. *Soil Tillage Res*, 90 (2006) 171.

17 Xiao L, Zhou S, Zhao R, Greenwood P & Kuhn NJ, Evaluating soil organic carbon stock changes induced by no-tillage based on fixed depth and equivalent soil mass approaches. *Agric Ecosyst Environ*, 300 (2020) 106982.

18 Rahmati M, Eskandari I, Kouselou M, Feiziasl V, Mahdavinia GR, Aliasgharzad N & McKenzie BM, Changes in soil organic carbon fractions and residence time five years

after implementing conventional and conservation tillage practices. *Soil Tillage Res*, 200 (2020) 104632.

19 Wang H, Wang S, Yu Q, Zhang Y, Wang R, Li J & Wang X, No tillage increases soil organic carbon storage and decreases carbon dioxide emission in the crop residue-returned farming system. *J Environ Manage*, 261 (2020) 2.

20 Page KL, Dang YP & Dalal RC, The Ability of Conservation Agriculture to Conserve Soil Organic Carbon and the Subsequent Impact on Soil Physical, Chemical, and Biological Properties and Yield. *Front Sustain Food Syst*, 4 (2020) 1.

21 Lenka S, Lenka NK, Singh RC, Subba Rao A, Kundu S, Raghuwansi J & Patidar CP, Greenhouse gas emission and soil properties as influenced by wheat biomass burning in Vertisols of central India. *Curr Sci*, 107 (2014) 1150.

22 Liu Y, Zhou Z, Zhang X, Xu X, Chen H & Xiong Z, Net global warming potential and greenhouse gas intensity from the double rice system with integrated soil-crop system management: Athree-year field study. *Atmos Environ*, 116 (2015) 92.

23 Oo AZ, Sudo S, Inubushi K, Mano M, Yamamoto A, Ono K, Osawa T, Hayashida S, Patra PK, Terao Y, Elayakumar P, Vanitha K, Umamageswari C, Jothimani P, Ravi V, Methane and nitrous oxide emissions from conventional and modified rice cultivation systems in South India. *Agric Ecosyst Environ*, 252 (2018) 148.

24 Pathak H, Greenhouse gas emission from Indian agriculture: Trends, drivers and mitigation strategies. *Proc Indian Natl Sci Acad*, 81 (2015) 1133.

25 Datta A, Santra SC & Adhya TK, Effect of inorganic fertilizers (N, P, K) on methane emission from tropical rice field of India. *Atmos Environ*, 66 (2013) 123.

26 Garg A, Kankal B & Shukla PR, Methane emissions in India: Sub-regional and sectoral trends. *Atmos Environ*, 45 (2011) 4922.

27 Lenka S, Lenka NK, Singh AB, Singh B & Raghuwanshi J, Global warming potential and greenhouse gas emission under different soil nutrient management practices in soybean–wheat system of central India. *Environ Sci Pollut Res*, 24 (2017) 4603.

28 Singh RC, Lenka S & Singh CD, Conservation tillage and manure effect on soil aggregation, yield and energy requirement for wheat (Triticum aestivum) in vertisols. *Indian J Agric Sci*, 84 (2014) 267.

29 Signor D & Cerri CEP, Nitrous oxide emissions in agricultural soils: a review. *Pesqui Agropecuária Trop*, 43 (2013) 322.

30 Torres MJ, Simon J, Rowley G, Bedmar EJ, Richardson DJ, Gates AJ & Delgado MJ, Nitrous Oxide Metabolism in Nitrate-Reducing Bacteria: Physiology and Regulatory Mechanisms. *Adv Microb Physiol*, 68 (2016) 61.

31 Shaaban M, Peng Q, Hu R, Lin S & Zhao J, Soil Nitrous oxide and Carbon dioxide emissions following incorporation of above- and below-ground biomass of green bean. *Int J Environ Sci Technol*, 13 (2016) 179.

32 Liu JS & Qiu WH, The potential for N_2O emission and nitrate leaching in seasonally open solar greenhouses during the summer fallow: $A^{15}N$ tracer study. *Soil Use Manag*, 32 (2016) 89.

33 Krauss M, Ruser R, Müller T, Hansen S, Mäder P & Gattinger A, Impact of reduced tillage on greenhouse gas emissions and soil carbon stocks in an organic grass-clover ley - winter wheat cropping sequence. *Agric Ecosyst Environ*, 239 (2017) 324.

34 Oertel C, Matschullat J, Zurba K, Zimmermann F & Erasmi S, Greenhouse gas emissions from soils—A review. *Chemie der Erde - Geochemistry*, 76 (2016) 327.

35 McSwiney CP & Robertson GP, Nonlinear response of N_2O flux to incremental fertilizer addition in a continuous maize (Zea mays L.) cropping system, *Glob Chang Biol*, 11 (2005) 1712.

36 Chen S, Huang Y & Zou J, Relationship between nitrous oxide emission and winter wheat production. *Biol Fertil Soils*, 44 (2008) 985.

37 Haque MM, Biswas JC, Kim SY & Kim PJ, Suppressing methane emission and global warming potential from rice fields through intermittent drainage and green biomass amendment, *Soil Use Manag*, 32 (2016) 72.

38 Lehtinen T, Schlatter N, Baumgarten A, Bechini L, Krüger J, Grignani C, Zavattaro L, Costamagna C & Spiegel H, Effect of crop residue incorporation on soil organic carbon and greenhouse gas emissions in European agricultural soils. *Soil Use Manag*, 30 (2014) 524.

39 Kong D, Liu N, Wang W, Akhtar K, Li N, Ren G, Feng Y & Yang G, Soil respiration from fields under three crop rotation treatments and three straw retention treatments. *PLoS ONE*, 14 (2019) 1.