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Influence of Conservation Agriculture Practices on Physical, Chemical and Biological Properties of Soil and Soil Organic Carbon Dynamics in the Subtropical Climatic Conditions: A Review

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Soil tillage is one of the fundamental agro technical operations in agriculture because of its influence on soil properties, environment and crop growth. Since continuous soil tillage strongly influence the soil properties, it is important to apply appropriate tillage practices that avoid the degradation of soil structure, maintain crop yield as well as ecosystem stability. The efficiency of input use viz. water, fertilizers, herbicides and others depend on tillage and crop establishment practices. It is therefore, essential that the soil environment be manipulated suitably for ensuring a good crop stand and improve resource-use efficiency. Sustaining production and productivity of any system is of paramount importance by improving the soil's physical, chemical and biological properties. Conventional tillage operations will alter these properties in every cropping cycle thereby affecting the soil system. Conservation agriculture (CA), practising agriculture in such a way so as to cause minimum damage to the environment is being advocated at a large scale world-wide. Conservation tillage, the most important aspect of CA, is thought to take care of the soil health, plant growth and the environment. This paper aims to review the work done on conservation tillage in different agro-ecological regions so as to understand its impact from the perspectives of the soil, the crop and the environment. Research reports have identified several benefits of conservation tillage over conventional tillage (CT) with respect to soil physical, chemical and biological properties as well as crop yields.The largest contribution of CA to reducing emissions from farming activities is made by the reduction of tillage operations. Altering crop rotation can influence soil C stocks by changing quantity and quality of organic matter input. Therefore, conservation tillage involving ZT and minimum tillage which has potential to break the surface compact zone in soil with reduced soil disturbance offers to lead to a better soil environment and crop yield with minimal impact on the environment.

Keywords: Carbon sequestration, Soil health, Tillage Residue management, CO_2 emission.

Conservation agriculture (CA) has been regarded as management of soil, water and agricultural resources to achieve economic, ecological and socially sustainable agricultural production (Jat *et al.*, 2012). CA is more sustainable agriculture production practice than narrowly-defined 'conservation tillage' (Naresh *et al.*, 2014).

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Conservation tillage is a widely-used terminology to denote only soil management systems in which at least 30% of the soil surface being covered with crop residues after seeding (Jarecki and Lal, 2003).C A is a system of agronomic practices that include reduced tillage (RT) or no-till (NT), permanent organic soil cover by retaining crop residues, and crop rotations, including cover crops. Together these practices aim to increase crop yields by enhancing several regulating and supporting agro ecosystems (AEs). Though CA was originally introduced to regulate wind and water erosion (Baveye *et al*., 2011), it is now considered to deliver multiple AE. This paper focuses on the effects of CA on soil carbon sequestration and greenhouse gas emissions through modification of several soil properties and processes. Over the past ten years numerous research papers and reviews have looked at the extent to which AE are generated through CA compared to conventional practices. Much of that research has focused on effects of RT and NT compared with conventional tillage (CT) where the effects of residue management and crop rotations are often confounded with tillage. Previous reviews indicate that CA can reduce water and wind erosion due to protection of the soil surface with residue retention and increased water infiltration and decreased runoff with NT (Verhulst *et al*., 2010). Benefits of CA on other AES including nutrient cycling, carbon sequestration, and pest and disease control are quite variable, from positive, too neutral or even negative depending on site-specific context, management, soil type, and climate. This paper summarizes the state-of-knowledge of CA needed to provide a more predictive framework for soil health. The summaries are based on the global literature including the growing literature on CA from smallholder farming systems, particularly North Indo Gangetic Plains. The types of experiments installed for testing CA and comparing with conventional practices (tillage, residue removal or incorporation and mono- cultures) do not necessarily have the design required to separate the individual and combined effects of the different CA practices on AE. Comparisons often come from experiments that include one or two of the practices, with comparisons of tillage practices with residues being the most common.

Influence of CA on physical soil quality

Bulk density

Verhulst *et al*. (2011) in their study reported that most of the physical soil parameters measured were significantly affected by tillage-straw system, only bulk density showed no effect. A layer of 7 to 15–20 cm depth has high bulk density, low porosity and high mechanical resistance so referred to as a, no-till pan . The effect of tillage on soil bulk density is remains unchanged in deeper soil layers while in deeper soil layers, soil bulk density is generally similar in no and conventional till. But a plough pan may be formed by tillage immediately underneath the tilled soil; causing higher bulk density in this horizon. Bulk density was 23.02% higher in no till as compared to till plot (1.55 mg m^{-3}) in Boigneville while 14.29% lower in no till in Versailles in 0-10 cm soil depth (Chaplain *et al*., 2011).Bulk density of the 0-7.5 and 7.5-15cm depths was greater under no till than the till treatments by 15% (1.14 g cm^{-3} versus 0.99 g cm^{-3}) and 9% (1.41 g cm^{-3} versus 1.29 g cm^{-3}), respectively, in the Black Chernozem and by 18% (1.27 g cm^{-3} versus 1.08 g cm^{-3}) and 13% (1.57 g cm^{-3} versus 1.39 g cm^{-3}) in the Gray Luvisol (Singh and Malhi, 2006). Blanco-Canqui and Lal (2007a) measured bulk density in no till plots that had receiving three levels of wheat straw mulch (0, 8, and 16 t $ha^{-1}r^{-1}$) for 10 consecutive years on a silt loam in central Ohio. Straw management had a large impact on bulk density in the surface layer (0-10 cm) but not significant in the 10-20 cm depth. The bulk density under the high-mulch treatment was 58% lower and that under the low-mulch treatment was 19% lower than the bulk density under the un-mulched treatment for the 0-3 cm depth. In the 3-10 cm depth, bulk density under the high-mulch treatment was only 36% lower and that under the low-mulch treatment was 9% lower than under the control. Annual application of 16 t ha^{-1} of rice straw for 3 years decreased bulk density from 1.20 to 0.98 g cm^{-3} in the 0-5 cm layer on a sandy loam (Lal, 2000).

Hu *et al*. (2007) reported that NT significantly increased the topsoil (0-5 cm) bulk density (BD), while reduced tillage RT) maintained a lower BD as CT. Ram *et al*. (2010) reported that soil bulk density recorded in NT/NT (1.50 g/cm^3) was significantly higher than sequential fresh bed and permanent bed treatments. Dalal *et al*. (2011) also reported the residues management practices had not significant influence on the bulk density of vertisol soil of Australia. Naresh *et al*., 2016 also reported that mean soil bulk density in the 0- to 20-cm soil layer of the FIRB with residue retention and ZT with residue retention plots was 12.4 and

6.8% lower, respectively ($P < 0.05$), than the CT plots. In addition, the FIRB treatment had significantly ($P < 0.05$) lower soil bulk density in the 0- to 10- and 10- to 20-cm soil layers than CT by 14.3 and 12.8%, respectively. The changes in bulk density were mainly confined to top 10-15 cm layer.

