



Soil organic carbon, carbon sequestration, soil microbial biomass carbon and nitrogen, and soil enzymatic activity as influenced by conservation agriculture in pigeonpea (*Cajanus cajan*) + soybean (*Glycine max*) intercropping system

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ABSTRACT

Field experiments were conducted during the year 2014-15 and 2015-16 at MARS, Dharwad, Karnataka to study the influence of conservation agriculture (CA) practices on soil health in a pigeonpea [*Cajanus cajan* (L.) Millsp] + soybean [*Glycine max* (L.) Merr.] intercropping system. The experiment consisted of 6 tillage systems [CT₁: No tillage with broad bed and furrow (BBF) and crop residue retained on the surface, CT₂: Reduced tillage with BBF and incorporation of crop residue, CT₃: No tillage with flatbed and crop residue retained on the surface, CT₄: reduced tillage with flatbed and incorporation of crop residue, CT₅: Conventional tillage with incorporation of crop residue and CT₆: Conventional tillage without crop residue]. The experiment was laid out in strip block design and replicated thrice. The CA treatments significantly improves soil health. The pooled data revealed that, all the CA systems i.e. CT₁, CT₂, CT₃ and CT₄ recorded significantly higher soil organic carbon at 0-15 cm depth (0.62, 0.64, 0.60 and 0.62 %, respectively) and 15-30 cm depth (0.56, 0.56, 0.54 and 0.55 %, respectively), higher soil carbon sequestration (15.1, 15.4, 14.6 and 14.7 t/ha, respectively) over conventional till systems. However, soil microbial biomass carbon and nitrogen were significantly higher in all the CA systems. While, significantly higher soil urease activity (11.76, 11.86, 11.10 and 11.44 µg NH₄-N/g/day), dehydrogenase activity (32.29, 32.29, 31.14 and 31.55 µg TPF/g/day) and total phosphatase activity (173.21, 174.55, 170.09 and 173.21 µg PNP/g/hr) were recorded in CT₁, CT₂, CT₃ and CT₄ over CT₅ and CT₆.

Key words: Carbon sequestration, Conservation agriculture, Enzymatic activity, No tillage, Reduced tillage, Soil microbial carbon and nitrogen, Soil organic carbon

Tillage includes all operations and practice that are followed for the purpose of modifying the physical characteristics of soil so as to provide favourable conditions. Tillage is the most difficult and time consuming work in production of crops. It has been estimated that on an average about 30% of the total expenditure of crop production is towards tillage operations (Prashanth 2013). There is plenty of scope in reducing this expenditure if the objectives of tillage are understood and if the operations are carried out at the right time with proper implement (Rangaswamy 2000). This intensive soil cultivation has worldwide resulted in the degradation of agricultural soils with decrease in soil organic matter, loss of soil structure, thus adversely affected soil health and caused a long term threat to future yields and soil health (Bujarbaruah 2004).

Carbon pools act as storage houses for large amount

of carbon. Any movement of carbon between these carbon pools is called a flux. Soil plays a major role in maintaining balance between global carbon cycle through sequestration of atmospheric carbon as soil organic carbon. Soils store about three times as much carbon as the terrestrial vegetation. Soil C pool comprises soil organic carbon (SOC) and soil inorganic carbon (SIC) pool (Lal 2004). Soil organic carbon and carbon sequestration builds soil fertility, improves soil quality and agronomic productivity, protect soil from compaction and nurture soil biodiversity. Increased organic matter in soil, improves soil aggregation, which in turn improves soil aeration, soil water storage, reduces soil erosion, improves infiltration, and generally improves surface and groundwater quality. This enhanced soil health, facilitates use of agricultural inputs in an efficient manner and helps in sustaining agricultural productivity at higher level. It is also helpful in the protection of streams, lakes, and rivers from sediment, runoff from agricultural fields, and enhanced wildlife habitat. Besides these, it has major roles in mitigating GHG (green house gas) emissions and tackling the effects of climate change.

