Biomass production, carbon sequestration potential and productivity of different peanut (Arachis hypogaea)-based cropping systems and their effect on soil carbon dynamics

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Biomass production, carbon sequestration potential and productivity of different peanut (*Arachis hypogaea*)-based cropping systems and their effect on soil carbon dynamics

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ABSTRACT

A field experiment was conducted during 2011-12 and 2012-13 at Junagadh (Gujarat) with fourteen treatment combinations comprising cropping systems, tillage, crop residues incorporation and green manuring with three replications. Results revealed that maximum biomass production (30.05 t/ha) and carbon sequestration potential (12.63 t/ha) were recorded under peanut (*Arachis hypogaea* L.)+pigeonpea [*Cajanus cajan* (L.) Millsp.]-*Sesbania* cropping system. On the other hand, maximum peanut-pod equivalent yield (3.64 t/ha) was obtained under peanut-wheat (ZT)-*Sesbania* which was significantly higher by 102.2 per cent compared to sole peanut. The inorganic soil carbon was significantly altered in peanut-based cropping systems whereas soil organic carbon (SOC) was found non-significant both in plough and sub-soil layers. The highest labile soil carbon was recorded under peanut-wheat (ZT)-*Sesbania* cropping system (0.77 g/kg) under plough soil layer. On the other hand, the highest non-labile soil carbon was found in peanut-wheat (ZT) (7.07 to 8.03 g/kg) with and without plant residues incorporation at both soil depths (i.e. plough and sub-soil layers). The inorganic carbon increased appreciably (3 to 57%) with increase in soil depth. In contrary, values of organic, labile and non-labile soil carbons, showed declining trend with the increase in soil depth under these cropping systems. In general, the highest values of all soil carbon fractions were observed in peanut-wheat (ZT) at all the soil depths except 15-30 cm for inorganic carbon. The highest MBC (441 mg/kg), SOC stock (17.3 t/ha) and CMI (188.8) were registered under peanut-wheat (ZT)-*Sesbania* while MQ was higher in peanut-wheat (CT) (4.90%).

Key words: Biomass production, Carbon sequestration potential, Peanut-based cropping systems, Peanut-pod equivalent yield, Soil carbon dynamics.

Indian agricultural soils are generally poor in soil carbon content (<5 g/kg soil) due to exhaustive and faulty soil management practices (Lal 2004) and removal of above ground biomass (80%) at crop harvest. This situation is further aggravated in case of peanut (*Arachis hypogaea* L.) where nearly 100% above and below ground biomass is removed at harvest. Srinivasarao *et al*. (2012) reported that continuous cultivation of peanut without addition of organic or inorganic fertilizers resulted in the net depletion of 3.57 Mg C/ha during 20 years period. They further noticed that the critical amount of C input to the soil required for maintaining the SOC levels (zero change) is 1.12 Mg C/ha/yr for alfisols under a groundnut cropping system. Similarly, about 7.6 tonnes/ha/annum residues were needed to compensate the loss of soil organic carbon (Ghosh and Dayal 2004). However, higher rates of biomass carbon are needed to raise the SOC concentration above the threshold level (1.1-1.5%). Peanut-wheat, peanut-wheat-greengram, peanut+pigeonpea and peanut+pearl millet are the some important peanut-based cropping systems in India. Groundnut-wheat-greengram and groundnut intercropped with pigeonpea maintained higher level of organic carbon and also had more activities of microbes in the soil compared with sole groundnut and groundnut intercropped in pearl millet (Dayal and Pal 2001). Significant variation in soil organic carbon was observed in different groundnut-based cropping systems, and groundnut-wheat sequence was better than groundnut-mustard, groundnut-chickpea, groundnut-sunflower and groundnut- groundnut (Ghosh *et al*. 2006).

It is widely evidenced that the management practices like zero tillage, residue incorporation, green manuring, cropping systems, etc. significantly altered the soil carbon pools. However, meagre information was available on various soil carbon dynamics and indices as influenced by carbon sequestered under different cropping system based management practices. Our objective was to study the biomass production and carbon sequestration potential of

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different peanut-based cropping systems and their effect on soil carbon dynamics in calcareous vertisols prevailed in peanut growing areas of India.

MATERIALS AND METHODS

The field was located at the research farm of ICAR-Directorate of Groundnut Research, Junagadh (Gujarat), India (70^0 26' E longitude and 21^0 31' N latitude and about 60 m AMSL). The climate is sub-tropical characterized by fairly cool-dry winter, hot-dry summer and warm with moderately humid rainy season. The rainy season commence in the first fortnight of June to September and generally July and August are the months of heavy rainfall.The soils are Typic Haplustepts with meliolitic limestone under-layer of high clay content. The soil was alkaline in reaction, shallow to medium in depth, medium black in colour and slightly calcareous in nature, good in cation exchange capacity dominated by calcium (>70%) and magnesium (>15%) cations and no salinity hazard. Water retention capacity of the surface soil was about 24-30% at field capacity and 14-16% at wilting point. The initial soil fertility status is given in Table 1.

A field experiment was conducted for two consecutive years (2011-12 to 2012-13) at a fixed site. Fourteen treatment combinations comprising of cropping systems, tillage, residues incorporation, and green manuring were taken as mentioned in Table 2-5. The experiment was laid out in randomized block design with 3 replications. The treatments were randomly allocated to plots within blocks in the first year as per random number table and remained on the same plots throughout experimentation. In the first cycle of present experimentation (2011-12), all the 14 treatment combinations were applied to peanut-based cropping systems; hence the peanut-pod equivalent yield is being discussed based on effect of treatments on second year experimentation.