Infiltration

Infiltration is generally higher in no till with residue retention compared to conventional tillage and no till without residue. Abid and Lal (2009) observed significantly higher infiltration in no till (I= 71.4 cm) than conventional till (I = 48.9 cm) on silt loam soil. Tillage and residue management also influenced cumulative and steady-state infiltration (Sharratt *et al*., 2006). Retention of the straw on the surface also significantly influenced the cumulative infiltration and steady state infiltration (104 mm, 73 mm h^{-1}) as compared to residue removal (84 mm, 54 mm h^{-1}).Naresh *et al*., 2015a found that the infiltration rate was consistently highest with an overall average of 84.7mm h^{-1} (raised bed), lowest at 50.3 mm h^{-1} in conventional tillage (puddling), and intermediate 55.7; 62.2 mm ha^{-1} in rotary tillage and zero tillage. Infiltration after permanent wide raised beds and zero till flat beds increased with time, indicating improvement in soil structure, as also supported by soil aggregation. Savabi *et al*. (2007) reported that ZT in medium textured soils (silty loam and silty clay loam) enhanced infiltration rates with time. The moreover, aggregates are more stable under no till with residue retention compared to conventional till and no till without residue (Li *et al*., 2011). The residues present in the surface act as a succession of barriers, reducing the runoff velocity and giving more time for infiltration. Application of crop residues, however, increased the infiltration rate even in the conventional tillage (Sarkar and Kar, 2011). Lipiec *et al*. (2006) also reported the similar finding as conventional till plot had the highest infiltration throughout the time of water application. After 10 min, the cumulative infiltration being 20.2 cm (infiltration rate of 69.0 cm h^{-1}), it was lower in no till by 58%. Higher contribution of large pores and flow-active porosity throughout the profile in conventional till had increased infiltration rate than in no till system. Naresh *et al*., (2015) reported that retaining crop residues on the soil surface with conservation tillage would reduce evapo-transpiration and increase infiltration rate.

Soil water storage

Zero tillage practices have proven effective in helping to increase plant-available water under drought and to improve crop water-use efficiency (Bradford and Peterson, 2000). Nielsen (2006) showed the combined effects of residue management and tillage method on precipitation stored in the soil. Tanwar *et al*., 2014 found the amount of irrigation water applied to wheat ranged from 2890 to 3167 m^3 ha^{-1} in bed planting system and 3830–3970 m^3 ha^{-1} in conventional planting. Bed planting saved 23%, 24% and 19% irrigation water over conventional system during 2009–2010, 2010–2011 and 2011–2012, respectively.

Vita *et al*. (2007) stated that higher soil water content under no-till than under conventional tillage indicated the reduced water evaporation during preceding period. They also found that across growing season, soil water content under no-till was about 20 % greater than under conventional tillage. Sharma *et al*. (2011) reported that no tillage retained the highest moisture followed by minimum tillage, raised bed and conventional tillage at different soil depths. Sharma *et al*. (2011) reported that no tillage retained the highest moisture followed by minimum tillage, raised bed and conventional tillage at different soil depths. Maintenance of crop residues on the soil can be an effective mean for improving plant available water. Naresh *et al*., 2014). Moisture accumulated more with depth with residues than without under ZT (Govaerts *et al*., 2007).

Soil temperature

Soil temperatures in surface layers can be significantly lower (often between 2 and 8°C) during daytime (in summer) in zero tilled soils with residue retention compared to conventional tillage (Oliveira *et al*. 2001). Dahiya *et al*. (2007) compared the thermal regime of a loess soil during two weeks after wheat harvest between a treatment with wheat straw mulching, one with rotary hoeing and a control with no mulching and no rotary hoeing. Compared to the control, mulching reduced average soil temperatures by 0.74, 0.66, 0.58°C at 5, 15, and 30 cm depth respectively, during the study period. The rotary hoeing tillage slightly increased the average soil temperature by 0.21°C at 5 cm depth compared to the control. The tillage effect did not transmit to deeper depths. Gupta *et al.* (1983) also found that the difference between zero tillage with and without residue cover was larger than the difference between conventional tillage (mouldboard ploughing) and zero tillage with residue retention. Both mouldboard ploughing and zero tillage without residue cover had a higher soil temperature than zero tillage with residue cover, but the difference between mouldboard ploughing and zero tillage with residue cover was approximately one-third the difference between zero tillage with and without residue. Cutforth and McConkey (1997) showed that the soil temperature regime for wheat grown understanding stubble differed from that for wheat grown after conventional cultivation, and suggested that temperature could be at least partly responsible for the observed growth lag. Similarly, Kirkegaard *et al.* (1994) observed lower daytime soil temperatures in zero tillage when stubble was retained and suggested that this might be partly responsible for the reduced wheat growth and rooting depth observed for this practice.

Naresh *et al.*, 2015 showed that Soil temperature at transplanting zone depth (5 cm) during rice crop establishment was lower in 2009 than in 2010 and did not differ in the years 2010 to 2011. Treatments T_1 and T_2 reduced the mean maximum soil temperature at transplanting zone depth by 3.6 and 2.7°C compared to the treatment T_3, respectively. Zero tillage reduced the impact of solar radiation by acting as a physical barrier resulting in lower soil temperature than the plough soil. This result is in agreement with Sekhon *et al.* (2005).The increased value of soil temperature for narrow raised beds was probably due to exposure of more surface area to the incident solar radiation in narrow raised beds than in flat conventional treatments. T_3 and T_4 recorded higher soil temperature (mean of 38.4 V/S 37.7°C) compared to the flat treatments T_1, T_2 and T_5 at 15 DAT. Dalmago *et al.* (2004) stated that surface covering is the most important factor affecting soil temperature when comparing RT to CT practices. Vegetative cover in the form of crop residues, insulate the soil and captures a large amount of sunlight, causing less heat to flow into the soil and protecting the soil beneath from getting as warm as the bare soil during days (Zhang *et al.*, 2009). As a consequence of these depressive effects of crop residues, the final result is reduction in soil temperature extremes in RT systems on a diurnal basis in comparison to CT practices (Wall & Stobbe, 1984).A decrease of about 0.8 to 2.8°C due to the presence of crop residues on the surface on RT was recorded by Alletto *et al.*, 2011.

Water Stable Aggregates

Aggregation is a dynamic process that depends on various agents such as soil fauna, roots, inorganic binding agents and environmental variables. Macro aggregates are gradually bound together by temporary (i.e., fungal hyphae and roots) and transient binding agents (i.e., microbial and plant-derived polysaccharides) as the decomposition of soil organic matter takes place (Six *et al.*, 2004). Zero tillage with residue retention improves soil structure compared to conventional tillage (Govaerts *et al.*, 2007). Research on conservation agriculture showed that no-till with stubble retained treatment had more water stable aggregation (Zhang *et al.*, 2009).Retaining crop residues on the soil surface lead to an increase of soil organic carbon, which gives rise to improved soil aggregate stability (Limon-Ortega *et al.*, 2002) and the return of biological diversity to the soil, particularly earthworms (Chan 2001).

