*Indian Journal of Agricultural Sciences* **88** (4): 523–9, April 2018/Article

# Effect of long-term use of organic, inorganic and integrated management practices on carbon sequestration and soil carbon pools in different cropping systems in Tarai region of Kumayun hills

DEBASHIS DUTTA[1], D K SINGH[2], N SUBASH[3], N RAVISANKAR[4], VINOD KUMAR[5], A L MEENA[6], R P MISHRA[7], SHWETA SINGH[8], VAIBHAV KUMAR[9] and A S PANWAR[10]

*ICAR-Indian Institute of Farming Systems Research, Modipuram, Meerut, Uttar Pradesh 250 110*

Received: 04 January 2017; Accepted: 03 January 2018

ABSTRACT

A study was undertaken during 2004-05 to 2013-14 to study the influence of different management options including cropping systems on carbon sequestration and soil carbon pools under Typic haplaquoll soil condition. Complete organic management (as per National Programme for Organic Production standards) with supply of 100% nutrient through organic sources, integrated crop management (nutrient and pests) with supply of 50% nitrogen through organic and 50% through inorganic and inorganic crop management with 100% nitrogen through inorganic sources while in sub plots four cropping systems namely Basmati rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.)-*Sesbania*, Basmati rice-lentil (*Lens culinaris* Medic.)-*Sesbania*, Basmati rice-vegetable pea (*Pisum sativum* L.)- *Sesbania* and Basmati rice-*Brassica napus*- *Sesbania* cropping system were tested in strip plot design at G B Pant University of Agriculture and Technology, Pantnagar, Uttarakhand. The three main plot treatments consisted of 100% organic, 50% organic + 50% inorganic and 100% inorganic fertilizer. Parameters such as bulk density, soil organic carbon, labile carbon pool, water soluble carbon, dehydrogenase activity were studied in all the treatments besides cropping systems equivalent yield. Bulk density varied from 1.24 to 1.44 $Mg/m^3$ in 0-15 cm soil under different nutrient management practices and the same increased with the increase in depth. Soil organic carbon (SOC) did not vary significantly among different cropping systems in 0-15 cm soil. The soil organic carbon content ranged from 10.70 to 11.13 g/kg under different cropping systems. The labile carbon pools and water soluble carbon content decreased with the increase of soil depth. The labile carbon pool (2450.21 mg/kg), water soluble carbon (21.39 mg/kg) and dehydrogenase activity (319.44 mg TPF/day/g soil) was higher in 0-15 cm soil depth with organic management of basmati rice-wheat-*Sesbania* systems compared to other systems and management practices. Among the management practice, basmati rice equivalent yield was higher in organic management (7130 kg/ha) in the year 2014. Among the cropping systems, Basmati rice-lentil- *Sesbania* (green manuring) (7865 kg/ha) system recorded higher equivalent yield compared to other systems. The carbon sequestration (15.36 Mg/ha) was higher in basmati rice-brassica-*Sesbania* cropping system with organic management practice and the sequestration rate was at par with basmati rice-wheat-*Sesbania* cropping systems. Therefore, either basmati rice-wheat-sesbania or basmati rice-*Brassica napus*-*Sesbania* cropping system with organic or integrated management is better for sequestering higher C in the soil than the present rice-wheat system with inorganic management.

**Key words:** Carbon pool, Carbon sequestration, Cropping systems, Management practices, System equivalent yield

Carbon sequestration through various agri-management options has a critical role in helping the world to meet the challenge of climate change. On agricultural lands, carbon can enter the soil through roots, litter, harvest residues etc. and stored primarily as soil organic matter. Soil is the largest carbon reservoir of the terrestrial carbon cycle and the 4$^{th}$ IPCC Assessment Report found that 89% of agriculture's technical mitigation potential lies in improving soil carbon sinks through crop land management, grazing land management, restoration of organic soils and degraded lands, bio-energy and water management. The rice–wheat cropping system occupies about 13.5 million ha in the Indo-Gangetic Plains of South Asia and provides food for 400 million people (Ladha *et al*. 2003). Crops are grown with available amounts of fertilizer and different organics. Majumder *et al.* (2008) reported that balanced NPK fertilization along with an adequate amount of FYM is most suitable for the continuous rice–wheat cropping system in the subtropical Indo-Gangetic Plains of India