Table 1 Physico-chemical properties of the soil prior to experimentation

Physico-chemical properties	Surface soil (0-30 cm)	Sub-surface soil (30-45 cm)
pH	8.08 to 8.24	8.16 to 8.31
EC (dS/m)	0.51 to 0.62	0.46 to 0.52
Bulk density (Mg/m^3)	1.22 to 1.31	1.28 to 1.38
Soil texture	Clayey	Clayey
Available N (kg/ha)	90 to 111	82 to 92
Available P (kg/ha)	9 to 16	7 to 11
Available K (kg/ha)	251 to 305	216 to 258
Inorganic carbon (g/kg)	17.6 to 26.0	15.7 to 30.9
Organic carbon (g/kg)	7.30 to 8.43	6.68 to 7.46
Labile carbon (g/kg)	0.41 to 0.55	0.32 to 0.45
Non-labile carbon (g/kg)	6.82 to 7.90	6.25 to 7.35
Microbial Biomass Carbon (mg/kg)	102 to 143	24 to 52
Calcium carbonate (%)	4.0 to 8.0	12.6 to 17.6
Cation Exchange Capacity (Cmol(+)/kg soil)	27 to 39	-
Field capacity (%)	24 to 30	15 to 22
Permanent wilting point (%)	14 to 16	5 to 8

The field was prepared by tilling twice with cultivator followed by harrowing and planking once during *kharif* season. Conventional sowing of peanut TG 37A was carried out using 100 kg kernels/ha in the last week of June to first week of July at 30 cm × 10 cm spacing. NPK @ 25:22:24.9 kg/ha was applied at the time of sowing. In peanut+pigeonpea intercropping system (3:1), after every three rows of peanut at 30 cm × 10 cm, a row of pigeonpea BDN 2 was sown in replacement series. The NPK fertilizers in both the crops were applied on the basis of number of rows occupied by each crop. Peanut crop was harvested in the second fortnight of October every year while pigeonpea pods were picked starting from second fortnight of November to first week of March every year. After harvesting of peanut and pre-sowing irrigation, wheat GW 366 was sown @ 100 kg/ha in the mid November with seed cum fertilizer drill at 22.5 cm row spacing for conventional tillage plots, and zero till fertilizer seed drill was used in zero-tilled plots. NPK @ 50:22:24.9 kg/ha was applied at the time of sowing. Whereas, additional 50 kg N/ha was also applied in two equal splits at the time of first and second irrigations. The crop was grown with recommended package of practices. The crop was harvested in the first fortnight of March during both the years. The wheat straw (stubbles) was recycled as per treatments, and irrigate the plots for further decomposition. In the summer season, the same field was pre-irrigated and the green manure crops, i.e. *Sesbania aculeata* Local and green gram GM 1 were sown in the first to second week of March as per treatments using 50 and 40 kg/ha seed rate, respectively at 20 cm x 5 cm spacing. NPK @ 20:17.6:24.9 kg/ha was applied at the time of sowing. Both the crops were recycled into the soil using disc plough at 45-50 days after planting.

The productivity of different cropping systems was computed by converting yields of pigeonpea and wheat into peanut-pod equivalent yield (PPEY) as per following formula:

$$\text{PPEY (t/ha)} = \frac{\text{Yield of each crop (t/ha)} \times \text{Economic value (₹/t)}}{\text{Price of peanut (₹/t)}}$$

The converted pigeonpea and wheat yields were then added to the actual pod yield of peanut to obtain PPEY (system productivity) based on the prevailing market/minimum support price. Biomass yield of green manuring crops were not taken into consideration as they were turned into the soil.

The biomass production represents both above-ground and below-ground biomass harvested from individual plot from each cropping system within the year. The above-ground portion includes haulm in peanut, grain and straw in wheat, pods and stalk in pigeonpea, and fodder in *Sesbania aculeata* and green gram. In pigeonpea, the leaf fall was

Table 2 Biomass production and carbon sequestration potential as influenced by various peanut-based cropping systems coupled with different plant residue management practices and tillage

Cropping system	2011-12				2012-13				Total			
	NR	GM-Se	GM-GG	WSI	NR	GM-Se	GM-GG	WSI	NR	GM-Se	GM-GG	WSI
Biomass production (t/ha)												
Peanut	3.24	7.75	7.01		2.08	4.46	4.13		5.32	12.21	11.14	
Peanut-Wheat (CT)	12.50	15.74	15.99	11.04	8.37	11.33	11.52	8.96	20.87	27.04	27.51	20.00
Peanut-Wheat (ZT)	12.01	15.88	15.87	11.20	9.61	12.69	11.57	8.83	21.62	28.57	27.44	20.03
Peanut+Pigeonpea	13.41	16.96	15.84		10.31	13.09	13.06		23.72	30.05	28.90	
LSD (P≤0.05)	2.17				0.91				2.28			
Carbon sequestration potential (t/ha)												
Peanut	1.29	3.2	2.73		0.82	1.82	1.6		2.11	5.02	4.32	
Peanut-Wheat (CT)	5.08	6.25	6.53	4.51	3.46	4.47	4.83	3.67	8.54	10.72	11.36	8.18
Peanut-Wheat (ZT)	4.85	6.66	6.46	4.53	4.02	5.42	4.86	3.54	8.87	12.08	11.32	8.07
Peanut+Pigeonpea	5.51	7.08	6.49		4.37	5.55	5.53		9.88	12.63	12.02	
LSD (P≤0.05)	1.10				0.43				1.33			

ZT; Zero tillage, NR; No residues, GM-Se; Green manuring with *Sesbania*, GM-GG; Green manuring with green gram, WSI; Wheat straw incorporation.

Table 3 Soil carbon as influenced by various peanut-based cropping systems coupled with different plant residue management practices and tillage

Cropping system	Plough soil layer (0-30 cm soil depth)				Sub-soil layer (30-45 cm soil depth)			
	NR	GM-Se	GM-GG	WSI	NR	GM-Se	GM-GG	WSI
Inorganic carbon (g/kg)								
Peanut	18.9	19.9	20.4	NA	27.0	27.3	30.1	NA
Peanut-Wheat (CT)	19.9	21.2	19.2	18.2	27.4	30.7	27.4	28.4
Peanut-Wheat (ZT)	19.5	19.5	17.6	19.9	27.1	29.5	30.6	30.7
Peanut+Pigeonpea	18.3	17.4	18.7	NA	29.6	25.6	27.3	NA
LSD (P≤0.05)	3.42				4.02			
Organic carbon (g/kg)								
Peanut	7.3	8.4	8.4	NA	7.0	7.5	7.8	NA
Peanut-Wheat (CT)	8.0	8.2	8.1	8.1	7.0	8.0	7.8	7.8
Peanut-Wheat (ZT)	8.3	8.8	8.5	8.4	7.5	8.2	8.0	8.1
Peanut+Pigeonpea	8.2	8.3	8.2	NA	7.9	7.7	7.6	NA
LSD (P≤0.05)	NS				NS			
Labile carbon (g/kg)								
Peanut	0.45	0.68	0.66	NA	0.38	0.57	0.48	NA
Peanut-Wheat (CT)	0.63	0.68	0.69	0.62	0.54	0.57	0.54	0.46
Peanut-Wheat (ZT)	0.67	0.77	0.70	0.64	0.47	0.60	0.53	0.56
Peanut+Pigeonpea	0.52	0.60	0.56	NA	0.45	0.5	0.46	NA
LSD (P≤0.05)	0.122				0.093			
Non-labile carbon (g/kg)								
Peanut	6.81	7.73	7.72	NA	6.57	6.95	7.36	NA
Peanut-Wheat (CT)	7.36	7.53	7.45	7.47	6.49	7.42	7.30	7.34
Peanut-Wheat (ZT)	7.63	8.03	7.82	7.74	7.07	7.57	7.44	7.54
Peanut+Pigeonpea	7.64	7.68	7.66	NA	7.41	7.22	7.15	NA
LSD (P≤0.05)	NS				NS			

