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Aggregate-associated N and global warming potential of conservation agriculture-based cropping of maize-wheat system in the north-western Indo-Gangetic Plains

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ABSTRACT

Despite conservation agriculture (CA) is being promoted as a climate resilient technology, limited information is available on its impacts on N storage within soil aggregates *vis a vis* global warming potential (GWP) under tropical agro-ecosystems. Hence, this study assessed the effects of a medium-term (5-years) CA on total soil N (TSN) changes in bulk soils and aggregates, N_2O and CO_2emission, GWP and total C fixed in soils under maize (*Zea mays* L.)- wheat (*Triticum aestivum* L.) system on the Indo-Gangetic Plains (IGP). The treatments were: conventional tillage (CT), zero tillage (ZT) with planting on permanent narrow beds (PNB), PNB with residue (PNB + R), ZT with planting on permanent broad beds (PBB), PBB with residue (PBB + R), ZT on flat land/plains without crop residue (ZT) and with crop residue retention (ZR + R). Soil samples were collected after five years of a maize–wheat system and TSN in bulk soils and their aggregates of the 0–5 and 5–15 cm soil layers were measured along with N_2O and CO_2 emissions during the fifth year (2014–15).The soils under PBB + Rhad 37 and 9% more macro-aggregate-and micro-aggregate-associated N concentrations in topsoil (0–5 cm layer) than CT (248 and 299 kg N ha^{-1}). However, topsoil soil aggregation and aggregate-associated N contents of PNB + R and ZT + R were similar to CT plots. The dehydrogenase and fluorescein diacetate activities and TSN, microbial biomass N, NO_3-N and NH_4-N concentrations were also highest in PBB + R plots in topsoil. The topsoil dehydrogenase activity was significantly correlated ($r = 0.426$, $n = 21$, $p < 0.05$) with CO_2emission and with N_2O emission ($r = 0.770$, $n = 21$, $P < 0.01$) during wheat (2014–15). However, topsoil FDA activities and MBN concentrations were only significantly correlated with N_2O emission in wheat. In the maize–wheat system, highest N_2O emission was observed in PNB + R plots and least in CT plots. But, PBB + R and PNB + R plots had similar CO_2 emissions to CT plots in both crops. Despite GWP of ZT + R and PBB + R plots in the maize-wheat system were ~5% higher than CT, greenhouse gas (GHG) intensities in the CT, PBB + R and ZT + R plots were similar. Thus, PBB + R practice is a better management alternative for soil N improvement (and a reduced fertilizer N dose could be adopted in future) than CT since this practice also had 36% and 8.2% higher biomass productivities of maize and wheat, respectively in the maize-wheat cropping system and similar GHG intensity to CT plots.

1. Introduction

Nitrous oxide is a potential greenhouse gas (GHG). The concentration of N_2O has reached up to 319 ppbv in the earth's atmosphere (Bhatia et al., 2013a). It constitutes ~6% of the total greenhouse effect (IPCC, 2013). Agricultural practice accounted for 60% emission

Abbreviations: CA, conservation agriculture; CT, conventional tillage; DHA, dehydrogenase activity; FDA, fluorescein diacetate activity; GHG, greenhouse gas; GWP, global warming potential; IGP, Indo-Gangetic Plains; OM, organic matter; MBC, microbial biomass C; PNB, permanentnarrow bed; PBB, permanentbroad bed; PNB + R, PNB with residue retention; PBB + R, PBB with residue retention; SOC, soil organic carbon; SOM, soil organic matter; TSN, total soil N; ZT, zero tillage; ZT + R, zero tillage with residue retention

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of global anthropogenic emissions in 2005, N_2O emission have increased by ~17% from 1990 to 2005 (Smith et al., 2007). Its primary cause is increased use of N fertilizer in the last few decades to meet nutrient requirement of crops. Increased N_2O emission is a result of inefficient use of externally added N fertilizers by crop plants (Pathak et al., 2016,), and can be minimized by agricultural practices that enhance the N use efficiency by crop plants (Gupta et al., 2016a,b).

Conservation agriculture generally affects soil aggregation and aggregate-associated soil organic matter (SOM) (Bhattacharyya et al., 2009; 2015; Das et al., 2013; Ghosh et al., 2016), thus, soil structure. Soil structure plays a very important role in soil functioning and enables to evaluate the sustainability of crop production systems (Lichter et al., 2008). Soil aggregates provide physical protection to organic matter (OM) and also are helpful in reducing loss of soil water due to evaporation. Conservation agriculture, the combination of zero tillage (ZT) and residue retention, generally increases soil organic C (SOC) and total soil N (TSN) within soil aggregates (Bhattacharyya et al., 2013a, 2013b) and thus, has the potential to be a climate resilient technology. Of late, adoption of bed planting under CA is thought to have aggrading impacts, as bed planting is a cost effective production technique and is also helpful in resource conservation (Lichter et al., 2008). Bed planting (performed using a bed planter) is a system of farming where crops are grown on slightly raised platforms and these platforms are separated from each other by furrows. In bed planting, rain water holding capacity is more than conventional practice (Govaerts et al., 2007), and hence saves irrigation water. Weeding and fertilization can be done by modern equipments (Limon-Ortega et al., 2002), which reduces time consumption and labour in plots under bed planting. Bed planting improves soil structure, because of less damage by tillage to crop zone. Thus, it favours formation of soil aggregates and enhances OM level (Bhattacharyya et al., 2013a). Despite the impacts of bed widths on crop productivity, water use efficiency and economics of crop production have been extensively studied (Das et al., 2014, 2016, 2018), bed width effects on soil aggregate associated-N and emission of GHGs have rarely been studied. Sayre et al. (2005) observed that plots under permanent bed planting with residue retention had significantly higher soil aggregation than plots under CT with residue incorporation in Mexico. Bhattacharyya et al. (2013a) observed thatgreater N concentrations in large and small macroaggregates under bed planting than conventional planting in a sandy loam soil of the IGP.As bed planting with residue retention could augment macroaggregate-N, the N_2O emission could also be increased due to more aggregate turnover in tropical systems. In Mexico, Dendooven et al. (2012) observed that retention of crop residue in permanent beds increased theemission of CO_2 compared with where it was removed. They also found that net GWP (considering soil C sequestration, GHG emissions, fuel used, glyphosate application, fertilizer and seed production) was higher in conventionally tilled beds with crop-residue retention than in permanent beds with crop-residue retention (Dendooven et al., 2012).