[1,3,4,5,6,7,8,9,10]e mail: debashisdutta74@gmail.com, ICAR-Indian Institute of Farming System Research, Modipuram, Meerut, Uttar Pradesh 250 110. [2]GBPUAT, Pantnagar, Uttarakhand.

for improving the soil organic carbon stock and sustaining crop productivity. Optimum levels of soil organic matter can be maintained through crop rotation, fertility maintenance organic manures, tillage methods, and other cropping system components (Purakayastha *et al*. 2008). Among management practices, proper cropping systems and balanced fertilization are believed to offer the greatest potential for increasing soil organic carbon storage in agricultural soils (Lal 2005). Each 1% increase in average soil organic carbon levels could in principle reduce atmospheric $CO_2$ by up to 2% (Azeez 2009). Carbon sequestration potential of soil is influenced by many factors such as climate and soil conditions (Miller *et al*. 2004, Chabbi *et al*. 2009), cropping systems (Jagadamma and Lal 2010), management including tillage (Ogle *et al.* 2005) and fertilization (Bhattacharyya *et al*. 2007). There is need to identify and adopt the best management practices to maintain or improve Soil organic Carbon (SOC) levels particularly in the tropical regions where soils are low in organic carbon and production systems are inherently low in soil fertility (Mandal *et al*. 2005). Therefore, the present study was undertaken during 2004-05 to 2013-14 to assess the long term effect of organic, inorganic and integrated management on soil organic carbon pools and carbon sequestration in Tarai region of Kumayun hills at Pantnagar of northern India.

## MATERIALS AND METHODS

The study was conducted as a part of an ongoing Network Project on Organic Farming (established since 2004) under four cropping systems, viz. CS1 Basmati rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.)-*Sesbania* - (green manuring) , CS2 Basmati rice-lentil (*Lens culinaris* Medic.)-*Sesbania* (green manuring) , CS3 Basmati rice-vegetable pea (*Pisum sativum* L.)- *Sesbania* (green manuring) and CS 4 Basmati rice-*Brassica napus*-*Sesbania* (green manuring). The study was conducted at Organic Farming Research Centre, G B Pant University of Agriculture and Technology, Pantnagar (29°08'N 79°05'E), Uttarakhand, having soil type of Typic Haplaquoll, fine loamy and mix calcareous to understand the carbon sequestration potential and soil carbon pools as influenced by management practices including cropping systems. Permanent plot site was established during 2003-04 under Network Project on Organic Farming to compare the productivity of different cropping systems under various management options (organic, integrated and inorganic) and it was continued up to 2013-14. The experiment was in strip plot design at G B Pant University of Agriculture and Technology, Pantnagar, Uttarkhand. The three main plot treatments consisted of 100% organic, 50% organic + 50% inorganic and 100% inorganic management while 4 cropping systems were assigned to sub plots. In all the cropping system in the sub plots, stubbles of crops were incorporated in the soil while above ground residues were recycled after decomposition in the form of organic manures for supplementing the recommended dose of nutrients. The mean annual rainfall of the site was 2118 mm. Mean annual relative humidity (RH) was 70.7% while mean maximum and minimum temperature was 29.4$^0$C and 17.0$^0$C respectively. This region belongs to sub- arid ecosystem characterized by hot air conditions. Initial soil fertility status was medium (0.65%) organic carbon, low in available N (238 kg/ha), medium P (16.7 kg/ha) and medium available K (156 kg/ha).

