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Soil organic Carbondynamics in Conservation Agriculture

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ABSTRACT
Conservation agriculture is not a single component technology but a system that includes the cumulative effect of all its three basic components viz. minimum soil disturbance, at least 30 per cent of the soil surface being covered with crop residues after seeding of the subsequent crop and crop intensification component. Tillage, residue management and crop rotation have a significant impact on soil organic carbon (SOC) and nutrient distribution and transformation in soil. Increased stratification of SOC is generally observed, with enhanced conservation and availability of nutrients near the soil surface under conservation tillage as compared to conventional tillage. Hence understanding the impact of conservation agriculture on SOC dynamics is important for developing sustainable agriculture production systems.
Key words: Conservation agriculture, Soil organic carbon, carbon dynamics

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INTRODUCTION

Conventional "arable" agriculture is normally based on soil tillage as the main operation. Long term continuous use of this process leads to a reduction of soil organic matter and its quality. Soil organic matter not only provides nutrients for the crop, but it is also, above all else, a crucial element for the stabilization of soil structure and other physical conditions. Therefore, most soils degrade under prolonged intensive agriculture practices. This structural degradation of the soils results in the formation of crusts and compaction and leads more runoff from soil surface and to soil erosion turns reducing rain water productivity. Mechanization of soil tillage, allowing higher working depths and speeds and the use of certain implements like ploughs, disk harrows and rotary cultivators have particularly detrimental effects on soil structure. Soil erosion resulting from soil tillage has forced us to look for alternatives and to reverse the process of soil degradation [12]. The logical approach to this has been to reduce tillage and maintaining crop residues on the surface, this led finally to movements promoting conservation tillage. Conservation Agriculture (CA) is an approach, which involve designing and management of sustainable resource-conserving agricultural systems to make agriculture more resilient, productive and profitable. It seeks to conserve, improve and make more efficient use of natural resources through integrated management of soil, water, crops and other biological resources in combination with selected external inputs. Such a technological interventions represents a resource saving and efficient agriculture that contributes to environmental conservation and at the same time enhances production on a sustainable basis [17].

Conservation agriculture has been proposed as a widely adapted set of management principles that can assure more sustainable agricultural production. Conservation tillage is widely-used terminology in CA to denote soil management systems that result in at least 30 per cent of the soil surface being covered with crop residues after seeding of the subsequent crop [16]. This helps to improve the soil organic carbon, physical, chemical and biological properties of the soil. Tillage, residue management and crop rotation have a significant impact on nutrient distribution and transformation in soil. Increased stratification of nutrients is generally observed, with enhanced conservation and availability of nutrients near the soil surface under conservation tillage as compared to conventional tillage [5]. The altered nutrient availability under conservation tillage may be due to surface placement of crop residues. Slower decomposition of surface placed residues may prevent rapid leaching of nutrients through the soil profile, which is more likely when residues are incorporated into the soil. The response of soil chemical fertility to tillage is site-specific and depends on soil type, cropping systems, climate, fertilizer application and management practices. Hence, understanding the impact of conservation agriculture on soil nutrient dynamics is important for developing sustainable agriculture production systems [18]. More importantly, CA practices reduce resource degradation. CA leads to sustainable improvements in efficient use of water and nutrients by improving nutrient balance and availability, infiltration and retention by the soil, reducing water loss due to evaporation and improving the quality and availability of ground and surface water.