ZT; Zero tillage, NR; No residues, GM-Se; Green manuring with *Sesbania*, GM-GG; Green manuring with green gram, WSI; Wheat straw incorporation.

also collected and weighed after drying at 65°C. For below-ground biomass, the roots of three representative plants were excavated randomly from soil up to 20 cm depth in wheat, green gram, *Sesbania*, and up to 45 cm in pigeonpea at the time of harvest. However, root biomass of peanut was not taken into account separately as the whole peanut plant was excavated from the soil at crop harvest. The observations for biomass production was made using 1 m x 1 m grid for all the crops. The collected plant samples were washed and dried in an oven at 65°C, ground and homogenized before further use for elemental analysis. Carbon content in plant parts were determined by dry combustion in a furnace at temperature of 550°following the method as outlined by Sangwan and Phogat (2007).

Soil samples from each plot were also collected using soil core at 15, 30 and 45 cm soil depths before commencement and after completion of second year experimentation. In order to determine various soil properties, these soil samples were air-dried, sieved through 2-mm mesh and analyzed using standard protocols. Different soil carbon fractions were analyzed using standard protocols and methodologies. The total carbon (TC) and inorganic carbon (IC) of the soil was determined by combustion-oxidation and carbonate acidification reaction using TOC analyser (Shimandzu, SSM-5000A model), respectively. The soil organic carbon (SOC) was obtained as the difference between measured total carbon and inorganic carbon. The labile carbon (LC) was determined using $KMnO_4$ oxidation method (Blair *et al*. 1995). However, the non-labile carbon (NLC) was estimated as the difference between SOC and LC. The soil microbial biomass carbon (MBC) was determined using $CHCl_3$ fumigation-extraction method as described by Jenkinson and Powlson (1976). Soil bulk density was determined usning undisturbed soil core with the help of soil core auger. The carbon sequestration represents the temporal difference of carbon pools estimated at end of the experiment (2013) and the carbon pools at initiation of the experiment (2011).

Various SOC indices, viz. microbial biomass carbon (MBC), microbial quotient (MQ), soil organic carbon (SOC) stock, carbon management index (CMI) and carbon lability (LC) in the soil were computed using standard mathematical expressions. In view of short term study, the computation of soil carbon indices was confined to surface soil up to 15 cm soil depth.

Statistical analysis of various parameters studied was performed using the t-test as described by Gomez and Gomez (1984). The least significant difference values (LSD at P≤0.05) were used for determining the significance of differences between means.

Table 4 Per cent change in soil carbon fractions as influenced by various peanut-based cropping systems coupled with different plant residue management practices and tillage for two years

Cropping system	No residues	*Sesbania* as green manure	Green gram as green manure	Wheat straw incorporation (WSI)
		Inorganic carbon		
Peanut	6.7	6.1	27.5	
Peanut-Wheat (CT)	35.7	15.4	28.6	12.7
Peanut-Wheat (ZT)	27.3	-4.5	-0.2	0.9
Peanut +Pigeonpea	33.7	-4.4	17.0	
		Organic carbon		
Peanut	-5.1	5.0	10.5	
Peanut-Wheat (CT)	1.3	8.5	6.0	4.2
Peanut-Wheat (ZT)	5.0	9.1	14.6	3.8
Peanut +Pigeonpea	7.2	4.3	5.3	
		Labile carbon		
Peanut	-3.4	42.6	30.4	
Peanut-Wheat (CT)	24.0	59.5	48.4	26.2
Peanut-Wheat (ZT)	24.5	49.3	34.1	59.7
Peanut +Pigeonpea	15.8	26.0	21.9	
		Non-labile carbon		
Peanut	-5.3	2.7	9.1	
Peanut-Wheat (CT)	-0.3	5.7	3.5	3.0
Peanut-Wheat (ZT)	3.7	6.6	13.2	1.1
Peanu t+Pigeonpea	6.5	3.0	4.3	
		Microbial biomass carbon		
Peanut	110.6	242.6	199.2	
Peanut-Wheat (CT)	127.2	184.6	198.5	209.6
Peanut-Wheat (ZT)	168.6	212.8	259.6	294.1
Peanut +Pigeonpea	159.7	160.5	207.2	

RESULTS AND DISCUSSION

Biomass production, carbon sequestration potential and system productivity

The peanut-based cropping systems varied greatly in biomass production and carbon sequestration potential both under no-residues and residues recycling using *Sesbania* and greengram as green manure crops and wheat straw. A significantly (P≤0.05) higher biomass production was recorded in all the peanut-based cropping systems compared to sole peanut during both the years (Table 2). The highest biomass production was registered under peanut+pigeonpea intercropping system with and without green manuring. The recycling of green manure crops increased the total biomass production appreciably, being highest in sole peanut (109-130%) followed by peanut-wheat system (27-32%) and peanut+pigeonpea intercropping system (22-27%). Similar trend was also observed during individual years (i.e. 2011-12 and 2012-13) with highest biomass production in sole peanut (116-139% & 99-114%) followed by peanut-wheat (26-32% & 20-38%) and the least in peanut+pigeonpea intercropping system (18-27% & 27%), respectively. However, the recycling of wheat straw both under conventional and zero tillage practices reduced the total biomass production (4-7%) in peanut-wheat cropping system. This might be due to the effect of nutrient immobilization during decomposition of dried wheat straw.