Soil samples were collected by boring at 4 random places with the help of post hole auger from all the plots at four soil depths (0–15, 15–30, 30–45 and 45–60 cm) after the harvesting of wheat in 2014. Soil core sampler (each core had an inner diameter of 7 cm and length of 4.5 cm) was used to take the sample for the determination of bulk density (BD). Soil samples were air dried in shade (Blake *et al*. 1986). Less than 2 mm size fraction of soil samples were used for determining different fractions of carbon. The rapid titration method using 1 N $K_2Cr_2O_7$ solution as described by Walkley and Black (1934) was followed for the determination of SOC. Labile carbon (LC) was determined by $KMnO_4$ oxidation method (Blair *et al*. 1995).

While water soluble carbon (WSC) was determined using the method described by McGill *et al*. (1986) and WSC (%) was calculated with equation (B-S) × 0.01× 0003 ×100/10, where 'B' is ml of 0.01 N ferrous ammonium sulfate (FAS) used in the blank and 'S' is ml of 0.01 N FAS used in soil sample.

Dehydrogenase activity was determined by the reduction of triphenyltetrazolium chloride (TTC) to triphenylformazan (TPF) as described by Serra-Wittling *et al*. (1995).

Soil organic pool was calculated using the below given formula:

SOC pool (Mg/h) = Soil organic carbon (%) × soil depth (m) × bulk density (Mg/m)×$10^4$ $m^2$/h ×$10^{-2}$

The carbon sequestration was determined by subtracting the value of C pools at start of the experiment (2004) from the value of C pools in the year 2014. The ratio of carbon sequestration over C initial (2004) was also calculated. The annual rate of C sequestration was calculated by ratio of changes in C pools over total number of years.

Cropping system equivalent yields of different crops were calculated by converting the yield of different crops into equivalent yield of basmati rice based on price of the produce. It was computed by multiplying the grain yield of the crops with their respective per unit price. The calculated total return (₹/ha) was divided by the price of basmati rice and was added to the basmati rice grain yield.

The data for different soil carbon fractions and parameters were subjected to Duncan's Multiple Range Test at 5% level of significance for comparing the means using AGRES (Agricultural Research) package.

## RESULTS AND DISCUSSION

### *Bulk density*

Bulk density of the soil varied among different management practices but the variation was not statistically significant. However, it exhibited an increasing trend with increase in soil depth (0–60 cm) (Table 1). Lower

Table 1 Long term influence of organic, inorganic and integrated production systmes on soil bulk density (Mg/m$^3$)

| Depth | Organic | Inorganic | Integrated |
|---|---|---|---|
| 0-15 cm | 1.24 | 1.44 | 1.33 |
| 15-30 cm | 1.28 | 1.5 | 1.38 |
| 30-45 cm | 1.32 | 1.54 | 1.40 |
| 45-60 cm | 1.39 | 1.58 | 1.50 |

bulk density observed under organic practice compared to inorganic and integrated crop management practices. The lower bulk density under organic management over the years could be attributed to the addition of root and plant biomass and to the conversion of some micro-pores into macro-pores due to cementing action of organic acids and polysaccharides formed during the decomposition of organic residues by higher microbial activities. Results also corroborated the findings of Brar *et al*. (2015).