Table 1: Status of conservation agriculture

Country	Area (M ha)	% of Global area
USA	26.5	21.2
Brazil	25.5	20.4
Argentina	25.5	20.4
Australia	17.0	13.6
Canada	13.5	10.8
Russia	4.5	3.6
China	3.1	2.5
Paraguay	2.4	1.9
Kazakhstan	1.6	1.3
India	**1.25**	**1.1**
Others	4.05	3.1
Total	**124.8**	**100**

Source: [11]

INFLUENCE OF CONSERVATION AGRICULTURE ON SOIL ORGANIC CARBON

Conservation agriculture is not a single component technology but a system that includes the cumulative effect of all its three basic components. The crop intensification component will result inan added effect on SOC in zero tillage systems. West and Post [30]reported that although relative increases in SOC were small, increases due to the adoption of zero tillage were greater and occurred much faster in continuously-cropped than in fallow-based rotations. Sisti *et al*. [27] found that under a continuous sequence of wheat (winter) and soybean (summer) the concentrations of SOC to 100 cmdepth under zero tillage were not significantly different from those under conventional tillage. However, in the rotations with vetch planted as a winter green-manure crop, SOC concentrations were approximately 17 Mg ha^{-1} higher under zero tillage than under conventional tillage. It appears that the contribution of N_2 fixation by the leguminous green manure (vetch) in the cropping system was the principal factor responsible for the observed C accumulation in the soil under zero tillage, and that most accumulated C was derived from crop roots. To obtain an accumulation of SOM there must be not only a C input from crop residues but a net external input of N e.g. including an N-fixing green manure in the crop rotation [27]. Conventional tillage can diminish the effect of an N fixing green-manure either because the N-input can be reduced by soil mineral N release or the N canbe lost by leaching (NO_3^-) or in gaseous forms (via Denitrification or NH_3 volatilisation) due to SOM mineralization stimulated by tillage [2]. Hence, intensification of cropping practices by the elimination of fallow and moving toward continuous cropping is the first step toward increased SOC contents. Reducing tillage intensity, by the adoption of zero tillage enhances the cropping intensity effect.

SOIL ORGANIC CARBON FRACTIONATION

Hermle *et al*. (2008) distinguished the following soil C fractions: (i) the easily decomposable fraction(labile), representing an early stage in the humification process, (ii) material stabilised by physical–chemical mechanisms (intermediary) and (iii) the biochemically recalcitrant fraction (stable). The different carbon fractions of the soil have different availability and turnover times in the soil. The SOC of the labile pool, which consists mainly of particulate organic matter (POM) and some dissolved organic carbon, is readily available and consequently rapidly decomposed while the resistant SOC fraction is old, in close contact with mineral surfaces, and provides limited access to micro-organisms[14]. The labile fraction plays a crucial role in the formation of aggregates (Six *et al*.2001), and responds rapidly to changes in soil management because of its rapid turnover time[13]. Therefore, it can be a good indicator of early changes in SOC, 58% of the difference in SOC between tillage and zero tillage was due to a difference in total POM (labile fraction).Research generally shows an enrichment of the organic matter in labile forms as tillage intensity reduces [8]. Some studies use different POM characteristics (e.g. fine, coarse…), complicating comparisons. Zero tillage favours the accumulation of decomposable C. 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 [26]. After 19 years, Chan et al. [8] 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 μm, both free and associated), whereas stubble burning reduced the incorporated organic C (<53 μm).Hermle *et al.* [14] concluded that the intermediate SOC fraction contributes up to 60% of thetotal 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. 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. According to Pikul *et al.* [26], systems thatused more diverse crop rotations (maize-soyabean, maize-soyabean-spring wheat-alfalfa [*Medicagosativa* L.], maize-soybean-oat and pea hay [*Pisum sativum* L.]-Alfalfa-alfalfa) had greater proportions of fine POM than monoculture (continuous maize). The effects of tillage system on light fraction C were less than those of cropping intensity (fallow frequency). Also Arshad *et al.* [3] found an effect of crop rotation and fallow intensity on light fraction C under zero tillage. Light fraction C was greater under continuous wheat than under other crop rotations, but especially greater than under the rotation with fallow.