Mehuys (1988) observed a decrease in MWD of WSA after four years plough till compared with no-till. No tillage increased the proportion of the macro aggregates (>2 mm) at 0-5 cm but not at 5-15 cm depth. The majority of SOC and SON storage under both CT and NT was observed in the largest aggregate size fractions (>2 mm, 250 mm to 2 m. Aulakh *et al.*, 2013 showed total WSA after 2 years of the experiment in 0 - 5 cm soil layer of CT system, T_2 and T_4 treatments increased total WSA from 71% in control (T_1) to79 and 81% without CR,and to 82 (T_6) and 83% (T_8) with CR. The corresponding increase of total WSA under CA system was 75% in control (T_9) to 81 (T_{10}) and 82% (T_{12}) without CR and 83 (T_{14}) and 85% (T_{16}) in with CR. Naresh *et al* 2016 revealed that the small macro-aggregates accounted for >30% of the total aggregates (mean of both main plots) in the surface soil layer. Silt- plus clay-sized aggregates comprised the greatest proportion of the whole soil, followed by the small macro-aggregates. The amount of water-stable large and small macro-aggregates in the FIRB and ZT plots were significantly higher than in the CT plots in the 0- to 5-cm soil layer. Naresh *et al.* (2012) showed significant effects of NT and residue retention on soil aggregate stability in western Uttar Pradesh under an alternative wheat production system. These differences may be attributed to the different planting systems. A reduced presence of macro aggregates (>0.25 mm) under TT was partly due to excessive tillage and heavy traffic, which hindered the soil biological activity (Tisdall and Oades, 1979).

Distribution of Aggregates in Different Size

Wang *et al.*, 2013 revealed that the conservation tillage treatments produced significantly higher amounts of >2 mm macro-aggregates compared with conventional tillage. This was because conservation tillage practices decreased tillage times and reduced the mechanical destruction to soil aggregates. Conventional tillage with frequent tillage operations disturb soil, and increase the effect of drying–rewetting and freezing–thawing, which increase macro-aggregate susceptibility to disruption. Denef *et al.* (2002) suggested that enhanced C and N stabilization within the micro-aggregate-within-macro-aggregate fraction under permanent raised beds compared to conventionally tilled raised beds was related to the dynamic behavior rather than the amount of the micro-aggregates (and the macro-aggregates that protect them). In other words, the differences in the amount and concentration of C of micro-aggregates-within-macro-aggregates between management systems can be linked to differences in amount and stability, as well as the turnover, of the micro-aggregates-within-macro-aggregates.Naresh *et al.*, 2015a revealed that macro-aggregates are less stable than micro-aggregates and more susceptible to the disruptive forces of tillage, and the >2 mm macro-aggregates showed the lowest percentage distribution at both depths. This might be attributed to the mechanical disruption of macro-aggregates with frequent tillage operations and reduced aggregate stability. The proportion of the micro-aggregates in all treatments was small and they had the lowest organic C content. However, micro-aggregate formation (Zhang *et al.*, 2012) and micro-aggregates within the macro-aggregates (Kumari *et al.*, 2011) can play an important role in C storage and stabilization in the long term.The formation of micro-aggregates occurs in advanced stages of organic C decomposition, so the organic matter in the micro-aggregates is more stable or recalcitrant compared to the organic C found in other aggregates, thereby favoring aggregate stability and C retention. Naresh *et al.*, 2015 proved that W Bed-TPR WBedZT-DSW+100% SR treatment (T_9) has the highest potential to secure sustainable yield increment (8.4%) and good soil health by improving soil aggregation (26.5%) and SOC sequestration (36.7%) with respect to the conventional tillage puddle transplanted rice (T_{10}) after 4 years of continuous RWCS in light textured soil of North India.

Bhattacharyya *et al.*, 2013 found that small macro-aggregates accounted for >30% of the total aggregates (mean of both main plots) in the surface soil layer. Silt- plus clay-sized aggregates comprised the greatest proportion of the whole soil, followed by the small macro-aggregates. The amount of water-stable large and small macro-aggregates in the ZT plots was significantly higher than in the CT plots in the 0- to 5-cm soil layer. Hence, the plots under CT had significantly smaller MWD than ZT plots in the 0- to 5-cm soil layer. Gupta Chaudhary *et al.*, 2014 compared to conventional tillage, conservation tillage (RT and ZT) coupled with DSR increased 50.13% water stable macro-aggregates and decreased 10.1% water stable micro- aggregates in surface soil. Among all the treatments, T_6 had significantly higher (52.8%) proportion of water stable macro-aggregates than the other treatments. In T_5, T_6, T_7 and T_8 treatments, the percent macro-aggregates were found to be 3.8, 4.9, 4.1 and 3.1 times higher than their corresponding micro-aggregates.

Hydraulic conductivity (Ks)

After rice and wheat harvest, the laboratory estimated K_{sat} values in the 0–15 cm soil depth under zero tillage plots were higher than that of the tilled plots (Bhattacharyya *et al.*, 2006b and Bhattacharyya *et al.*, 2008). The decrease of K_{sat} by tillage in the surface soil layer was probably due to destruction of soil aggregates and reduction of non-capillary pores, whereas in zero tillage plots the pore continuity was probably maintained due to better aggregate stability and pore geometry (Bhattacharyya *et al.*, 2006a). Similarly, Increase in hydraulic conductivity in zero tillage as compared to conventional tillage, apparently earthworm channels and termite galleries, being the major contributors'. Hydraulic conductivity can be improved and evaporation can be decreased by no-tillage and crop residue cover (Li *et al*., 2011). Tripathi *et al*., 2007 found removing residues decreased Ks in all the tillage systems. In wheat season, Ks were generally lower under ZT than under CT. In comparison to reduced puddling with residue incorporation, conventional puddling led to a significant degradation in soil structure in 4 years of rice–wheat system.

Bhattacharyya *et al*. (2008) observed increments in hydraulic conductivity up to 45-cm depth after 8 years of farmyard manure application in a silty clay loam soil of India. Saturated hydraulic conductivity (Ksat) values in all the studied soil depths were significantly greater under ZT than those under CT (range from 300 to 344 mm/day) and the unsaturated conductivity {k(h)} values at 0–75 mm soil depth under ZT were significantly higher than those computed under CT at all the suction levels, except at %10, %100 and % 400 kPa suction (Bhattacharyya *et al*., 2006). Conventional tillage caused loosening of the surface soil layer thereby increasing the macro porosity and hence increasing the *K*sat. The soil *K*sat (0 - 0.15 m depth), deter-mined at wheat harvest, was 57 times higher under CT than ZT. Singh *et al*., 2014 reported that saturated hydraulic conductivity (Ks) values for various depths of soils were largely higher under ZT than that of CT, however, differences were significant to a depth of 0.10 m. The magnitude of increase in Ks of surface 0.05 m depth was highest in loam (51%) followed by sandy loam (40%) and clay loam (38%) soil. Since Ks is a function of the size and continuity of pores, therefore, higher accumulation of soil organic carbon and less soil disturbance in ZT might have promoted the formation of macro pores responsible for higher water transmission as compared to CT practice. Higher Ks under ZT than CT has also been reported by (Castellini and Ventrella, 2012) but Sharma *et al*. (2005) observed lower values of Ks under ZT than that of CT in silty clay loam soil under rice–wheat cropping system of Tarai region of Northern India. Zero tillage increased the maximum hydraulic conductivity in both rice and wheat compares to reduce and conventional tillage (Tripathi *et al*., 2007).