*Soil organic carbon*

Soil organic carbon (SOC) was significantly influenced by different management practices while the same was not affected due to cropping systems evaluation. Irrespective of the cropping systems, the surface soil (0-15 cm) had significantly higher organic carbon content over 15-30 (5.57%), 30-45 (14.31%) and 45-60 (21.21 %) cm soil depth under organic management practice (Table 2). Among the management practices, organic management recorded significantly higher SOC i.e 59.05%, 65.56%, 71.26% and 90.02% higher over inorganic and 13.63%, 16.34%, 12.62% and 15.45% higher over integrated at 0-15, 15-30, 30-45, and 45-60 cm soil depth respectively compared to other management options. Continuous addition of organic manures viz. vermicompost and FYM under organic management resulted in higher organic carbon, indicating soil as best carbon sink even in sub arid conditions. Though the soil organic carbon was not significantly influenced due to cropping systems, it was observed that basmati rice-*Brassica napus* -*Sesbania* system resulted in higher organic carbon content at 0-15 cm (11.13 g/kg), 30-45 cm (9.93 g/kg) and 45-60 cm (9.19 g/kg) while basmati rice -wheat- *Sesbania* recorded higher SOC at 15-30 cm soil depth (10.43 g/kg). Interaction effect of cropping systems and management indicates that at all depths in all the cropping systems, organic and integrated management resulted in at par SOC but it was significantly better than inorganic management. Significantly different pattern of SOC in various management practices at lower depth can be attributed to differential movement of carbon through the soil profile. Study made by Brar *et al*. (2015) also revealed that long term application of organic manure results in better SOC. Significant influence of cropping systems on SOC was also reported by Al-Kaisi and Grote (2006).

*Labile carbon pool*

The variation of labile carbon pool under different cropping systems was not statistically significant but the averaged across the different cropping systems, the labile carbon pool was 12.1% higher in organic management compared to inorganic management at 0-15 cm depth. Averaged across the different management practice, the labile carbon pool was higher under basmati rice–wheat-*Sesbania* (13.85% over Basmati rice – vegetable pea-*Sesbania*) at 0-15 cm (Table 3). Significant quantity of labile carbon content was recorded at 15-30 cm soil depth under basmati rice–wheat-*Sesbania* systems under inorganic management compared to all other cropping systems in the same depth. The labile carbon contents at 30-45 cm soil were not significantly different but 18.2% higher labile carbon pool was recorded with basmati rice-lentil-*Sesbania* systems compared to basmati rice –vegetable pea – *Sesbania* cropping systems. The variation of labile carbon contents at 45-60 cm depth were significant and it was found that basmati rice-wheat-*Sesbania* with organic and integrated management practice and basmati rice-lentil-*Sesbania* with organic management only recorded higher carbon content. The labile carbon pool was higher in soil with organic management irrespective of cropping systems. Neogi *et al*. (2014) also reported similar findings in confirming the results.

Table 2 Long term effect of organic, inorganic and integrated production systems on soil organic carbon (g/kg)

| Management | CS1 | CS2 | CS3 | CS4 | Mean |
|---|---|---|---|---|---|
| | | *Depth 0-15 cm* | | | |
| Organic | 13.37 | 12.91 | 12.35 | 13.62 | 13.06$^{a}$ |
| Inorganic | 7.48 | 8.81 | 8.33 | 8.23 | 8.21$^{c}$ |
| Integrated | 12.25 | 10.40 | 11.72 | 11.61 | 11.50$^{b}$ |
| Mean | 10.90$^{a}$ | 10.70$^{a}$ | 10.77$^{a}$ | 11.13$^{a}$ | |
| | | *Depth 15-30 cm* | | | |
| Organic | 13.20$^{a}$ | 12.64$^{a}$ | 11.83$^{a}$ | 11.83$^{a}$ | 12.37$^{a}$ |
| Inorganic | 6.61$^{e}$ | 8.03$^{e}$ | 7.92d$^{e}$ | 7.32$^{e}$ | 7.47$^{c}$ |
| Integrated | 11.72$^{a}$ | 9.31$^{cd}$ | 9.97$^{bc}$ | 11.52$^{ab}$ | 10.63$^{b}$ |
| Mean | 10.43$^{a}$ | 9.97$^{a}$ | 9.87$^{a}$ | 10.20$^{a}$ | |
| | | *Depth 30-45 cm* | | | |
| Organic | 10.51$^{a}$ | 11.36$^{a}$ | 11.36$^{a}$ | 11.36$^{a}$ | 11.19$^{a}$ |
| Inorganic | 5.17$^{d}$ | 7.31$^{c}$ | 6.65$^{c}$ | 7.02$^{c}$ | 6.53$^{c}$ |
| Integrated | 11.47$^{a}$ | 8.95$^{b}$ | 7.94b$^{c}$ | 11.42$^{a}$ | 9.94$^{b}$ |
| Mean | 9.05$^{b}$ | 9.21$^{ab}$ | 8.65$^{b}$ | 9.93$^{a}$ | |
| | | *Depth 45-60 cm* | | | |
| Organic | 8.85$^{ab}$ | 8.32$^{bc}$ | 10.29$^{a}$ | 10.29$^{a}$ | 10.29$^{a}$ |
| Inorganic | 4.61$^{ef}$ | 6.01$^{de}$ | 4.21$^{f}$ | 6.81$^{cd}$ | 5.41$^{b}$ |
| Integrated | 10.23$^{a}$ | 8.25$^{bc}$ | 6.7$^{cd}$ | 10.47$^{a}$ | 8.92$^{a}$ |
| Mean | 7.42$^{b}$ | 7.13$^{b}$ | 5.46$^{b}$ | 9.19$^{a}$ | |