Table 2: Soil organic carbon on equivalent mass basis as affected by tillage system (5 years)

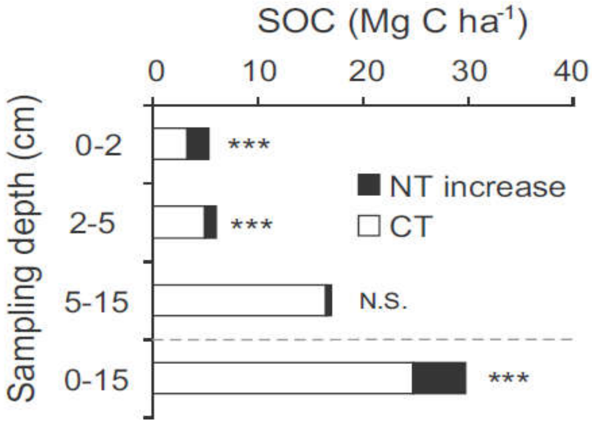
Depth	**October 2002**			**June 2007**		
	NT	**MT**	**CT**	**NT**	**MT**	**CT**
C stocks, Mg/ha						
0-5 cm	12.39a	7.35b	6.56c	14.38a	7.86b	6.83b
5-10 cm	9.59a	8.01b	6.46c	10.93a	7.96ab	6.75b
10-20 cm	9.56a	9.40a	8.90a	9.09a	9.66a	9.25a
20-30 cm	7.95b	7.78b	9.06a	6.71b	7.25a	7.96a
Soil (0-30cm)	39.49a	32.54b	30.98b	41.11a	32.73bc	29.80c

Lopez and Pardo (2009)

Note: Cropping system: Pea-barley;NT= no tillage; MT= minimum tillage; CT = conventional tillage.

Lopez and Pardo [21] conducted the experiment for five years to know the effects of tillage practices on soil organic carbon over different soil depths and observed that in the 0–30 cm depth, SOC and N had increased under NT and ZT compared with MT and CT. Most dramatic changes occurred within the 0–5 cm depth where plots under NT and ZT had respectively 7.0 Mg ha^{-1} and 6.2 Mg ha^{-1} more SOC as compared to CT (6.56 Mg ha^{-1}). Chatterjee and Lal [9] also found in the same no tillage (NT) treatment higher SOC concentration by 30, 50 and 67 % and higher N content by 27, 44 and 54 % over plough tillage (PT) soils at 0–5 cm depth in the experiment conducted for more than four years in three different places of USA. Similar results were also observed by Kasper *et al.* (2009) highest amounts of organic C (C_{org}) and total N (N_{tot}) were recorded under MT in all three aggregate fractions 630–1,000, 250–630 and 63–250 μm, with 8.9 %, 3.8 %, and 1.3 % for C_{org}, and 0.4 %, 0.3 %, and 0.1 % for N_{tot}. Apart from the fraction 630–1,000 μm, the aggregates of RT and CT contained <50 % of the C_{org} and N_{tot} values of MT. The dissolved organic carbon release from stable aggregates after 10 min of ultrasonic dispersion was highest from MT soil (86.7 mg l^{-1}). The values for RT and CT were 21% and 25% below this value. The results indicated that tillage type influences both aggregate stability and aggregate chemical composition. These findings confirm that CT interferes more with the natural soil properties than RT and MT. Furthermore, MT had the highest potential to sequester C and N. The soil organic C stored under NT was mainly accumulated in the top 2-cm of soil. The biological indicators showed a greater biological soil quality under NT than under CT.Soil organic carbon (SOC) and nutrient content improved under residue management. Raised bed with residue + hedge leaves mulching (NT) resulted in the maximum SOC stock, and it was 2.0 $Mgha^{-1}$ and 2.7 Mg ha^{-1} higher than that of the antecedent level and FP, respectively under rainfed groundnut–rapeseed cropping system [20].