Influence of CA on chemical soil quality

Soil P^H

Govaerts *et al*. (2007) found a higher p^H in permanent bed with all the residues retained than with part or all of the residues removed in a rainfed experiment in the highlands of Mexico. Duiker and Beegle (2006) did not observe significant tillage effects on the average p^H of the 0–15 cm layer. Kettler *et al*. (2000) found that the main effect of ploughing on soil p^H was more significant for 0–7.5 cm soil depth and both no-till and sub-till treatments, which leave plant residues at or near soil surface, were of lower p^H than mould board ploughing treatments at all depths. Tillage and straw management usually had little or no effect on soil ^{pH} in any soil layer (Malhi *et al*., 2011a). Kumar and Yadav (2005) observed slight decrease in the soil ^{pH} than initial values in conventional tillage, Chinese seeder and Pantnagar zero till drill. One possible way of protecting soil from acidification is by returning the crop residues to the soil (Miyazawa *et al*., 1993) and p^H increased significantly with crop residue application, thus, there are contrasting views about soil P^H. The lower p^H in ZT was attributed to accumulation of organic matter in the upper few centimetres under ZT soil (Rhoton, 2000) causing increases in the concentration of electrolytes and reduction in p^H. Retention of crop residue on the soil (Sushant *et al*., 2004) reduced the bulk density, enhanced organic carbon and EC but reduced the pH of the soil

Cation Exchange Capacity

Kumar *et al*., 2015 reported that the cation exchange capacity (CEC) was also increased due to tillage crop establishment. The highest CEC increase (10.3%) was found in T_1 followed by T_5 (4.2%) and T_3 (1.4%). Treatment T_7 showed the lowest increase of CEC from the experimentation. The large loss of aggregate stability for the zero-till system is of particular concern, as it suggests that the increased aggregate stability of surface soil under no-till is due to surface residue rather than an intrinsic property of zero-tillage. This observation is consistent with that of Hammer beck *et al*., (2012). (Duiker and Beegle 2006). However, the average CEC in the 0–15 cm layer was not significantly different between tillage systems in the same study. This was confirmed by Govaerts *et al*. (2007), who did not find an effect of tillage practices and crop on CEC. The retention of crop residues, however, significantly increased the CEC in the 0–5 cm layer of permanent raised beds compared to soil from which the residues were removed, but there was no difference in the 5–20 cm layer Mohanty *et al*., 2015 observed that adoption of MT enhanced the CEC of soils even within a short span of two years and the increase was in the tune of 11.2% over CT system {26.2 c mol (p+) kg^{-1}}.

Total Organic C, Total N and C/N Ratio

Soil organic C is an important index of soil quality because of its relationship to crop productivity (Lal *et al*., 1997).Decomposition rates of soil organic matter are lower with minimal tillage and residue retention, consequently organic carbon content increases with time (Gwenzi *et al*., 2009). Tillage practice can also influence the distribution of SOC in the profile with higher soil organic matter (SOM) content in surface layers with zero tillage than with conventional tillage, but a higher content of SOC in the deeper layers where residue is incorporated through tillage (Jantalia *et al*., 2000). Soil C storage is affected more by quantity than by the type or quality of organic inputs. The quality of the residues is determined primarily by the C: N ratio and can be modified by the amounts of lignin and polyphenolics in the material (Palm and Sanchez, 1991).Quality may affect short-term soil C storage and dynamics but does not seem to influence the longer-term C stabilization and storage in the soil (Chivenge *et al*., 2011; Gentile *et al*., 2011). The quality of the residues may, however, affect soil fertility and thus the amount of residues produced for C inputs. For example, materials with high C: N, characteristic of cereal crop residues, reduce the available Nin the soil due to N immobilization and could result in lower crop production, while residues with high N contents and low C:N ratios, as is the case with many legume residues and legume cover crops, increase soil N availability and possibly crop production (Powlson *et al*., 2011b; Palm *et al*., 2001). It is generally recognized that the differential effects of rotations on soil C are simply related to the amounts of above and below ground biomass (residues and roots) produced and retained in the system (West and Post, 2002). Unfortunately, few studies have measured or reported the residue inputs, particularly root biomass or rooting patterns, to better explain rotation effects. In Brazil, Boddey *et al*. (2010) attributed higher soil C storage in NT than CT to the inclusion of legume intercrops or cover crops in the rotations, and not due simply to higher production and residue inputs. They indicated slower decomposition of residues and lower mineral N in NT compared to CT result in higher root: shoot ratios and belowground C input with NT (Boddey *et al*., 2010).

Crop residues provide a source of organic matter, so when returned to soil the residues increase the storage of organic C and N in soil, whereas their removal results in a substantial loss of organic C and N from the soil system (Malhi and Lemke 2007). Therefore, one would expect a dramatic increase in organic C in soil from a combination of ZT, straw retention and proper/ balanced fertilization (Malhi *et al*., 2011b). Naresh *et al*., 2016 also found significantly higher POC content was probably also due to higher biomass C. Results on PON content after 3-year showed that in 0-5 cm soil layer of CT system, T_1, and T_5 treatments increased PON content from 35.8 $mg·kg^{-1}$ in CT (T_9) to 47.3 and 67.7 $mg·kg^{-1}$ without CR, and to 78.3, 92.4 and 103.8 $mg·kg^{-1}$ with CR @ 2, 4 and 6 tha^{-1}, respectively. The corresponding increase of PON content under CA system was from 35.9 $mg·kg^{-1}$ in CT system to 49 and 69.6 $mg·kg^{-1}$ without CR and 79.3, 93.0 and 104.3 $mg·kg^{-1}$ with CR @ 2, 4 and 6 tha^{-1}, respectively. Small improvement in PON content was observed after 4 years of the experiment. Singh *et al*., 2014 found that carbon stock of 18.75, 19.84 and 23.83 Mg ha^{-1} in the surface 0.4 m soil depth observed under CT was increased to 22.32, 26.73 and 33.07 Mg ha^{-1} in 15 years of ZT in sandy loam, loam and clay loam soil. This increase was highest in clay loam (38.8%) followed by loam (34.7%) and sandy loam (19.0%) soil. The carbon sequestration rate was found to be 0.24, 0.46 and 0.62 Mg ha^{-1} $year^{-1}$ in sandy loam, loam and clay loam soil under ZT over CT. Thus, fine textured soils have more potential for storing carbon and ZT practice enhances carbon sequestration rate in soils by providing better conditions in terms of moisture and temperature for higher biomass production and reduced oxidation (Gonzalez-Sanchez *et al*., 2012).