*Values within a column, followed by different letters are significantly different at $P<0.05$ by Duncan's multiple range test. CS1: Basmati rice-wheat-*Sesbania* - (green manuring), CS2: Basmati rice-lentil-*Sesbania* (green manuring), CS3: Basmati rice-vegetable pea- *Sesbania* (green manuring) and CS4: Basmati rice-*Brassica napus*- *Sesbania* (green manuring).

Table 3 Long term effect of organic, inorganic and integrated production systems on labile carbon pool (mg/kg) in soil

| Management | CS1 | CS2 | CS3 | CS4 | Mean |
|---|---|---|---|---|---|
| | | | *Depth 0-15 cm* | | |
| Organic | 2450.21 | 1925.32 | 2150.12 | 2175.81 | 2175.37$^{a}$ |
| Inorganic | 2087.56 | 1950.43 | 1825.52 | 1900.62 | 1941.03$^{b}$ |
| Integrated | 2237.55 | 2225.62 | 1975.31 | 2225.71 | 2166.05$^{a}$ |
| Mean | 2258.44$^{a}$ | 2033.79$^{b}$ | 1983.65$^{b}$ | 2100.71$^{ab}$ | |
| | | | *Depth 15-30 cm* | | |
| Organic | 2050.24$^{bc}$ | 2150.27$^{ab}$ | 2050.24$^{bc}$ | 1475.61$^{ef}$ | 1931.59$^{a}$ |
| Inorganic | 2437.53$^{a}$ | 1762.56$^{cde}$ | 1350.37$^{f}$ | 1562.54$^{def}$ | 1778.25$^{a}$ |
| Integrated | 1762.52$^{cde}$ | 1875.28$^{bcd}$ | 1612.53$^{def}$ | 2062.57$^{bc}$ | 1828.23$^{a}$ |
| Mean | 2083.43$^{a}$ | 1929.37$^{a}$ | 1671.05$^{bH}$ | 1700.24$^{b}$ | |
| | | | *Depth 30-45 cm* | | |
| Organic | 1775.52 | 1987.53 | 1475.02 | 1850.81 | 1772.22$^{a}$ |
| Inorganic | 1637.54 | 1562.57 | 1525.36 | 1312.57 | 1509.51$^{b}$ |
| Integrated | 1875.91 | 1887.57 | 1600.71 | 1537.52 | 1725.43$^{a}$ |
| Mean | 1762.99$^{a}$ | 1812.56$^{a}$ | 1533.7$^{b}$ | 1566.97$^{b}$ | |
| | | | *Depth 45-60 cm* | | |
| Organic | 1481.25$^{a}$ | 1378.12$^{a}$ | 937.57$^{bcd}$ | 975.34$^{bcd}$ | 1193.07$^{a}$ |
| Inorganic | 1068.75$^{bc}$ | 853.13$^{de}$ | 1134.38$^{b}$ | 871.88$^{cde}$ | 982.04$^{b}$ |
| Integrated | 1481.25$^{a}$ | 1059.38$^{bc}$ | 937.50$^{bcd}$ | 731.25$^{e}$ | 1052.35$^{b}$ |
| Mean | 1343.75$^{a}$ | 1096.88$^{b}$ | 1003.15$^{b}$ | 859.49$^{c}$ | |