Compared to sole peanut, carbon sequestration potential was higher in peanut-based cropping systems involving pigeonpea or wheat. Significantly higher total carbon sequestration potential for two years was reported in peanut+pigeonpea intercropping system (9.88 to 12.63 t/ha) followed by peanut-wheat (ZT) (8.07 to 12.08 t/ha), peanut-wheat (CT) (8.18 to 11.36 t/ha) and the least in sole peanut (2.11 to 5.02 t/ha) with and without residues recycling (Table 2). This increase in carbon sequestration potential was higher (4 to 5 times) for no-residues recycling than use of green manure crops (2 to 2.5 times) over sole peanut. Hence, about 2.21 to 10.52 t/ha higher biomass carbon was sequestered in these cropping systems during the course of study which may have the possibility of improving soil organic carbon content by adopting these cropping systems. Recycling of *Sesbania* and green gram crops as green manure further increased the total carbon sequestration potential compared to no-residues recycling in all the peanut-based cropping systems. This increase was highest (105-138%) in sole peanut followed by peanut-wheat (ZT) (28-36%), peanut-wheat (CT) (26-33%) and least under peanut+pigeonpea intercropping system (22 to 28%). Similar results were observed during individual years with maximum increase in sole peanut (112-148 % & 95-122%) followed by peanut-wheat (ZT) (33-37% & 21-35%), peanut-wheat (CT) (23-29% & 29-40%) and the least in peanut+pigeonpea intercropping system (18-28% & 27%) during 2011-12 and 2012-13, respectively. Further among residues, highest potential for carbon sequestration through biomass accumulation was reported with use of *Sesbania* green manure crop followed by green gram. However, recycling of wheat straw reduced the carbon sequestration potential by 2 to 4 per cent both under conventional and zero tillage practices. No significant response of tillage on total carbon sequestration potential was observed in the present study except under peanut-wheat (ZT)-*Sesbania* cropping system wherein it improved significantly over peanut-wheat (CT)-*Sesbania* cropping system.

The enhanced biomass accumulation and carbon sequestration potential in the soil also reflected as increase in peanut-pod equivalent yield (PPEY) due to various management practices and peanut-based cropping systems. The peanut-wheat (ZT)-*Sesbania*, being at par with peanut-wheat (CT)- *Sesbania*/green gram/WSI, peanut-wheat (ZT) and peanut-wheat (ZT)-green gram/WSI cropping systems, produced significantly higher peanut-pod equivalent yield (3.64 t/ha) compared to sole peanut (with or without green manuring), peanut-wheat (CT), and peanut+pigeonpea (with or without green manuring) (Table 5). Peanut followed by wheat (ZT) and green manuring with *Sesbania* increased peanut-pod equivalent yield by 102.2 per cent compared to sole peanut. This might be due to enhanced biomass accumulation and subsequent enrichment of soil fertility. The use of legumes as green manuring to enhance soil productivity has been traced back to the days of Cato (234-149 BC) as they fix atmospheric nitrogen in the root nodules through symbiotic association with *Rhizobium* bacterium and leave part of it for utilization for the companion or succeeding crop (Butter and Rana, 2014). Besides this, they reduce soil pH, improves soil fertility, soil structure, porosity, water holding capacity and partially reduces the need of nitrogen fertilizer for the succeeding crop. The practices that promoted the maintenance of crop residues at the soil surface also had beneficial effects on soil fertility through enhancement of soil microbial biomass and supply of mineralizable nutrients (Wright *et al*. 2005).

Soil carbon dynamics

The total carbon of the soil under study was characterized into inorganic (71 to 75%) and organic soil carbon (25 to 29%) among different peanut-based cropping systems. The soil organic carbon was further characterized as labile (5 to 7%) and non-labile (93 to 95%) soil organic carbon. The cropping systems and management practices played significant role in dynamics of soil carbon. The peanut-based cropping systems with and without plant residues incorporation considerably altered the soil carbon fractions (Table 3). The inorganic soil carbon was significantly ($P \leq 0.05$) altered in peanut-based cropping systems, whereas soil organic carbon was found non-significant both in plough and sub-soil layers. Increase in inorganic soil carbon (37 to 74%) was noticed in sub-soil (30-45 cm soil depth) than the plough soil layer (0-30 cm soil depth) depending upon the cropping systems and plant residues recycling.

The organic soil carbon was found non-significant among different peanut-based cropping systems with highest in peanut-wheat (ZT) cropping system where about 1-13 per cent increase in soil organic carbon was observed over sole peanut (Table 3). The green manuring with *Sesbania* and green gram also increased the soil organic carbon over no-residues depending upon different peanut-based cropping systems. This increase was highest in sole peanut (7 to 15%) followed by peanut-wheat (CT) (1.2 to 14%) and peanut-wheat (ZT) (2.5 to 14%) both in plough and sub-soil layers. Further incorporation of wheat straw also enhanced the soil organic carbon which was higher in sub-soils. The SOC showed declining trend with increase in soil depth and it was more in surface layers (7.3 to 8.8 g/kg soil) than in

Table 5 Peanut-pod equivalent yield and different soil carbon indices as influenced by peanut-based cropping systems coupled with plant residue management practices and tillage after two years