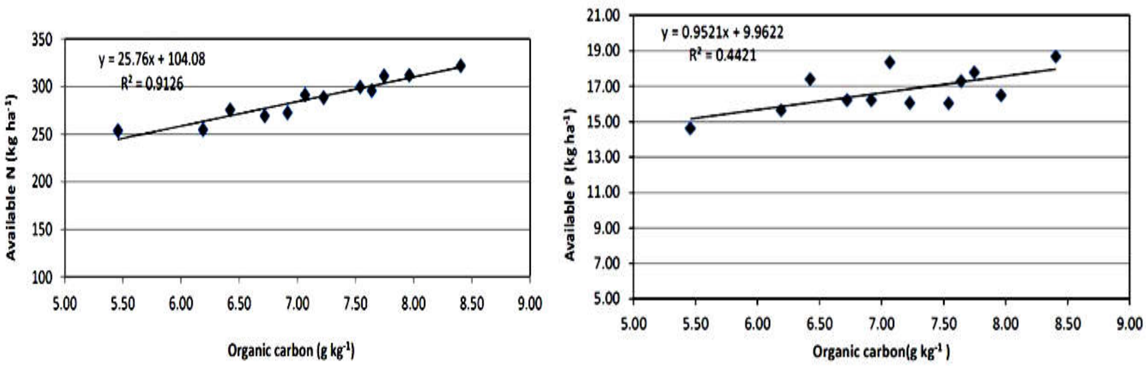
Fig 1: Total soil organic carbon after 9 years due to Tillage system effects

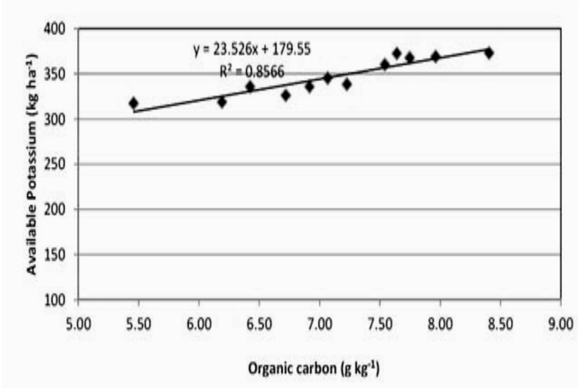


Martinez *et al.* (2013)

Minimum (MT) or no tillage (NT) and increased cropping intensity can enhance soil structure and raise carbon sequestration in agricultural soils. Soil organic carbon (SOC) is a good indicator of soil quality and conservation. Aurora and Avelino (2010) conducted ten-year study of conservation tillage and crop rotation in a semi-arid area and reported that SOC was 25 % greater with NT than CT, 16 % greater with NT than MT, and 17 % higher with MT than CT. Crop rotation had non-significant effect on the SOC content in different soil depths. Similarly Mishra *et al*. [23] reported that reduced soil disturbance in NT system slows the decomposition of SOC which increases soil C sequestration. They observed CT soils have 26–55 % lower SOC and 7–34 % lower N pool compared to undisturbed soils. Most of the historic SOC and N losses in cultivated soils occurred within the plough (0–25 cm) layer. Tabaglio *et al*. [29] also reported that NT significantly increased SOC (+ 15.8 %), total N (+ 9.6 %), C/N (+ 5.3 %), exchangeable K (+ 37.1 %) and wet aggregate stability (+ 64.8 %) in maize as compared to CT. The effectiveness of these procedures depends on soil type, crops, and tillage management systems. Increases in the organic carbon content may be affected by crop type, crop rotation and the quality and quantity of crop residues left on the soil surface. The present study was conducted for 10 years and they found that at a depth of 0–10 cm, the SOC content was significantly higher with NT than CT or MT, by 58% and 11%, respectively. SOC values were 41% higher with MT, in turn, than with CT. At a depth of 10–20 cm, the SOC content was 30% higher with NT than with CT and 7% higher than with MT. And at 20–30 cm, it was 7% higher with MT than with CT, 12% higher with NT than CT and 9% higher with no-till than minimum-till. In 2004, at the end of the 10 years period, SOC was 25% greater with NT than CT, 16% greater with NT than MT, and 17% higher with MT than CT. Crop rotation was not observed to have any significant effect on the SOC content in last year, however. These findings suggest that carbon sequestration in the 30 cm layer can be improved if NT or MT are used in conventional practice. The total crop residue returning to the soil was significantly greater in plots sown with legume after cereal harvest than in plots left fallow.