Intensification of cropping systems with high above and belowground biomass (i.e, deep-rooted plant species) input may enhance CA systems for storing soil C relative to CT (Luo *et al*., 2010). Gupta Chaudhary *et al*., 2014 reported that conservation tillage (both RT and ZT) caused 21.2%, 9.5%, 28.4%,13.6%,15.3%,2.9% and 24.7% higher accumulation of SOC in >2 mm,2.1–1.0 mm,1.0–0.5mm, 0.5–0.25mm,0.25–0.1mm,0.1–0.05 mm and<0.05 mm sized particles than conventional tillage (T_1 and T_2) treatments. Direct seeded rice combined with zero tillage and residue retention (T_6) had the highest capability to hold the organic carbon in surface (11.57 g kg^{-1} soil aggregates) and retained least amount of SOC in sub-surface (9.05 g kg^{-1}soil aggregates) soil. In comparison with transplanted rice (TPR), direct seeded rice (DSR) enhanced 16.8%, 7.8%,17.9%,12.9%, 14.6%, 7.9% and 17.5% SOC in>2mm,2.1–1.0 mm,1.0–0.5 mm,0.5–0.25 mm,0.25–0.1 mm, 0.1–0.05 mm and <0.05 mm sized particles.Positive effects of manure and straw application on the MWD have been reported in a number of other studies (Singh *et al.*, 2007). A lower C/N ratio and polyphenol content of green manure are susceptible to rapid decomposition and yield lower values of the MWD as compared to FYM and paddy straw with a greater C/N ratio and lingopolyphenol contents, Aulakh *et al*., 2013 found in 0 - 5 cm layer of CT system, T_2, T_3 and T_4 treatments increased TOC content from 3.84 g·kg^{-1} in control (T_1) to 4.19, 4.33 and 4.45 g·kg^{-1} without CR, and to 4.40,4.83 and 5.79 g·kg^{-1} with CR (T_6, T_7 and T_8) after 2 years. The corresponding values of TOC content under CA system were 4.55 g·kg^{-1} in control to 4.73, 4.79 and 5.02 g·kg^{-1} without CR and to 4.95, 5.07 and 5.30 g·kg^{-1} with CR. After 4 years of these treatments, there was further improvement in TOC content from 1% to 26% in CT and none to 19% in CA treatments. Naresh *et al*., 2015 reported the av.SOC concentration of the control treatment was 0.54%, which increased to 0.65% in the RDF treatment and 0.82% in the RDF+FYM treatment. Compared to F_1 control treatment the RDF+FYM treatment sequestered 0.33 Mg C ha^{-1} yr^{-1} whereas the NPK treatment sequestered 0.16 Mg C ha^{-1} yr^{-1}.

Water Soluble C

Aulakh *et al*., 2013 reported that an application of fertilizer N, P, FYM and crop residue (CR) significantly increased water stable aggregates and had profound effects in increasing the mean weight diameter as well as the formation of macro-aggregates, which were the highest in both surface (85%) and subsurface (81%) soil layers with application of 20 kg N + 60 kg P_2O_5 + 10 t FYM + 6 t WR ha^{-1} applied to soybean and 120 kg N + 60 kg P_2O_5 + 3 t SR ha^{-1} applied to wheat crop in CA, respectively, and were 83% and 77% in CT treatments after 2 years. Hence, better aggregation was found with 100% NP + FYM + CR, where macro-aggregates were greater than 50% of total soil mass. Bhattacharya *et al*., 2013 found that the amount of water-stable large and small macro - aggregates in the ZT plots was significantly higher than in the CT plots in the 0- to 5-cm soil layer. Hence, the plots under CT had significantly smaller MWD than ZT plots in the 0- to 5-cm soil layer. Similarly, Naresh *et al*., 2015 reported as compared to the conventional tillage treatments, reduced and zero tillage treatments had significantly higher amount of total aggregate associated carbon within all the aggregate size classes in surface soil depth. In the 0 to 5 cm layer of soil with residue retention the organic C content in the large macro-aggregates was greater (av.4.9%) than in soil where residue was removed (av.3.4%), except in theT_2 treatment where it was similar (4.4%) to treatment T_7 (4.8%). In the small macro-aggregates, the greatest organic C was found in treatment T_9 (av.4.52%), while the lowest organic C was found in soil without residues cultivated with rice and rice-wheat in rotation (av.3.47%). Gupta Choudhury *et al*., 2014 revealed residue incorporation or retention caused a significant increment of 15.65% in total water stable aggregates in surface soil (0–15 cm) and 7.53% in sub-surface soil (15–30 cm), which depicted that residue management could improve 2.1-fold higher water stable aggregates as compared to the other treatments without residue incorporation/retention. Naresh *et al*., 2016 reported that FIRB and ZT with application of 6 tha^{-1} rice straw treatment also enhanced the labile C and N fractions such as water soluble C, particulate and light fraction organic matter from 7.1 mg·kg^{-1} conventional tillage to 17.6 mg·kg^{-1} in surface layer and from 6.5 to 16.3 mg·kg^{-1} in subsurface layer after 3 years leading to the 42% and 39% higher water soluble C stocks over CT in 0-15 cm soil layers, respectively.

Particulate Organic C and N

Ogle *et al.* (2005) found that management impacts were sensitive to climate in the following order from largest to smallest changes in SOC: tropical moist > tropical dry > temperate moist > temperate dry. For example, converting from conventional tillage to zero tillage increased SOC storage over 20 years by a factor of 1.23 ± 0.05 in tropical moist climates, which is a 23% increase in SOC, while the corresponding change in tropical dry climates was 1.17 ± 0.05, temperate moist was 1.16 ± 0.02, and temperate dry was 1.10 ± 0.03. Aulakh *et al.*, 2013 revealed that after 2 years of the experiment, in 0 - 5 cm soil layer of CT system, T_2, T_3 and T_4 treatments increased POC content from 390 mg·kg^{-1} in control (T_1) to 550, 646 and 780 mg·kg^{-1} without CR, and to 920, 1040 and 1310 mg·kg^{-1} with CR (T_6, T_7 and T_8), respectively. The corresponding increase of POC content under CA system was from 500 mg·kg^{-1} in control to 690, 730 and 910 mg·kg^{-1} without CR and 1050, 1110 and 1440 mg·kg^{-1} with CR.