Cropping system	Peanut-pod equivalent yield (t/ha)*	MBC (mg/kg)	MQ (%)	SOC Stock (t/ha)	Carbon management index (CMI)	Lability of carbon (LC)
Peanut (Pn)	1.80	238	3.21	13.6	100.0	0.065
Peanut-*Sesbania* (Se)	2.23	394	4.59	15.6	158.5	0.090
Peanut-Greengram (GG)	2.21	353	4.14	15.5	154.4	0.087
Peanut-Wheat (CT)	3.26	309	3.69	15.4	145.6	0.084
Peanut-Wheat (CT)-*Sesbania* (Se)	3.59	407	4.90	15.2	169.8	0.098
Peanut-Wheat (CT)-Greengram (GG)	3.62	388	4.70	15.1	161.2	0.095
Peanut-Wheat (CT)-Wheat (WSI)	3.49	356	4.37	14.8	138.1	0.082
Peanut-Wheat (ZT)	3.49	368	4.27	16.7	161.1	0.090
Peanut-Wheat (ZT)-*Sesbania* (Se)	3.64	441	4.88	17.3	188.8	0.102
Peanut-Wheat (ZT)–Greengram (GG)	3.57	410	4.70	16.8	172.1	0.096
Peanut-Wheat (ZT)-Wheat (WSI)	3.28	402	4.66	16.6	153.5	0.086
Peanut + Pigeonpea (PP)	2.99	309	3.73	15.3	118.2	0.069
Peanut + Pigeonpea-*Sesbania* (Se)	2.89	323	3.86	15.4	139.1	0.081
Peanut+Pigeonpea–Greengram (GG)	3.08	341	4.04	15.5	125.6	0.072
LSD (P≤0.05)	0.37	65.3	0.84	1.5	36.8	NS

*2012-13; MBC; Microbial biomass carbon, MQ; Microbial quotient, SOC; Soil organic carbon, ZT; Zero tillage, Se; *Sesbania*, GG; green gram, WSI; Wheat straw incorporation.

sub-surface layers (7.0 to 8.2 g/kg) regardless of cropping systems and residues recycling.

Soil labile carbon varied significantly (p≤0.05) among various peanut-based cropping systems with and without plant residues incorporation in the soil (Table 3). The highest labile soil carbon was reported under peanut-wheat (ZT)-*Sesbania* cropping system (0.77 g/kg) followed by peanut-wheat (ZT)-green gram (0.70 g/kg) under plough soil layer. The increase was more in peanut-based cropping systems with no-residues over sole peanut both under plough (16 to 49%) and sub-soil (18 to 42%) layers. However, this increase was comparatively lesser (<15%) when recycled *Sesbania* and green gram as green manure crops in the soil with highest in peanut-wheat (ZT) cropping system. The peanut+pigeonpea intercropping system was found almost at par to sole peanut for labile soil carbon.

The non-labile soil carbon also varied with cropping systems, plant residues recycling and soil depth (Table 3). The highest non-labile soil carbon was found in peanut-wheat (ZT) (7.07 to 8.03 g/kg) with and without plant residues incorporation at both soil depths (i.e. plough and sub-soil layers). The better performance of peanut+pigeonpea intercropping system without plant residue recycling for non-labile soil carbon was probably due to continuous litter fall in this system which may enhance the soil microbial activities as well as nutrient mobilization for plant nutrition. However, when *Sesbania* and green gram as green manure crops and wheat straw were recycled in the soil, then the magnitude of change in non-labile soil carbon was found at par in all the peanut-based cropping systems. The non-labile soil carbon also decreased (2 to 12%) with increase in soil depth in all the peanut-based cropping systems and plant residues recycled in the soil.

The considerable temporal variation in different soil carbon fractions were observed in plant residues recycling/incorporation in various peanut-based cropping systems during the course of study (Table 4). The highest effect was observed on microbial soil carbon (111 to 294%)> labile carbon (-3 to 60%)> inorganic carbon (-0.2 to 36%) > organic carbon (-4 to 15) > non-labile carbon (-0.3 to 13%) in various peanut-based cropping systems compared to the initial soil carbon fractions. The negative results were obtained in sole peanut due to almost no-residues incorporation in the soil during two cropping years. Decline in SOC after four years of cropping system were also reported in fallow as well as groundnut-based cropping systems, except groundnut-wheat plots by Ghosh *et al*. (2003). Different soil carbon fractions influenced variably with soil depth in different peanut-based cropping systems (Fig 1). The inorganic carbon increased appreciably (3 to 57%) with increase in soil depth. In contrary, values of organic, labile and non-labile soil carbons, showed declining trend with the increase in soil depth under these cropping systems. In general, the highest values of all soil carbon fractions were observed in peanut-wheat (ZT) at all the soil depths except 15-30 cm for inorganic carbon. This may be due to slightly higher/at par yield of wheat under zero tillage and associated greater amount of stabilized root residues and left-over stubbles of wheat supplemented with green manure crop as a fast decomposing substrate for microbial decomposition.

Significant increase in organic carbon due to continuous zero tillage in wheat to a depth of 0.10, 0.15 and 0.25 m in sandy loam, loam and clay loam soils, respectively indicating its build up in the soil, was reported by Singh *et al*. (2014). The increase in OC in the absence of tillage might be due to deep penetration of wheat roots and reduced oxidation of *in situ* organic matter (Reicosky *et al*. 1995) and also due to green manuring (Tanwar *et al*. 2014). Zero tillage combined with or without crop residues increases SOC, limits soil disturbance, and enhances soil aggregation. Jat *et al*. (2012) were of the opinion that improvement in soil organic carbon in maize-wheat cropping system could be result of direct addition of organic matter through *Sesbania* green manuring and wheat straw and its beneficial effect on crop roots as well as on total microbial biomass of soil. Leite *et al*. (2004) reported that in intensive tillage systems, SOC was reduced. This reduction was higher in labile carbon than recalcitrant carbon content. The least soil inorganic and labile carbon values were observed in peanut+pigeonpea intercropping system, however, organic and non-labile soil carbon values were observed in sole peanut. The maximum labile carbon content was observed at surface layer which may be attributed to addition of crop root and/or crop residues and microbial activity (Murage *et al*. 2007, Wang *et al*. 2014). It has been widely accepted that conservation tillage practices like NT and crop residue could increase labile organic carbon in the upper soil profile (Wang *et al*. 2014). The depth-wise distribution of labile carbon content showed a decreasing trend with increase in soil depth in each treatment. Wang *et al*. (2014) while studying the impacts of 9 years of a new conservational agricultural management on soil organic carbon fractions found decrease in labile