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Conservation tillage is defined as any tillage practice that minimizes the loss of soil and water, which often requires the presence of at least 30% of the mulch or crop residue on the soil surface throughout the year. Conservation tillage minimizes soil erosion, conserves water within the root zone and improves soil fertility and productivity (Derpsch 2005). Intercropping of short duration crops in the inter space between two rows of a wide spaced crops like pigeonpea, which has initial slow growth, can help in better resource utilization, soil cover and stabilize crop productivity by reducing impact of weather vagaries and increase the cropping intensity (Ghosh 2010).

MATERIALS AND METHODS

Field experiments were carried out in the fixed experiment site of Conservation Agriculture Project plot at the Main Agricultural Research Station (MARS), University of Agricultural Sciences, Dharwad (Karnataka) during the year 2014-15 and 2015-16 on *vertic inceptisols* with neutral pH (7.4), soil organic carbon (0.52%), available nitrogen (261.58 kg/ha), available phosphorus (32.26 kg/ha) and available potassium (307.20 kg/ha). Dharwad is located at 15° 26'N latitude and 75° 7' East longitude and at an altitude of 678 m above the mean sea level. The region receives an average annual rainfall of 711.44 mm, which was well distributed from April to November.

During 2014, the total annual rainfall received was about 962.4 mm which was 34% more than normal. The delayed onset of monsoon during *kharif* (July) resulted in delayed sowing of *kharif* crops. The rainfall received during *rabi* season mainly during October and November was 152.2 mm and the October rainfall was 17% less than the normal. However, the rainfall of 48.8 mm received in November which was 15% higher than the normal helped to get good crop stand and optimum yield. The highest and lowest mean monthly maximum temperatures recorded were 37.8°C and 27°C, respectively during the months of May and August, respectively. Whereas mean monthly minimum temperature ranged from 14.5°C (December) to 21.6°C (June). Mean monthly maximum relative humidity of 89% and mean monthly minimum relative humidity of 42% were observed during the month of June and March, respectively. During 2015, the total rainfall received was 716.2 mm which was 3% less than the normal rainfall. The crops were sown early in *kharif* (June) as compared to first year. In June and October, there was 160.2 and 179.8 mm rainfall, respectively. During crop growth period (July, August and September), there was less rainfall received (42.8 mm, 34.4 mm and 22.4 mm, respectively) and it was about 73, 66 and 79% lesser than the normal rainfall hence, one protective irrigation was given through sprinkler on 18th of August. Dry spells during August, September and October affected the growth and development of the crops during early stages of crops which resulted in lower productivity. The highest and lowest mean monthly maximum temperatures observed were 35.1°C and 28.6°C, respectively during the month of April and January,

respectively. Similarly, highest and lowest mean monthly minimum temperature were recorded in the month of May (21.9°C) and January (13.3°C). Mean monthly maximum relative humidity of 80% and monthly maximum relative humidity of 40% was observed during the month of June and February, respectively.

The experiment was laid out in strip block design and replicated thrice. A pigeonpea [*Cajanus cajan* (L.) Millsp.] + soybean [*Glycine max* (L.) Merr.] intercropping system was conducted in the experimental site under six different tillage systems, viz., CT₁: No tillage with BBF and crop residue retained on the surface, CT₂: Reduced tillage with BBF and incorporation of crop residue, CT₃: No tillage with flatbed and crop residue retained on the surface, CT₄: reduced tillage with flatbed and incorporation of crop residue, CT₅: Conventional tillage with incorporation of crop residue and CT₆: Conventional tillage without crop residue

The experiment was initiated during 2013-14 and conservation tillage plots were permanently maintained with bigger plot size of 15 m width and 9 m length. In convention plots, the land was ploughed with mould board plough once, cultivated and harrowed and soil was brought to fine tilth. In conservation tillage plots, minimum tillage for crop residue incorporation with rotovator two months before sowing and no tillage plots maintained with crop residue shredding and retention on the surface during 1st week of April, till than residues were maintained on the surface. Intercrops i.e. soybean (Dharwad soybean- 21) was sown at 30 cm spacing with the help of tractor drawn seed drill by skipping one row for every two rows and in a skipped row pigeonpea (TS 3R) seeds were dibbled in the spacing of 90 cm × 30 cm. After every 6 rows (180 cm), a row was skipped for opening furrow (30 cm) which help to layout Broad Bed and Furrows (BBF) with 180 cm bed and 30 cm furrow immediately after sowing of the crops. All the recommended package of practices for pigeonpea and soybean were followed to raise the healthy crops.