*Values within a column, followed by different letters are significantly different at $P<0.05$ by Duncan's multiple range tests. CS1: Basmati rice-wheat-*Sesbania* - (green manuring), CS2: Basmati rice-lentil-*Sesbania* (green manuring), CS3: Basmati rice-vegetable pea- *Sesbania* (green manuring) and CS4: Basmati rice-*Brassica napus*- *Sesbania* (green manuring).

*Water soluble carbon (WSC)*

Application of organic manure in basmati rice –wheat-*Sesbania* significantly increased the water soluble carbon upto the soil depth of 45 cm. In respect of WSC content in soil, rice–wheat-*Sesbania* cropping systems resulted as better system compared to other cropping system for the enrichment of soil organic carbon content (Table 4). The water soluble carbon in 0-15 cm soil depth was 12.1% and 24.7% higher under organic management practice over the inorganic and integrated management practice respectively. The higher WSC content in surface layer might be due to addition of plant residues and microbial activity. The depth wise distribution of WSC showed a decreasing trend in each treatment averaged across the different cropping systems. In 15-30 cm soil layer, WSC content increased by 9.5% and 28.4% in integrated crop management over organic and inorganic management practice, respectively. Among the cropping systems, rice –wheat-*Sesbania* systems recorded better WSC compared to other cropping systems. The beneficial effects of FYM application under rice–wheat cropping system on WSC content were documented by Manna *et al*. (2006) and the present results also confirmed the same.

*Dehydrogenase activity*

Soil enzyme activities were strongly affected by the organic, inorganic and integrated management practices. Application of organic manures increased dehydrogenase activity, which is an index of microbial activity of soil. The dehydrogenase enzyme activity was significantly different among all the cropping systems as well as depth of soil. The dehydrogenase activity varied from 238.93 to 44.89 mg TPF/day/g soil under different management practices (Table 5). Among the different cropping systems under organic management, significantly higher value of dehydrogenase activity was recorded in Basmati rice–wheat-*Sesbania* and Basmati rice-vegetable pea-*Sesbania* at 0-15 cm soil depth. The dehydrogenase activity was 44.3 and 18.5% higher under organic management over integrated and inorganic management at 0-15 cm depth. The dehydrogenase activity at 15-30 cm soil depth was statistically significant in basmati rice-lentil – *Sesbania* systems. A similar finding of dehydrogenase activity was also reported by Tripathi *et al*. (2010).

*Yield*

During 2013-14, the equivalent yield of various cropping systems under different management practices indicated that among the management practices, organic and integrated production systems resulted in 10.46 and 5.90% higher yield compared to inorganic management.

Among the cropping systems, Basmati rice-lentil-*Sesbania* resulted in higher mean system yield (7288 kg/ha) followed by Basmati rice-*Brassica napus*-*Sesbania* and Basmati rice-wheat-*Sesbania* (Table 6). Except basmati rice-

Table 4 Long term effect of organic, inorganic and integrated production systems on water soluble carbon (mg/kg) in soil