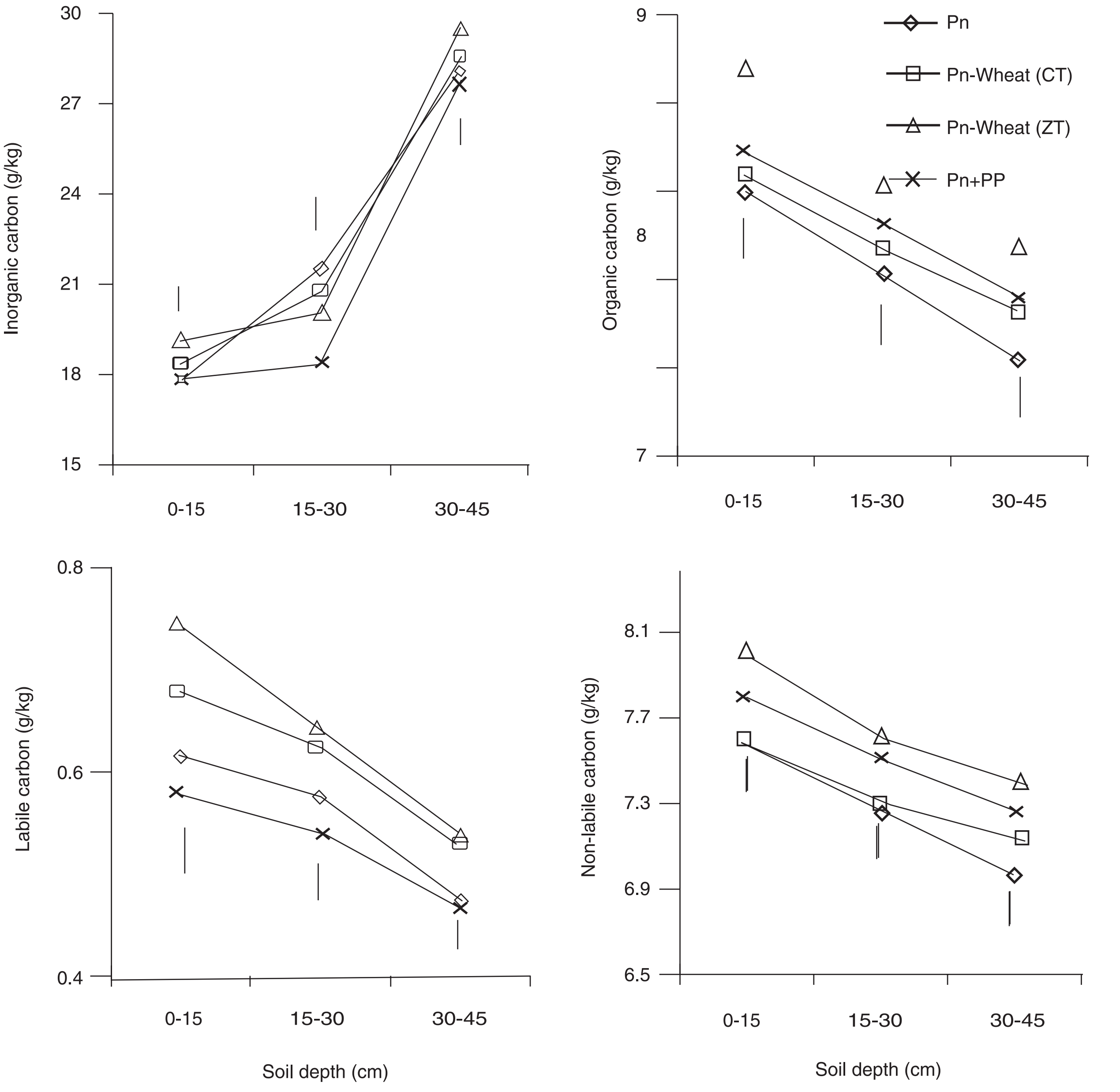

Fig 1 Soil carbon fractions as influenced by soil depth under different peanut-based cropping systems. Pn; Peanut, Pn-Wheat (CT); Peanut-Wheat (CT), Pn-Wheat (ZT); Peanut-Wheat (ZT), Pn+PP; Peanut+Pigeonpea; CT; Conventional tillage, ZT; Zero tillage.

carbon pools with increase in soil depth and observed higher values in new conservational agricultural management which includes no tillage with residue retention over conventional agricultural management. Further a considerable variation in soil carbon fractions (IC, OC, LC, NLC and MBC) were observed on recycling of different plant residues over no-residues (Fig. 2). This increase in different soil carbon fractions was observed in the order of MBC > LC > OC > IC > NLC. The type of plant residues recycled in the soil also had variable effect on these soil carbon fractions