Bhattacharya *et al.*, 2013 reported that tillage-induced changes in POM C were distinguishable only in the 0- to 5-cm soil layer; the differences were insignificant in the 5- to 15-cm soil layer. Plots under ZT had about 14% higher POM C than CT plots (3.61 g kg^{-1} bulk soil) in the surface soil layer. Six *et al.* (2000a) and Bhattacharyya *et al.* (2012), suggesting slower macro-aggregate turnover in the ZT plots compared with CT. This phenomenon might lead to micro-aggregate formation within macro-aggregates formed around fine intra-aggregate POM and to a long-term stabilization of SOC occluded within these micro-aggregates (Alvaro-Fuentes, 2009). Naresh *et al.*, 2015 also found that conservation tillage practices significantly influenced the total soil carbon (TC), total inorganic carbon (TIC), total soil organic carbon (SOC) and oxidizable organic carbon (OC) content of the surface (0 to 15 cm) soil. Wide raised beds transplanted rice and zero till wheat with 100% (T_9) or with 50% residue management (T_8) showed significantly higher TC, SOC content of 11.93 and10.73 g kg^{-1} in T_9 and 10.98 and 9.38 g kg^{-1},respectively in T_8 as compared to the other treatments. Irrespective of residue incorporation/ retention, wide raised beds with zero till wheat enhanced 40.5, 34.5, 36.7 and 34.6% of TIC, TC, SOC and OC in surface soil as compared to CT with transplanted rice cultivation.

Light Fraction Organic C and N

Oorts *et al.* (2007) stated that 58% of the difference in SOC between tillage and zero tillage was due to a difference in total POM (labile fraction). Alvaro-Fuentes *et al.* (2008) found higher POM-C levels and mineral-associated C fraction levels at the soil surface (0–5 cm) under zero tillage than under conventional tillage. Zero tillage increased the ratio of fine POM to total soil organic matter by 19 and 37% compared with tillage after 4 and 10 years, respectively (Pikul *et al.* 2007). After 19 years, Chan *et al.* (2002) observed that tillage and stubble burning resulted in lower levels of different organic C fractions compared to zero tillage and residue retention, respectively. Tillage preferentially reduced the particulate organic C (>53 ìm, both free and associated), whereas stubble burning reduced the incorporated organic C (<53 ìm). Hermle *et al.* (2008) concluded that the intermediate SOC fraction contributes up to 60% of the total SOC, but soil cover by plant residues under zero tillage favoured the accumulation of labile particulate C as compared to ploughing. Therefore, the observed higher SOC concentration (0–10 cm) for zero tillage compared to conventional tillage was mostly due to more labile organic matter. The importance of crop residue retention to the labile pool has also been reported by Graham *et al.* (2002): increased input of organic matter due to either increased return of crop residue or increased deposition due to higher yields (induced by fertilizer) caused a proportionally greater increase in labile organic matter than in total soil organic matter. Ha *et al.* (2008) reported that different residues resulted in different levels of POM, which cultivate distinct microbial communities.

Suitable soil tillage practice can increase the SOC content, and improve SOC density of the plough layer (Duan *et al.*, 2012). Effect of tillage methods on SOC dynamics depends on the tillage intensity (Haile *et al.*, 2008). Compared to conventional tillage (CT), no-tillage and reduced tillage could significantly improve the SOC content in cropland. The enhanced microbial activity induces the binding of residue and soil particles into macro-aggregates, which could increase aggregates stability thus improving the concentration of SOC and increasing C sequestration (Liqun *et al.*, 2014). Naresh *et al.*, 2015 reported that a considerable proportion of the total SOC was found to be captured by the macro-aggregates (>2 to 0.25 mm) under both surface (35.5%) and sub-surface layers (28.1%) leaving rest amount in micro-aggregates and <0.53 mm sized particles. Dou *et al.* (2008) found that ZT significantly ($P < 0.05$) increased the amount of SOC and the size of all labile SOC pools compared with CT, especially in the surface soil layer, after 20 yr in south-central Texas. The significantly higher labile SOC pool was probably also due to higher biomass C. Naresh *et al.*, 2016 showed that in 3-year experiment LFON content in 0 - 5 cm soil layer of CT system, T_1, and T_5 treatments increased LFOC content from 5.1 mg·kg^{-1} in CT (T_9) to 7.9 and 9.6 mg·kg^{-1} without CR, and to 10.3, 11.5 and 13.1 mg·kg^{-1} with crop residue @ 2, 4 and 6 tha^{-1}, respectively.

Influence of CA on biological soil quality

Potentially Mineralizable N

Kang *et al.*, 2005 found that application of organic residues increased PMN, which was positively related to increase in TOC content of soil. Walia and Kler, 2006 also found higher mineralizable N under organic farming treatments as compared to chemical fertilizers alone showing better availability of N under organic farming. Tirol-Padre *et al.*, 2007observed that PMN was highest with GM+NPK under anaerobic incubation. Aulakh *et al.*, 2013 showed that PMN content after 2 years of the experiment in 0-5 cm soil layer of CT system, T_2, T_3 and T_4 treatments increased PMN content from 2.7 mg·kg^{-1} 7d^{-1} in control (T_1) to 2.9, 3.9 and 5.1 mg·kg^{-1} 7d^{-1} without CR, and to 6.9, 8.4 and 9.7 mg·kg^{-1} 7d^{-1} with CR (T_6, T_7 and T_8), respectively. The corresponding increase of PMN content under CA system was from 3.6 mg·kg^{-1} 7d^{-1} in control to 3.9, 5.1 and 6.5 mg·kg^{-1} 7d^{-1} without CR and to 8.9, 10.3 and 12.1 mg·kg^{-1} 7d^{-1} with CR. PMN, a measure of the soil capacity to supply mineral N, constitutes an important measure of the soil health due to its strong relationship with the capability of soil to supply N for crop growth. The CT soil has reduced C concentrations from oxidation of labile SOM due to tillage (Purakayastha *et al.*, 2008). The contents of active carbon (AC) and microbial biomass carbon (MBC) in the long-term trial and contents of active carbon (AC) in the short-term trial were higher for conservation tillage (CT) than traditional tillage (TT) at 0–5 cm depth for both sampling periods (Melero *et al.*, 2009). Reported that microbial biomass and potentially mineralizable nitrogen in the 0–7.5 cm surface layer of no till soils were 34% higher than those of ploughed soils, although the opposite was true at 7.5- to 15-cm depth (Doran, 1987). Gupta *et al.* (1994) found higher values of microbial biomass in the first 5 cm of the soil profile under NT than under TT after one year of conservation management. Wright *et al.* (2005) found MBC to be greatest under no-till management but only in the surface 2.5 cm with little tillage effect to 20 cm (Wright *et al.*, 2005). Wright *et al.* (2005) found an increase of MBC and mineralizable N in the surface soil with corn and cotton cropping sequences for twenty years under no-till and minimum tillage systems but little change in MBC concentration in the 2.5 to 20 cm depths. The CT soil has reduced C concentrations from oxidation of labile SOM due to tillage (Purakayastha *et al.*, 2008). The contents of active carbon (AC) and microbial biomass carbon (MBC) in the long-term trial and contents of active carbon (AC) in the short-term trial were higher for conservation tillage (CT) than traditional tillage (TT) at 0–5 cm depth for both sampling periods (Melero *et al.*, 2009). In a Brazilian oxisol there was a consistent increase in biological activity and N mineralization with no-till management (Green *et al.*, 2007). Similar increases with depth have been observed in arid wheat based systems where total soil N (TSN) increased by38–68% (Dou and Hons, 2006). Interestingly, the CT soil mineralized as much N as the NT systems but had less TSN than NT (Purakayastha *et al.*, 2008). Tillage can greatly modify edaphic factors and thereby influences the rate of C mineralization (Huggins *et al.*, 2007; Curtin *et al.*, 2012). Therefore, measurement of a suite of SOC fractions and elucidation of the interactive relationships among different SOC fractions would perhaps more reflect tillage and N management induced changes in soil quality (Strosser, 2010).

