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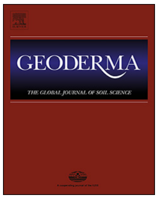

Four years of conservation agriculture affects topsoil aggregate-associated ^{15}nitrogen but not the ^{15}nitrogen use efficiency by wheat in a semi-arid climate

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ABSTRACT

Available results on the evaluation of nitrogen (N) use efficiency in conservation agriculture (CA) are inconsistent and studies that cover all three components of CA are sparse, especially in tropical agro-ecosystems. Hence, CA effects on variations in total soil N (TSN) and aggregate-associated ^{15}N on a sandy loam soil were evaluated after ^{15}N urea (~5% atom excess) application at 120 kg ha^{-1} to wheat in the fourth year of an experiment in the Indo-Gangetic Plains (IGP). The cropping system during 2008–2011 was cotton (*Gossypium hirsutum*)-wheat (*Triticum aestivum*), that was changed to maize (*Zea mays*)-wheat in 2011–2012. Results revealed that plots under zero tillage with residue retention of both crops (ZT + R) had better topsoil (0–5 cm layer) aggregation and higher residual ^{15}N in soils than conventionally tilled (CT) plots. The ZT + R plots also had higher macro-aggregates (0.25–8 mm) with less silt + clay sized particles than the CT plots in the 5–15 cm soil layer. Furthermore, both tillage and residue management had significant effects on TSN and aggregate-associated N stocks. The plots under ZT + R had ~9% higher TSN in topsoil than the CT plots and the ZT and ZT + R plots had about 48 and 34% higher large macro-aggregate associated N stocks than CT and CT + R plots, respectively. However, the potential N-mineralization data of the macro-aggregates of ZT + R (CA) and CT plots were similar. In addition, the fertilizer ^{15}N use efficiency, the residual fertilizer ^{15}N in soil (0–45 cm layer) and the calculated unaccounted fertilizer ^{15}N data of both CA and CT plots were also similar after the fourth year of cultivation. In summary, although CA (ZT + R) adoption had better soil aggregation and with more TSN accumulation within macro-aggregates, it could not affect the fertilizer ^{15}N use efficiency within a short period (4 years). Thus, with a short-term adoption of CA, fertilizer-N dose may not be reduced in a sandy loam soil of the IGP and similar agro-ecosystems.

1. Introduction

A difficult challenge for humanity in coming decades could be meeting food demands without causing further environmental degradation. The 'sustainable development goal' emphasizes on increasing yield with decreasing environmental impacts of arable systems (Mueller et al., 2012). Conservation agriculture (CA) involves achieving higher system productivity, profitability, and minimizing detrimental environmental impacts through minimum soil disturbances, incorporation of cover crop and diversified crop rotations (Bhattacharyya et al., 2009a). Despite many studies compare CA effects on N utilization, nutrient cycling and crop productivity (Govaerts et al., 2005; Lichter et al., 2008; Bhattacharyya et al., 2013a), limited information is available on the mechanisms governing soil N dynamics using ^{15}N. Information is also scanty on effects of CA on ^{15}N use efficiency and N balance, especially under tropical agro-ecosystems. Thus, knowledge on added fertilizer-N distribution within different soil size fractions in irrigated cropping systems of the Indo-Gangetic Plains (IGP) as affected by CA requires assessing ^{15}N use efficiency, total soil N (TSN) within aggregates, and the role of aggregate-associated N on N balance under CA.

Earlier studies indicate that N availability for crops is less under

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zero tillage (ZT) than conventional tillage (CT) (Peigné et al., 2007). Although ZT is effective in reducing surface losses of N, the effects of ZT and ZT + residue retention (CA) on N retention within soil size fractions are ambiguous. Zero tillage generally increases soil aggregation and macroporosity. The situation is further complicated by residue retention under CA, as residues aggravate immobilization and soil aggregation. Residue or any organic mulch retention not only increases soil aggregation, but also decreases aggregate disintegration by decreasing soil erosion and protecting the soil aggregates against the falling raindrops (Bhattacharyya et al., 2010). Mineralization of immobilized-N contributes to N supply, however better aggregation augment long-lived soil organic matter (SOM) pools, as SOM is mostly protected in free micro-aggregates (Six et al., 1998) and in micro-aggregates within the macro-aggregates (Six et al., 2000a; Bhattacharyya et al., 2012a).

One of the reasons of lower N availability under zero tilled and residue retained plots could be enhanced N sequestration within the long-lived pools. Luo et al. (2004) proposed that under excessive C supply, soil N availability could be decreased progressively due to interlocking of applied N within soil aggregates, a situation termed as progressive N limitation (PNL). Under such a scenario, additional N should be supplied to overcome the sequestered N. Thus, N supply could limit crop growth as well as soil organic carbon (SOC) retention in the long-run. Hence, the hypotheses of this study were: (i) plots under CA would significantly increase soil aggregation and fertilizer ^{15}N retention within soil aggregates compared to CT and CT with residue incorporation (CT + R) and (ii) CA plots would have less mineral N and more non-labile N due to greater N sequestration within aggregates that could lead to a difference in ^{15}N use efficiency by wheat compared to CT and CT + R plots. Based on aforementioned background, we framed the objectives of this study as: (i) to appraise added ^{15}N distribution in soil aggregates and soil N pools as affected by CT, residue incorporation (CT + R) and CA (ZT + R) and (ii) to assess ^{15}N use efficiency in wheat during the fourth year of the conventional versus conservation agricultural practices in a sandy loam soil of semi-arid climate, located at the IGP.