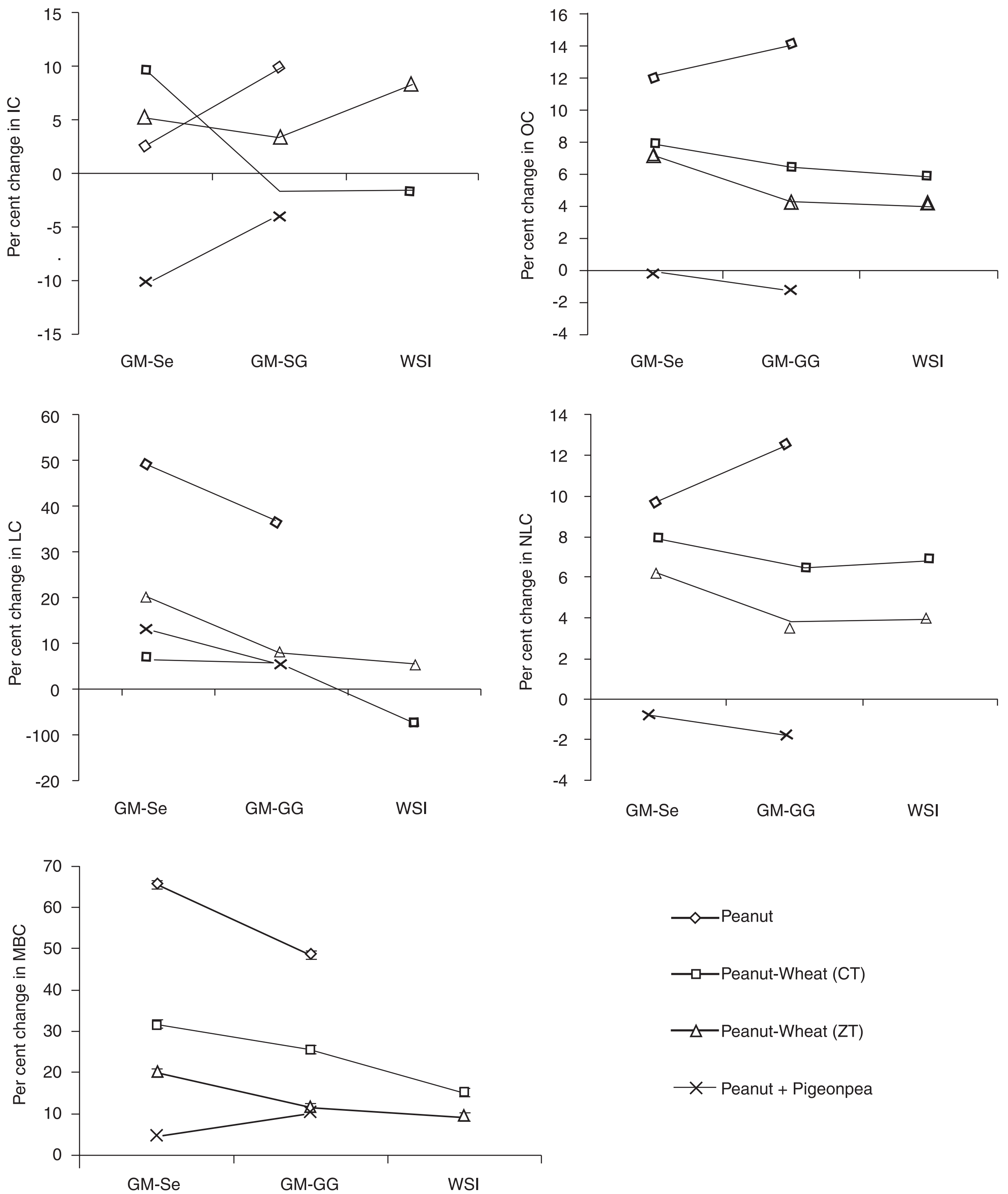

Fig 2 Changes in soil carbon fractions due to residues recycling under peanut-based cropping systems. (IC; Inorganic carbon, OC; Organic carbon, LC; Labile carbon, NLC; Non-labile carbon, MBC; Microbial biomass carbon, GG-Se: Green manuring with *Sesbania*, GM-GG; Green manuring with green gram, WSI; Wheat straw incorporation, CT; Conventional tillage, ZT; Zero tillage).

depending on the cropping systems.

Soil carbon indices

Significantly higher MBC was recorded in various peanut-based cropping systems compared to sole peanut (Table 5). The highest MBC was reported in peanut-wheat (ZT)-*Sesbania* (441 mg/kg) cropping system followed by peanut-wheat (ZT)-green gram(410 mg/kg) and peanut-wheat (ZT)-WSI (402 mg/kg). This increase in MBC over sole peanut ranged from 30 to 85 per cent in various peanut-based cropping systems under study. Green manuring by *Sesbania* was found most effective for enhanced MBC followed by green gram and wheat straw incorporation depending upon various peanut-based cropping systems. Irrespective of plant residues recycling, zero tillage was found better option for enhanced MBC in peanut-wheat cropping system. Practicing no tillage brings about two main modifications in the soil system. Firstly, retained crop residues in the field increases organic substrate for microorganisms near the soil surface and nutrient availability in the soil. Secondly, reduced disturbance of soil prevents disruption in microbial consortia and soil aggregates. Both factors together foster better microbial growth (Gonzalez-Chavez *et al*. 2010). Hence being an integral part of nutrient cycling, microbial biomass is strongly affected by soil management activities and its increment after adoption of no tillage practice and residue retention is a common observation. The higher conversion to microbial biomass suggests better stability of organic C in peanut-wheat cropping system both under conventional and zero tillage supplemented with *Sesbania* as green manure.

The significantly highest soil microbial quotient (MQ) value was observed in peanut-wheat (CT) (4.90%) followed by peanut-wheat (ZT) (4.88%) cropping system supplemented with *Sesbania* as green manure crop under both the systems (Table 5). Significantly lower MQ were recorded in sole peanut (3.21%) followed by peanut-wheat (3.69%) and peanut+pigeonpea (3.73% to 4.04%) with and without plant residues recycling. The zero tillage was also found better than conventional tillage in peanut-wheat cropping system for MQ.

Significantly higher soil organic carbon (SOC) stock was recorded in all the peanut-based cropping systems over sole peanut except peanut-wheat (CT)-wheat (WSI) (Table 5). The highest increase was observed in peanut-wheat (ZT)-*Sesbania* (17.3 t/ha) followed by peanut-wheat (ZT)- green gram (16.8 t/ha). The magnitude of increase in SOC stock ranged from 8.8-27.2 per cent among different peanut-based cropping systems. This higher SOC stock in zero tillage may be attributed to higher SOC concentrations as the continuous tillage accelerated the decomposition and depletion of soil organic matter, probably because of oxidation accentuated by enhanced aeration and consequently exposing the biomass to microbial processes (Dikgwatlhe *et al*. 2014).

Lability of carbon (LC) did not differ significantly due to cropping systems, tillage, green manuring and residue incorporation under various peanut-based cropping systems. However, maximum LC value (0.102) was recorded in peanut-wheat (ZT)-*Sesbania* cropping system (Table 5). Recycling of *Sesbania* and green gram as green manure crops considerably (4-38%) influenced the LC with highest (34-38%) in peanut followed by *Sesbania*/greengram. However, soil incorporation of wheat stubbles reduced the lability of carbon (2-4%) over respective cropping systems. Also zero tillage was found more effective for enhanced lability of carbon in the soil.

Carbon management index (CMI) differ significantly due to cropping systems, tillage, green manuring and residue incorporation under various peanut-based cropping systems with highest value (188.8) in peanut-wheat (ZT)-*Sesbania* in 0-15 cm surface layer (Table 5). The recycling of green manure crops also enhanced the CMI in different cropping systems over no-residues and the highest increase (54–59%) was observed in peanut-green manure cropping systems. However in other systems, it was increased by 7 to 18 per cent over no plant residues incorporation in the soil. Further, incorporation of the wheat straw in peanut-wheat cropping system reduced the CMI (4-5%) compared to no plant residues incorporation in the soil. The CMI also increased considerably (7-12%) under zero-tillage practice in peanut-wheat cropping system with and without recycling of plant residues in the soil. Vieira *et al*. (2007) also reported increase in CMI values when legumes were introduced in the crop rotations, reinforcing the role of legumes on the addition of photosynthesized C to the soil.