Fig: 2 Correlation between available N, P and K with organic carbon of the soils





Ayeshamohanty and Mishra (2014)

Tillage would increase net soil N mineralization rate (NMR) and reduce amount of SOC. But, these changes would depend on frequency of the tillage, *i.e*. greater would be the tillage frequency, higher the NMR and decline in the amount of SOC. Low tillage would increase NMR, but reduce SOC nearly equal to short term zero tillage. Increase in the NMR, the SOC declined in all tillage treatments, but the decline was the highest in the frequent till and the lowest in the long term zero till treatment[25]. The SOC in the low till (7.9 mg g^{-1}) treatment was nearly equal to that in the short term zero till treatment (8.8 mg g^{-1}). These results suggested that low tillage might be a good option for soil fertility maintenance and carbon stock build-up in the soils of the hot humid tropics. Notillage increased labile and more recalcitrant bio-products, soil organic C and total N compared to CT. Carmen *et al.* [7]suggested after 25 years of experimentation that NT in conjunction with crop rotation can be recommended for increased soil C sequestration.

The carbon-based sustainability index and carbon efficiency was significantly higher under permanent beds compared to zero and conventional till [17]. Choudhary [10] also found changes in the soil organic carbon content due to tillage practices over different depths. SOC was lowered at all soil depths from 0–5 to 25–30 cm (5 cm interval) under conventional tillage (1.54 %, 1.99 %, 1.53 %, 1.30 %, 0.49 % and 1.06 %, respectively). However, ZT registered higher SOC, 1.71 %, 0.91 %, 0.57 %, 0.65 %, 0.49 % and 0.10 %, respectively, at different soil depths from top to 30 cm soil depths from the initial SOC status of the soil. Comparatively SOC was higher at upper layer of soil and as depth increased SOC gradually decreased. Mohammad *et al*. [24] found similar results after four years of experimentation, average of the total OC content of soil was increased (0.43 t ha^{-1}) in no-tillage treatment (13.07 t ha^{-1}) than in tillage (12.64 ha^{-1}).

Alam *et al.*[1]observed after four years, highest organic matter content of the range 1.7 per cent was found in ZT and the lowest (1.2 %) in DT (deep tillage) during both years. The total N content was 73.6, 32.0, and 13.8% higher in ZT than the DT, CT, and MT, respectively. On an average, in NT the SOC stocks at 0–5 cm depth was greater than those of CT by 20%, soil total nitrogen stocks by 25 % and particulate organic carbon (POC) by 20 % in soybean based cropping systems. Same system accumulated mineral-associated organic C to the tune of 9% greater as compared to conventional tillage. NT systems with diversified crop species significantly increased SOC stocks ranging by 6 to 28 % and POC stocks by 56–127 % in the surface soils and tended to restore SOC and POC in the subsoil layers after five years [15].Similar findings were observed after 33 years, NT and DD (double disk) management increased SOC by 1.2 times and mean weight diameter (MWD) of aggregates by 2 times compared with CH (chisel) and PT (plough tillage) at 0–10 cm depth. At the 0–20 cm, NT had 1.1 times higher SOC concentration than CH and PT. When compared with data collected 24 years prior to this study, SOC at the 0–20 cm increased by 12.5 % across NT, DD, and CH and by 2.7 % for PT. No-till had 5 times higher total particulate organic matter concentration than PT, 4.7 times higher than CH, and 2.4 times higher than DD at the 0–10 cm depth [19].

CONCLUSION

- Combination of no tillage or reduced tillage with crop residue retention and crop diversity/intensity will increase the soil organic carbon in the top soil inturn increases the more microbial activities.
- Conservation agriculture may stimulate a gradual release of N in the long run and can reduce the susceptibility to runoff, leaching and denitrification losses.

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