Paraquat, a contact herbicide, was sprayed to kill the established weeds 10 days before sowing. The crop was weed free upto 30 days by pre-emergence application of pendimethalin and later weeds were managed by post emergence application of imazethapyr at 30 DAS with the help of hand operated knapsack sprayer.

Soil samples were collected and analyzed for important soil properties after the harvest of crops. Three samples were collected from each plot and composited. The collected soil samples were air dried, grinded, passed through 2 mm sieve and stored in polythene bags for further analysis. Fresh soil samples at 20 cm depth were collected and kept under refrigeration for estimation of soil microbial biomass carbon (SMB-C) and nitrogen (SMB-N) and enzymatic activity.

Organic carbon content in soil was estimated by Walkley and Black's wet oxidation method (Jackson 1967).

Soil microbial biomass carbon and nitrogen was estimated by fumigation and extraction method (Carter

1991) by using following formula.

$$\text{MBCg of soil} = \frac{\text{Ninhydrin reactive N in unfumigated soil} - \text{Ninhydrin reactive N in fumigated soil}}{\text{Weight of soil sample}} \times 24$$

$$\text{MBCg of soil} = \frac{\text{Ninhydrin reactive N in unfumigated soil} - \text{Ninhydrin reactive N in fumigated soil}}{\text{Weight of soil sample}}$$

Urease activity of the soil at 75 DAS was determined by following the procedure as given by Pancholy and Rice, (1973).

Dehydrogenase activity of the soil sample at 75 DAS was determined by following the procedure as described by Casida *et al.* (1964).

Phosphatase activity of soil sample at 75 DAS was determined by following the procedure of Eivazi and Tabatabai (1979).

The data obtained from various studies were statistically analyzed following the procedure as described by Gomez and Gomez (1984). The level of significance used in 'F' tests was P = 5% and 1% and the mean values were separately subjected to Duncan's Multiple Range Test (DMRT) using the corresponding error mean sum of squares and degrees of freedom values under M-STAT - C program.

RESULTS AND DISCUSSION

Soil organic carbon (SOC)

The SOC was significantly influenced by tillage practices at 0-15 and 15-30 cm depths (Table 1). At 0-15 cm, pooled data showed that the conservation tillage with BBF and incorporation of crop residue (CT₂) recorded significantly higher SOC (0.64 %) as compared to conventional tillage with incorporation of crop residue (CT₅) and without crop residue (CT₆) (0.56 and 0.48%, respectively) and it was at par with conservation tillage with BBF and crop residue

retained on the surface (CT₁, 0.62%) and conservation tillage with flat bed with incorporation of crop residue (CT₄, 0.62%). At 15-30 cm, all the conservation tillage practices such as CT₁, CT₂, CT₃ and CT₄, recorded significantly higher SOC (0.56, 0.56, 0.54, 0.55 % respectively) as compared to conventional tillage with (CT₅, 0.48 %) and without crop residue (CT₆, 0.39%). The higher amount of SOC in surface soil layer under conservation till might be due to higher accumulation of crop residue that derived carbon and lesser exposure of previous crop roots even after the crop harvest that reduced the oxidative losses of roots (West and Post 2002). While conventional tillage cause the greater incorporation of residues in the soil, its physical breakdown, overturning of soil and increase aeration, improve soil residue contact and disruption of soil aggregates that leading to oxidation of SOM and erosion which lowers SOC content in the surface soil (Roldan *et al.* 2003). Conventional tillage incorporates residue into moister environment where decomposition is fast as compared to residues left in soil surface (Halvorson *et al.* 2002). The higher SOC content in the plots under conservation tillage than conventional tillage plots might be attributed in part to less disruption of soil structure and aggregates (Das *et al.* 2013). During summer, conventional tilled soils tend to expose to sunlight which increases the loss of soil organic carbon due to increase in accelerate rate of decomposition of soil organic matter. Retention of crop residues and soil surface cover under conservation till during summer resulted in declining soil organic carbon loss, protect the SOC from water and wind erosion. Combined effect of conservation tillage with effective utilization of crop residue increased the soil organic carbon due to addition of organic matter through residue resulted in better root growth, decomposition of these residues and plant root exudates by microbial activity which resulted in leaching of organic matter constituents from the residue enriched layer to just above the bottom of plough zone (Gal *et al.* 2007). Higher SOC might be due to addition