Microbial Biomass C and N

The practice of crop residue retention and minimum tillage, in association with basal fertilizer application, increases the supply of C and N, which is reflected within one year in terms of increased microbial biomass, N-mineralization rates and available-N concentrations in the soil (Kushwaha and Singh, 2005). Studies conducted in Londrina, Brazil by Silva *et al.* (2010) reported that the microbial biomass carbon and nitrogen (MB-C and MB-N) values were consistently higher up to more than 100 % under NT in comparison to CT and were associated with higher grain yields. Population and diversity of genomic patterns of the N_2 fixing *Bradyhizobium* increased with no-till compared to conventional tillage in Southern Brazil. Nunez *et al*. (2012) reported bacterial diversity increase in zero tillage systems as compared to conventional tillage. Zero tillage proved to be more efficient than the other tillage systems (reduced and conventional tillage) in the conservation of organic carbon and microbial biomass carbon at the soil surface depth (0-5cm) as reported by Costantini *et al*. (1996).WenQing *et al*. (2011) reported higher organic matter content, microbial biomass C, microbial biomass N and enzyme activities in more superficial layers of soils under CA than in soils under conventional tillage. The increase in microbial populations, diversity and other biological indicators of soil health under CA practices can be attributed to a number of factors that favour microbial proliferation and activities. Wang *et al*. (2012) reported increased microbial biomass carbon with cropresidue application in comparison to no crop residue application.

Nyamadzawo *et al*., 2009 revealed that the favourable effects of ZT on soil structural properties may also be partly due to more activity of earthworms and more microbial biomass than in CT plots. Ghosh *et al*., 2012 found microbial biomass carbon (MBC) content of the soils varied from 250 to 776 $\mu g\ g^{-1}$ soil and the values constituted about 3.1% of the total SOC content of the soil. Although the addition of inorganic NPK (T_3) resulted in a significant increase in MBC over the control (T_2), this effect was significantly larger when fertilizer was applied along with the organic amendments .Microbial biomass nitrogen (MBN) content of the soils varied from 33.3 to 66.5 $\mu g\ g^{-1}$ soil, with the relative amount under different treatments as follows:

NPK + GM (T_6) >NPK+PS (T_5) >NPK+ FYM (T_4) = NPK (T_3) > fallow (T_1) > control (T_2). The amount of Min-C in the soils varied from 0.09 to 0.17 mg CO_2 24 h^{-1} g $soil^{-1}$, the relative magnitude under different treatments being as follows: fallow (T_1) >NPK (T_3) >NP +FYM (T_4)>NPK+PS (T_5) > NPK+GM (T_6) >control (T_2). James *et al*., 2010 revealed that long-term no-tilled soils have significantly greater levels of microbes, more active carbon, more SOM, and more stored carbon than conventional tilled soils. A majority of the microbes in the soil exist under starvation conditions and thus they tend to be in a dormant state, especially in tilled soils. Soil moisture conser-vation by NT is an important advantage even in industrial agriculture, as was the case during the summer drought of 2012 in the US Corn Belt (Lal *et al*. 2012; Goode 2015). In these situations, conver-sion to CA can also improve soil biological quality with respect to microbial com-munities (Zhang *et al*. 2012; Mathew *et al*. 2012), microbial growth and decomposition processes (Franzluebbers *et al*. 1995), soil food web and C dynamics. Spedding *et al*. (2004) found that residue management had more influence than tillage system on microbial characteristics, and higher SMB-C and N levels were found in plots with residue retention than with residue removal, although the differences were significant only in the 0-10 cm layer. Soil microbial biomass C and microbial biomass N are the sensitive biological indicators and are closely related to the cycle of C and N in the soil (Turner, Bristow, and Haygarth 2001). Meanwhile, the conversion rate of soil microbial biomass C and N can directly or indirectly reflect the changes in soil fertility (Vig *et al*. 2003). In this study, compared to the CIR method, the TIR method increased soil MBC by 13–240%, while soil MBN reduced by 6.5–47.3%, suggesting that alternating wetting and drying in TIR method can improve the soil MBC but cannot improve soil MBN.

Liu *et al*. (2012b) indicated that controlled and intermittent irrigation with continuous drying or alternating wetting and drying increases the MBC and MBN in paddy soil when compared to the flood irrigation, which is not fully in agreement with our study. Alvear *et al*. (2005) found higher SMB-C and N in the 0-20 cm layer under zero tillage than under conventional tillage (disk-harrowing to 20 cm) in an Ultisol from southern Chile and attributed this to the higher levels of C substrates available for microorganism growth, better soil physical conditions and higher water retention under zero tillage. Pankhurst *et al*. (2002) found that zero tillage with direct seeding into crop residue increased the build-up of organic C and SMB in the surface soil. Wright *et al*. (2005) found MBC to be greatest under no-till management but only in the surface 2.5 cm with little tillage effect to 20 cm

Proportion of Labile Organic C and N Fractions in Total Organic C and Total N

The significant increase in MBC in treatments containing FYM + CR could be ascribed to the availability of more carbon as was evident from several other fractions of TOC such as WSC, POM, LFOC, and MBC. The rapid build up of microbial biomass in subtropical conditions implies that MBN could serve as a potential source of mineralizable N for plant nutrition in such soils. MBC is an active component of SOM and constitutes an important soil health parameter as carbon contained within microbial biomass is a stored energy for microbial process. Thus MBC and MBN, the measure of potential microbial activity, are strongly related to soil aggregate stability.POM, dominated by un- decomposed plant residues that retain recognizable cell structures including fungal hyphae, seeds, spores, and fungal skeletons, is an active fraction of SOM, which supplies nutrients to the growing plants (Gregorich *et al*., 1996). POM-C and POM-N provide estimates of the intermediate pool of SOM between the active and passive pools (Cambardella and Elliott, 1992) and provide substrate for microorganisms and influence soil aggregation (Franzluebbers *et al*., 1999 and Six *et al*., 1999). LFOM, composed primarily of plant derived remains, and microbial and micro-faunal debris and other incompletely decomposed organic residues, is more sensitive to management practices than POM (Carter *et al*., 2003). Aulakh *et al*., 2013 found that an application of organic and inorganic fertilizers in soybean-wheat cropping system CA enhanced total organic C (TOC) from 3.8 $g \cdot kg^{-1}$ in no-NP-FYM-CR control to 5.8 $g \cdot kg^{-1}$ in surface layer and from 2.7 to 3.6 $g \cdot kg^{-1}$ in subsurface layer after 2 years leading to the 41% and 39% higher TOC stocks over CT-Control in 0 - 15 cm soil layers of CT and CA, respectively. The changes in TOC stocks after 4 years were 52% and 59%.Likewise, the labile C and N fractions such as water soluble C, particulate and light fraction organic matter, potentially mineralizable N and microbial biomass were also highest under this integrated inorganic and organic treatment.