It can be concluded that the peanut+pigeonpea-S*esbania* cropping system contributed highest total biomass and carbon sequestration potential compared to other cropping systems. On the other hand, significantly higher peanut-pod equivalent yield (3.64 t/ha) was obtained in peanut-wheat (ZT)-*Sesbania* (GM) cropping system and was at par with all peanut-wheat cropping systems with and without conservation tillage, green manuring and wheat stubble incorporation. The soil carbon dynamics as well as different soil carbon indices also considerably affected with peanut-wheat (ZT) followed by green manure crop(s).

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REFERENCES

Blair G J, Lefroy R D B and Lisle L. 1995. Soil carbon fractions based on their degree of oxidation, and the development of a carbon management index for agricultural systems. *Crop Pasture Science* **46**: 1459–66.

Butter G S and Rana D S. 2014. Legumes as green manures. In: Prasad R, Kumar D, Rana D S, Shivay Y S, Tewatia R K (Eds). Textbook of Plant Nutrient Management. Part 18. Indian Society of Agronomy, New Delhi, pp 311–25.

Dayal D and Pal K K. 2001. Studies on soil chemical and microbial properties and productivity of groundnut based cropping systems. Extended summaries, National Symposium on Farming Systems Research in New Millennium, held during 15-17 October, 2001 at PDCSR, Modipuram, Meerut, India, pp 278–9.

Dikgwatlhe S B, Chen Z D, Lal R, Zhang H L and Chen F. 2014. Changes in soil organic carbon and nitrogen as affected by tillage and residue management under wheat-maize cropping system in the North China Plain. *Soil Tillage Research* **144**: 110–8.

Ghosh P K and Dayal D. 2004. An assessment of carbon sequestration potential for groundnut and fallow based cropping systems. In: Current Trends of Research on Groundnut in India. Paper presented in National Symposium on Enhancing Productivity of Groundnut for Sustainable Food and Nutritional Security, Oct 11-13, 2004. pp 126–7.

Ghosh P K, Dayal D, Mandal K G, Wanjari R H and Hati K M. 2003. Optimization of fertilizer schedules in fallow and groundnut-based cropping systems and an assessment of system sustainability. *Field Crops Research* **80**: 83–98.

Ghosh P K, Manna M C, Dayal D and Wanjari R H. 2006. Carbon sequestration potential and sustainable yield index for groundnut-and-fallow based cropping systems. *Journal Agricultural Science* **144**: 249–59.

Gomez K A and Gomez A A. 1984. Statistical Procedures for Agricultural Research, 2nd ed. John Wiley and Sons, New York.

Gonzalez-Chavez M D C A, Aitkenhead-Peterson J A, Gentry T J, Zuberer D, Hons F and Loeppert R. 2010. Soil microbial community, C, N, and P responses to long-term tillage and crop rotation. *Soil Tillage Research* **106**: 285–93.

Jat N K, Kumar A, Meena S R, Rana D S, Meena B P and Rana K.S. 2012. Influence of integrated nutrient management on the productivity, quality and soil health of maize (*Zea mays*)-wheat (*Triticum aestivum*) cropping system. *Indian J Agron* **57**(4): 327–32.

Jenkinson D S and Powlson D S. 1976. The effects of biocidal treatments on metabolism in soil-V:A method for measuring soil biomass. *Soil Biol Biochem* **8**: 209–13.

Lal R. 2004. Soil carbon sequestration in India. *Climatic Change* **65**: 277–96.

Leite L F C, de Sa Mendonca E, de Almeida Machado P L O, Filho E I F and Neves J C L. 2004. Simulating trends in soil organic carbon of an Acrisol under no-tillage and disc-plow systems using century model. *Geoderma* **120**: 283–95.

Murage E W, Voroney P R, Kay B D, Deen B and Beyaert R P. 2007. Dynamics and turnover of soil organic matter as affected by tillage. *Soil Science Society America Journal* **71**: 1363–70.

Reicosky D C, Kemper W D, Langdale G W, Douglas C L Jr and Rasmussen P E. 1995. Soil organic matter changes resulting from tillage and biomass production. *Journal Soil and Water Conservation* **50**: 253–61.

Sangwan O P and Phogat V K. 2007. Carbon. In: Research Methods in Plant Sciences: Allelopathy. Vol. 4. Plant Analysis (Eds.) Narwal S S, Sangwan O P, Dhankhar O P. Jodhpur: Scientific Publishers (India). pp. 65–8.

Singh A, Phogat V K, Dahiya R and Batra S D. 2014. Impact of long-term zero till wheat on soil physical properties and wheat productivity under rice-wheat cropping system. *Soil Tillage Research* **140**: 98–105.

Srinivasarao C H, Venkateswarlu B, Lal R, Singh A K, Kundu S, Vittal K P R, Balaguravaiah G, Babu M V S, Chary G R, Prasadbabu M B B and Reddy T Y. 2012. Soil carbon sequestration and agronomic productivity of an Alfisol for a groundnut-based system in a semiarid environment in southern India. *European Journal of Agronomy* **43**: 40–8.

Tanwar S P S, Rao S S, Regar P L, Datt S, Kumar P, Jodha B S, Santra P, Kumar R and Ram R. 2014. Improving water and land use efficiency of fallow-wheat system in shallow Lithic Calciorthid soils of arid region: Introduction of bed planting and rainy season sorghum-legume intercropping. *Soil Tillage Research* **138**: 44–55.

Vieira F C B, Bayer C, Zanatta J A, Dieckow J, Mielniczuk J and He Z L. 2007. Carbon management index based on physical fractionation of soil organic matter in an Acrisol under long-term no-till cropping systems. *Soil Tillage Research* **96**: 195–204.

Wang Q, Wang Y, Wang Q and Liu J. 2014. Impacts of 9 years of a new conservational agricultural management on soil organic carbon fractions. *Soil Tillage Research* **143**: 1–6.

Wright A L, Hons F M and Matocha Jr J E. 2005. Tillage impacts on microbial biomass and soil carbon and nitrogen dynamics of corn and cotton rotations. *Applied Soil Ecology* **29**: 85–92.