Table 1 Soil organic carbon as influenced by different conservation agricultural practices

Treatment	Soil organic carbon (%)					
	0-15 cm			15-30 cm		
	2014	2015	Pooled	2014	2015	Pooled
CT ₁ —No tillage with BBF and crop residue retained on the surface.	0.60 ^a	0.64 ^a	0.62 ^{ab}	0.53 ^a	0.58 ^a	0.56 ^a
CT ₂ —Reduced tillage with BBF and incorporation of crop residue.	0.63 ^a	0.65 ^a	0.64 ^a	0.53 ^a	0.59 ^a	0.56 ^a
CT ₃ —No tillage with flat bed with crop residue retained on the surface.	0.57 ^{ab}	0.62 ^a	0.60 ^b	0.51 ^a	0.56 ^a	0.54 ^a
CT ₄ —Reduced tillage with flat bed with incorporation of crop residue.	0.59 ^{ab}	0.64 ^a	0.62 ^{ab}	0.51 ^a	0.58 ^a	0.55 ^a
CT ₅ —Conventional tillage with crop residue incorporation.	0.53 ^{bc}	0.58 ^b	0.56 ^c	0.43 ^b	0.52 ^b	0.48 ^b
CT ₆ —Conventional tillage without crop residue	0.50 ^c	0.45 ^c	0.48 ^d	0.38 ^b	0.39 ^c	0.39 ^c
S.Em ±	0.02	0.01	0.01	0.02	0.01	0.01
F test	5%	*	*	*	*	*

NS: Non significant, *Significant at P=0.05.

of organic matter through biomass of pigeonpea as well as soybean, root nodules and huge leaf fall decomposition in the system which led to the increase of microbial population that hastened decomposition of crop residues resulting in buildup of organic carbon in soil (Srinivasulu *et al.* 2000 and Kevizhalhou *et al.* 2014).

Soil organic carbon sequestration (SOCS)

Tillage practices had significant effect on SOCS after harvest of crops. Two years pooled data showed that, all the conservation tillage practices *viz.* CT₁, CT₂, CT₃ and CT₄ recorded significantly higher SOCS (15.07, 15.39, 14.58 and 14.72 t/ha, respectively) as compared to conventional tillage with (CT₅, 13.40 t/ha) and without crop residue (CT₆, 11.42 t/ha) (Fig. 1). The impacts of conservation tillage and crop residues combination have shown the remarkable potential in SOCS as compared to conventional tillage systems. Higher soil carbon sequestration under conservation tillage practices might be due to high crop residue addition tends to accumulate more carbon in the soil than is released into the atmosphere and also legume based cropping system helped in nutrient cycling and SOC accumulation under conservation tillage system and also improvement in conserving soil moisture, reducing soil erosion, improving soil structure, enhancing SOC concentration, and reducing the rate of enrichment of atmospheric CO₂ resulted in higher SOCS (Lal 2004). Conservation tillage, residues are retained on soil surface and partially incorporated into soil, the organic materials decompose slowly, and thus, CO₂ emission into the atmosphere is also slow. Thus in the total balance, net fixation or sequestration of carbon takes place and the soil becomes a net sink of carbon (Bot and Benites 2005).

Soil microbial biomass carbon and nitrogen (SMB-C and SMB-N)

Conservation tillage systems had significant effect on

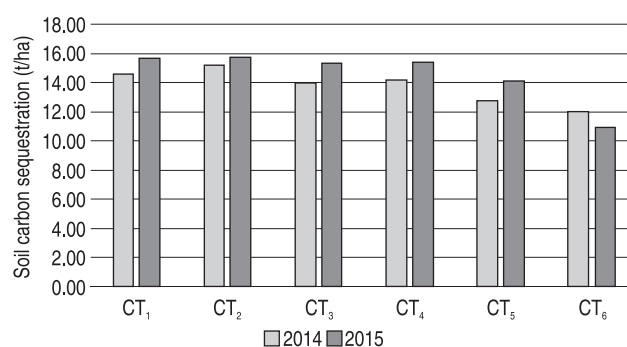


Fig 1 Soil carbon sequestration (t/ha) as influenced by conservation agricultural practices during 2014 and 2015.