Although CA has the potential to be a climate resilient technology, its effects on aggregate-associated N storage *vis a vis* N_2O emission and global warming potential (GWP) are poorly understood intropical upland agro-ecosystems. Soil aggregates stabilize N inside their structure (Elliot, 1986), but these aggregates release the trapped N pools on mechanical disruption. Though denitrification is an anaerobic process, it can occur even at high O_2 pressure, because anaerobic intra-aggregate pores are common in arable soils. These decrease the nitrification rate and increase the N_2O-N emission (Khalil et al., 2004). Soils with more macro-aggregates generally contain higher intra-aggregates and occluded micro-aggregates, causing more N_2O emission, but less leaching losses of N (Kong et al., 2007). Under ZT, N_2O emission is generally higher due to reduction rate of diffusion in presence of compact soils (Bhattacharyya et al., 2013b) and high soil moisture content. This condition promotes anaerobicstate, which benefits N_2O emission (Gupta et al., 2016a).

Considering all these facts, the main objective was to find a CA practice which would have reduced GWP compared to CT plots, increased aggregate formation and aggregate-associated N contents, without reducing crop productivity. Hence, the hypothesis was that permanent bed planting with residue retention (CA practice) could increase soil aggregates, aggregate-associated N, which would result in increased TSN and plant available N in the cultivated soils, and, therefore, would increase C fixed and reduce the GWP and GHG intensity of a maize-wheat cropping system in the region.

2. Materials and methods

2.1. Study site

A field study was initiated on the Research Farm at the ICAR-Indian Agricultural Research Institute (IARI), New Delhi (28°37'- 28° 39' N latitude and 77°9'-77° 11' E longitude); 217 m above the mean sea level), India in 2010. Before 2010, the experimental field was under rice–-wheat system for many years. The climate/weather (rainfall, maximum and minimum temperatures, evaporation) of this experimental site was same as reported by Das et al. (2014, 2018). The soil (0–15 cm layer) was sandy clay loamwith pH 7.7 (1:2.5 soil:water), EC 0.64 $dS\,m^{-1}$, oxidizable SOC 5.2 $g\,kg^{-1}$ (Walkley and Black, 1934), total soil N 1863 kg ha^{-1} (Bremner and Tabatabai, 1972), 0.5 M $NaHCO_3$ extractable P 23.3 kg ha^{-1}(Olsen et al., 1954), and 1 N NH_4OAc extractable K 250.5 kg ha^{-1}(Jackson, 1973). Soil pH and EC were measured following Jackson (1973).

2.2. Experimental details

The field experiment had five treatments [conventional tillage without crop residues (CT), permanent narrow-bed sowing without residues (PNB), permanent narrow-bed sowing with retention of crop residues (PNB + R), permanent broad-bed sowing without crop residues (PBB), permanent broad-bed sowing with retention of crop residues (PBB + R)] initially during 2010-11 (Table 1). From the second year onwards, two additional treatments, zero tillage with crop residue retention (ZT + R) and without residue retention (ZT) were employed on usual flat/even land. Similar maize-wheat rotation was followed in these two treatments under CT conditions in the previous year (2009-10). The treatments were laid out in a randomized complete block design with three replications. We used a ridge/bed maker to prepare the narrow beds. Two narrow beds were levelled to make one broad bed. The narrow and broad beds were not disturbed and existed permanently. Reshaping of beds was done once in a year in the rainy season before maize was sown by lifting soil from the furrows and putting on the beds. The treatments had a 30.0 m long and 8.4 m wide strip (~252.0 m^2) for carrying out field operations (e.g. sowing & fertilization, harvesting) easily by tractors and irrigation. The strip was sub-divided into three plots of 9.0 m x 8.4 m (~75.6 m^2) with 1.5 m wide gaps between the treatments/plots. The experimental details are the same as reported by Das et al. (2018).

In this study, around 40% residue of maize stover was retained in wheat crop, and 40% residue of wheat straw retained in maize crop in the residue retention (PNB + R, PBB + R and ZT + R) treatments. During the rainy season in first year (2010-11) of experiment, wheat residue was retained from the immediate previous wheat crop of 2009-10 grown in the experimental plots. Wheat straw yield was ~6.6 Mg ha^{-1} in 2009-10, and about 40% (~2.6 Mg ha^{-1}) of this straw biomass was returned in the residue retention plots in maize during 2010-11. Similarly, wheat residue was retained in the newly-introduced ZT + R plots in second year (2011-12). In wheat, about 40% of maize stover yield was returned in the residue retention plots (i.e., PNB + R, PBB + R, and ZT + R plots) in all years. The no residue (i.e., PNB, PBB and ZT) and CT treatments had negligible amount (~4.5%) of residues of maize and wheat left as stubble after harvest of these crops.

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