Kumar *et al*., 2015 reported that the contents of TOC, WSOC, EOC, HEC, HAC, HMC and BC, MBC were all higher in the residue retained tillage crop establishment than in the without residue and conventional tillage treatments. The increase amplitudes were larger for the EOC and HEC (65.5 and 53.2%) than for the HAC, HMC and BC (14.0, 17.7 and 16.1%). Similarly, higher soil organic C contents under zero till with residue return than under conventional tillage, under reduced tillage than under conventional tillage (Šimanský *et al*., 2008), have been reported. The short-term (10 years) effects of management on soil organic carbon (SOC) are complex and vary with soil conditions such as soil texture, climate, cropping system and kind of crop residue, as well as with the management itself (Al-Kaisi *et al*., 2005; Munoz *et al*., 2007). Compared with CT, ST and NT had significantly higher SOC concentration (Awale *et al*., 2013). Generally, the soil organic matters (SOM) in all treatments were generally higher under conservation than under conventional tillage (Vogeler *et al*., 2009).

Emission of Gaseous and Aerosol Species

Emissions from open biomass burning over tropical Asia were evaluated during seven fire years from 2000 to 2006 by Chang *et al.* (2010). Venkataraman, (2006) have inventoried the emissions from open biomass burning including crop residues in India using Moderate Resolution Imaging Spectro- radiometer (MODIS) active fire and land cover data approach. Sahai *et al.* (2007) have measured the emission of trace gases and particulate species from burning of wheat straw in agricultural fields in Pant Nagar, Uttar Pradesh.

Sahai *et al.* (2011) have estimated that burning of 63 Mt of crop residue emitted 4.86 Mt of CO_2 equivalents of GHGs 3.4 Mt of CO and 0.14 Mt of NOx. ZT reduced the C emission of farm operations with 74 kg C ha^{-1} y^{-1} compared to CT. This may seem a small difference, but while the amount of C that can be sequestered in soil is finite, the reduction in net CO_2 flux to the atmosphere by reduced fossil-fuel use can continue indefinitely (West and Marland, 2002). The net GWP (taking into account soil C sequestration, emissions of GHG from soil and fuel used for farm operations and the production of fertilizer and seeds) was near neutral for ZT with crop residue retention (40 kg CO_2 ha^{-1} y^{-1}), whereas in the other management practices it was approximately 2000 kg CO_2 ha^{-1} y^{-1}.Rochette (2008) concluded that N_2O emissions only increased in poorly-drained finely-textured agricultural soils under zero tillage located in regions with a humid climate, but not in well-drained aerated soils. Mosier *et al.*, 1991 also reported that a better aerated soil with no tillage and residue retention would also favor CH_4 reduction and inhibit CH_4 production. However, soil as a sink for CH4 is far less important than as a source for N_2O.

Incorporation of cereal residues into paddy fields at optimum time before rice transplanting can help in minimizing the adverse effect on rice growth and CH_4 emissions. The incorporation of wheat straw before transplanting of rice showed no significant effect on N_2O emission due to immobilization of mineral N by high C/N ratio of the straw incorporated (Ma *et al.* 2007). However, an increase in N_2O emission from fields with mulch compared to those with incorporated residue has been observed in subtropical Asian rice-based cropping systems Baggs *et al.* (2003) speculated that timing residue return such that the N becomes available when needed by the upland crop should minimize N_2O emission as compared with residue return at the beginning of the preseason fallow. CRM is unlikely to have significant overall effects on CH_4 emission in upland crops like wheat. For any CH_4 to be produced there must be at least a small number of anaerobic microsites for methanogenic bacteria to grow, so any treatment that makes the soil more anaerobic is likely to increase the risk of CH_4 emission, including a rainfall event or mulch application. As in flooded systems, any action that causes residue to decompose before becoming anaerobic will lessen the risk of CH_4 emission. From the perspective of mitigating GHG emissions from wheat crop in RW cropping system, residues are not the primary crop management concern. When soil is at or near field capacity, there would be such little CH_4 formation and N_2O emission and the effect of CRM would be negligible (Bijay- Singh *et al.* 2008).

CONCLUSION

CA practices improve soil aggregation; reduce bulk density in long run due to the presence of carbon pool and improvement of soil structure. Infiltration is generally higher and runoff reduced under CA as residues present in surface prevent crust formation on surface, reduce runoff velocity and more elapse time for infiltration. The higher amount of SOC in surface soil layer in CA is due to higher accumulation of crop residue which also increases the availability of mineral. Soil conservation management improved the quality of the soil by enhancing the labile and total organic carbon fractions and biological status. The enhanced proportions of WSC, POM-C, LFOM-C, MBC in TOC and that of POM-N, LFOM-N, MBN in CA with the supply of optimum and balanced N, P and organic manures and incorporation of crop residues indicate that the improvement in labile forms of both C and N was relatively rapid than control suggesting that active C and N pools reflect changes due to integrated nutrient management (INM). INM significantly increased water stable aggregates and had profound effects in increasing the mean weight diameter as well as the formation of macro-aggregates.

Emission of different air pollutants due to crop residue burning varied greatly among the different states of India depending on the residue generated, their utilization pattern and fraction of residues subjected to burning. The major states where maximum amount of crop residues were burnt on farm are Punjab, Uttar Pradesh, Haryana and Maharashtra. Rice, wheat and sugarcane are the major crops whose residues are subjected to on farm. Large scale burning of crop residues from rice-wheat system of Punjab, Haryana and western Uttar Pradesh is a matter of serious concern not only for GHG emission but also for problems of pollution, health hazards and loss of nutrients. There is a need to validate the emission estimates experimentally and the associated uncertainty in the estimates. The residues can be put to various productive usages such as incorporation in the fields, bio-energy etc. and this is possible only if residue is collected and managed properly. Awareness must be created amongst the farming communities about the negative impacts of crop biomass burning and importance of crop residues incorporation in soil for maintaining sustainable agricultural productivity.

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