2. Materials and methods

2.1. Experimental site

A field study on a wheat (*Triticum aestivum*)-based cropping system was carried out during 2008–2012 at the Division of Agronomy farm, ICAR-Indian Agricultural Research Institute (IARI), New Delhi, India. Prior to the initiation of the experiment, the surface soil (0–15 cm) was sandy loam in texture with 1.48 $Mg\ m^{-3}$ bulk density. It had 5.6 $g \cdot kg^{-1}$ oxidizable soil organic C (Walkley and Black, 1934), 172 kg available ($KMnO_4$ – oxidizable) N ha^{-1} (Jackson, 1973), 0.55 $g\ kg^{-1}$ total soil N (TSN) (Keeney and Nelson, 1982), 11.9 kg available (0.5 *N* $NaHCO_3$ – extractable) P ha^{-1}(Olsen et al., 1954), 230 kg available (1 *N* NH_4OAc-exchangeable) K ha^{-1}(Hanway and Heidel, 1952), 7.6 pH and 0.32 $dS\ m^{-1}$ EC (Jackson, 1973). The site was under maize-wheat cropping system with mineral (NPK) fertilization before initiation of this study.

2.2. Experimental details

During the first three years (2008–2009 to 2010–2011), the study was continued with a cotton (*Gossypium hirsutum*)-wheat rotation. However, in line with the principles of CA (diversified cropping system and crop cover), maize (*Zea mays*)-wheat-green gram (*Vigna radiata*) crop rotation was taken since June 2011. But this study was conducted at wheat harvest of the fourth year (April 2012). There were four tillage and residue management practices. These were conventional tillage (CT), conventional tillage with residue incorporation (CT + R), zero tillage (ZT) and ZT with residue retention (ZT + R). The treatments were distributed in a randomized block design with three replications for each treatment.

2.3. Tillage, residue management and sowing

Single ploughing (using a tractor drawn disc plough) succeeded by harrowing and planking was performed before each crop in the CT plots. However, in the ZT plots, no ploughing was done in any year. Crop residues were retained on soil surface in plots under ZT + R. Contrarily, crop residues were incorporated in the CT + R plots. All residues, except stubble, were taken away from the ZT and CT plots. Leaves, tender twigs and boll husk of the cotton crop (accounting ~20% of the stover yield) were kept in the CT + R and ZT + R plots. The entire wheat residue was used after its harvesting using a combine. Cotton (variety MRC 7017 ‘Nikki’) was sown at 70 × 60 cm spacing in all plots during May of the initial three years. In June 2011, the maize seeds were sown at 20 kg seed ha^{-1} at 70 cm row spacing in all plots. In all years, the wheat crop (variety HD 2932) was sown with a multi-crop planter at 18 cm row spacing in all plots in early November. For maize sowing, a seed-cum-fertilizer drill was used in ZT plots.

As soon as hairline cracks appeared due to dryness, all crops were irrigated. In November 2011, after the first irrigation, the poly-vinyl-chloride (PVC) open-ended pipes (45 cm deep and 30 cm internal diameter) were installed into the established wheat crop of each plot for estimation of added ^{15}N in different soil size fractions. The area within the PVC pipes is termed micro-plots. Each micro-plot included two wheat rows and on average six plants. We intended to install the PVC pipes at 1-m depth, but were unable due to difficulties in pressing them without disturbing the plots.

2.4. Crop management

A common dose of 100:60:40 kg ha^{-1} (N:60 P_2O_5:40 K_2O) was applied to cotton. For wheat and maize, a dose of 120:60:40 kg ha^{-1}(N:P_2O_5:K_2O) was applied in all plots. For all crops, entire amounts of P and K and one-half N were applied as basal and the remaining N was top-dressed in two equal splits. Details of N scheduling in different crops are given in Bhattacharyya et al. (2013a, 2013b).

During the fourth year, N was applied after installation of the PVC pipes. Within the micro-plots, ^{15}N labeled urea (5.065% atom excess) was applied (at 50% of 120 kg N ha^{-1} in the form of ^{15}N urea solution, using a syringe) in the fourth year just after wheat establishment. Then, 50% urea-N was broadcasted in the entire plot area, leaving the micro-plots that received ^{15}N urea. Rest 50% urea-N was top-dressed in two equal splits after first and second irrigations, respectively. Micro-plots also received corresponding ^{15}N labeled urea.

To manage the weeds, glyphosate was sprayed at 0.5 kg ha^{-1} in ZT plots about seven days before sowing of all crops. Pendimethalin was sprayed at 0.75 kg ha^{-1} in cotton within 2–3 days after sowing. Additionally, one hand weeding was performed in cotton at 40 DAS. In wheat, isoproturon at 1.0 kg ha^{-1} was applied at 30 days after sowing (DAS). Atrazine was sprayed at 1.25 kg active ingredient ha^{-1} in all maize plots on 1 DAS, followed by one hand weeding at 30–40 DAS. Other plant protection measures of different crops are detailed by Bhattacharyya et al. (2013b). Wheat was harvested in the first week of April 2012 from all plots (including micro-plots) and grain and straw weights were recorded and converted on a hectare basis. The maize grain yield was converted into wheat equivalent yield (WEY) based on year-wise market price of maize and wheat crops, following Bhattacharyya et al. (2009b). The converted maize grain yield of a year in terms of WEY was then added to the actual wheat grain yield in that year to obtain total maize-wheat system productivity.

2.5. Sampling and analyses

Before the addition of ^{15}N labeled urea, one set of triplicate soil