SMB-C and SMB-N (Table 2 and Fig 2). Pooled data on SMB-C and SMB-N showed that, all the tillage systems (CT₁, CT₂, CT₃, CT₄ and CT₅) recorded significantly higher SMB-C (364.00, 355.20, 327.20 and 362.00 mg/kg soil, respectively) and SMB-N (14.97, 14.60, 13.43 and 14.88 mg/kg soil, respectively) except conventional tillage without crop residue (CT₆, 294.00 mg/kg soil, respectively). The positive response of conservation tillage practices as compared to conventional tillage systems were probably due to higher levels of C substrates available for microorganism growth, as well as better soil physical conditions and higher water retention due to the altered land configurations and applied residues (Singh *et al.* 2009). The improvement in SMB-C and N is mainly due to rate of organic carbon input from plant biomass which is the dominant factor controlling the amount of SMB in soil. Reduction in loss of soil organic carbon in conservation tillage and continuous, uniform supply of carbon from crop residues serves as an energy source for microorganisms. Minimum soil disturbance under conservation tillage and crop residue retention/incorporation tend to better aggregation in soil might be attributed to increase in soil organic carbon as well as SMB-C and N

Table 2 Soil microbial biomass carbon and nitrogen as influenced by different conservation agricultural practices

Treatment	Soil microbial biomass carbon (mg/kg soil)			Soil microbial biomass nitrogen (mg/kg soil)		
	2014	2015	Pooled	2014	2015	Pooled
CT ₁ —No tillage with BBF and crop residue retained on the surface.	372.00 ^a	356.00 ^a	364.00 ^a	15.10 ^a	14.83 ^a	14.97 ^a
CT ₂ —Reduced tillage with BBF and incorporation of crop residue.	375.20 ^a	335.20 ^a	355.20 ^a	15.23 ^a	13.97 ^a	14.60 ^a
CT ₃ —No tillage with flat bed with crop residue retained on the surface.	342.40 ^a	312.00 ^a	327.20 ^a	13.87 ^a	13.00 ^a	13.43 ^a
CT ₄ —Reduced tillage with flat bed with incorporation of crop residue.	383.20 ^a	340.80 ^a	362.00 ^a	15.57 ^a	14.20 ^a	14.88 ^a
CT ₅ —Conventional tillage with crop residue incorporation.	342.13 ^a	308.80 ^a	325.47 ^a	13.86 ^a	12.87 ^a	13.36 ^a
CT ₆ —Conventional tillage without crop residue	312.80 ^b	275.20 ^b	294.00 ^b	12.63 ^b	11.47 ^b	12.05 ^b
S.Em ±	42.42	84.80	35.25	1.77	3.50	1.47
F test	5%	*	*	*	*	*

NS: Non significant, *Significant at P=0.05.

Table 3 Soil urease, dehydrogenase and total phosphatase activity at 75 DAS as influenced by different conservation tillage practices and intercropping systems

Treatment	Soil urease activity ($\mu\text{g NH}_4\text{-N/g/day}$)			Soil dehydrogenase activity ($\mu\text{g TPF/g/day}$)			Total phosphatase activity ($\mu\text{g PNP/g/hr}$)		
	2014	2015	Pooled	2014	2015	Pooled	2014	2015	Pooled
CT ₁ —No tillage with BBF and crop residue retained on the surface.	12.85 ^a	10.67 ^{ab}	11.76 ^a	34.27 ^a	30.31 ^{ab}	32.29 ^a	175.00 ^a	171.43 ^a	173.21 ^a
CT ₂ —Reduced tillage with BBF and incorporation of crop residue.	12.84 ^a	10.89 ^a	11.86 ^a	33.88 ^a	30.71 ^a	32.29 ^a	177.38 ^a	171.73 ^a	174.55 ^a
CT ₃ —No tillage with flat bed with crop residue retained on the surface.	12.59 ^{ab}	9.60 ^{cd}	11.10 ^{ab}	33.49 ^a	28.79 ^{cd}	31.14 ^b	175.89 ^a	164.29 ^b	170.09 ^b
CT ₄ —Reduced tillage with flat bed with incorporation of crop residue.	12.92 ^a	9.97 ^{bc}	11.44 ^a	33.62 ^a	29.48 ^{bc}	31.55 ^{ab}	177.98 ^a	168.45 ^a	173.21 ^a
CT ₅ —Conventional tillage with crop residue incorporation.	12.58 ^{ab}	9.66 ^{cd}	11.12 ^{ab}	31.31 ^b	28.09 ^d	29.70 ^c	170.54 ^b	150.30 ^c	160.42 ^c
CT ₆ —Conventional tillage without crop residue	11.74 ^b	9.04 ^d	10.39 ^b	29.04 ^c	25.82 ^e	27.43 ^d	163.39 ^c	145.24 ^d	154.32 ^d
S.Em \pm	0.30	0.26	0.27	0.46	0.34	0.34	1.39	1.20	0.82
F test	5%	*	*	*	*	*	*	*	*

NS: Non significant, *Significant at P=0.05.

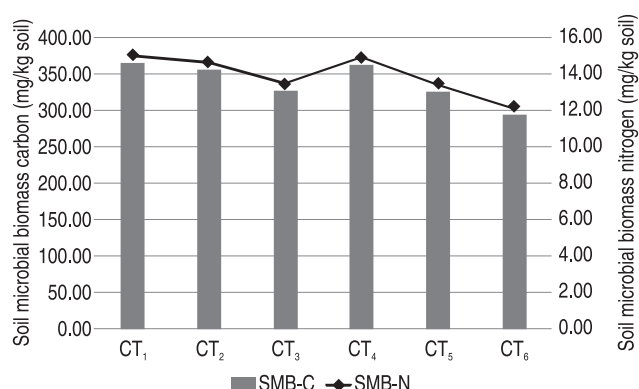


Fig 2 Soil microbial biomass carbon (SMB-C) and soil microbial biomass nitrogen (SMB-N) as influenced by conservation agricultural practices.

(Alvear *et al.* 2005 and Kumar 2012).

Soil enzymatic activity

Tillage practices had a significant effect on soil enzymatic activity at 75 DAS of crops (Table 3). Significantly higher soil urease activity (11.76, 11.86, 11.10 and 11.44 $\mu\text{g NH}_4\text{-N/g/day}$), higher dehydrogenase activity (32.29, 32.29, 31.14 and 31.55 $\mu\text{g TPF/g/day}$) and total phosphate activity (173.21, 174.55, 170.09 and 173.21 $\mu\text{g PNP/g/hr}$) were recorded in all the conservation tillage systems such as CT₁, CT₂, CT₃ and CT₄, respectively as compared to conventional tillage without crop residue (CT₆, 10.39 $\mu\text{g NH}_4\text{-N/g/day}$, 27.43 $\mu\text{g TPF/g/day}$ and 154.32 $\mu\text{g PNP/g/hr}$, respectively).

Higher soil enzymatic activity under conservation tillage practices could be attributed to the minimum soil disturbance, retention as well as incorporation of residues, root exudates from crops, availability of soil moisture, better aeration, optimum temperature and higher organic matter present increases the carbohydrate content which act as an energy source for microbes which resulted in higher soil enzymatic activity (Mina *et al.* 2008 and Nurbekov 2008).

In Northern Transition zone (Zone 8) Karnataka, pigeonpea-based intercropping system being advocated as sustainable intensification option to address the issues of declining water table, soil health, deterioration particularly decline in soil organic carbon and microbial biomass and increased soil compaction which results in declining factor productivity and farm profits. Our field experiment results showed that all the conservation tillage systems i.e. CT₁, CT₂, CT₃ and CT₄ led to significant improvement in soil health i.e. soil organic carbon, soil carbon sequestration, soil microbial biomass carbon and nitrogen and soil enzymatic activity over conventional tillage systems.

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