| Management | CS1 | CS2 | CS3 | CS4 | Mean |
|---|---|---|---|---|---|
| | | | *Depth 0-15 cm* | | |
| Organic | 21.39$^{a}$ | 12.32$^{f}$ | 13.82$^{de}$ | 16.26$^{bc}$ | 15.90$^{a}$ |
| Inorganic | 15.32$^{cd}$ | 12.32$^{f}$ | 13.82$^{fg}$ | 15.61$^{g}$ | 14.18$^{c}$ |
| Integrated | 16.88$^{b}$ | 12.61$^{ef}$ | 11.43$^{de}$ | 10.22$^{bc}$ | 12.75$^{b}$ |
| Mean | 17.70$^{a}$ | 12.40$^{c}$ | 13.00$^{c}$ | 14.00$^{b}$ | |
| | | | *Depth 15-30 cm* | | |
| Organic | 14.4$^{a}$ | 11.42$^{b}$ | 7.81$^{c}$ | 7.81$^{c}$ | 10.36$^{a}$ |
| Inorganic | 9.38$^{d}$ | 9.63$^{d}$ | 9.36$^{d}$ | 6.98$^{e}$ | 8.84$^{c}$ |
| Integrated | 12.6$^{b}$ | 9.63$^{d}$ | 10.85$^{b}$ | 12.32$^{b}$ | 11.35$^{b}$ |
| Mean | 12.13$^{a}$ | 10.23$^{b}$ | 9.34$^{c}$ | 9.04$^{c}$ | |
| | | | *Depth 30-45 cm* | | |
| Organic | 11.18$^{a}$ | 9.32$^{b}$ | 6.32$^{de}$ | 6.37$^{d}$ | 8.30$^{a}$ |
| Inorganic | 6.92$^{cd}$ | 5.75$^{e}$ | 5.71$^{de}$ | 7.55$^{c}$ | 6.48$^{c}$ |
| Integrated | 8.71$^{b}$ | 6.34d$^{e}$ | 6.32$^{e}$ | 10.59$^{ab}$ | 7.99$^{b}$ |
| Mean | 8.94$^{a}$ | 7.14$^{c}$ | 6.12$^{d}$ | 8.17$^{b}$ | |
| | | | *Depth 45-60 cm* | | |
| Organic | 6.12 | 3.91 | 4.26 | 6.35 | 5.16$^{a}$ |
| Inorganic | 5.73 | 3.35 | 5.41 | 3.92 | 4.60$^{b}$ |
| Integrated | 6.34 | 3.27 | 4.23 | 9.33 | 5.79$^{a}$ |
| Mean | 6.06$^{a}$ | 3.51$^{c}$ | 4.63$^{b}$ | 6.53$^{b}$ | |

*Values within a column, followed by different letters are significantly different at P<0.05 by Duncan's multiple range tests. CS1: Basmati rice-wheat-*Sesbania* - (green manuring), CS2: Basmati rice-lentil-*Sesbania* (green manuring), CS3: Basmati rice-vegetable pea- *Sesbania* (green manuring) and CS4: Basmati rice-*Brassica napus*- *Sesbania* (green manuring).

Table 5 Long term effect of organic, inorganic and integrated production systems on dehydrogenase activity (mg TPF/ day/g soil) in soil

| Management | CS1 | CS2 | CS3 | CS4 | Mean |
|---|---|---|---|---|---|
| | | | *Depth 0-15 cm* | | |
| Organic | 319.44$^{a}$ | 235.82$^{b}$ | 298.53$^{a}$ | 101.93$^{e}$ | 238.93$^{a}$ |
| Inorganic | 261.62$^{b}$ | 192.23$^{c}$ | 249.16$^{b}$ | 103.71$^{e}$ | 201.68$^{b}$ |
| Integrated | 242.05$^{b}$ | 181.11$^{c}$ | 140.19$^{d}$ | 98.82$^{e}$ | 165.54$^{c}$ |
| Mean | 274.37$^{a}$ | 203.05$^{c}$ | 229.29$^{b}$ | 101.49$^{d}$ | |
| | | | *Depth 15-30 cm* | | |
| Organic | 99.27$^{bc}$ | 177.99$^{a}$ | 73.91$^{e}$ | 58.79$^{fg}$ | 102.49$^{a}$ |
| Inorganic | 86.37$^{d}$ | 73.91$^{e}$ | 53.90$^{g}$ | 57.45$^{g}$ | 67.9075$^{c}$ |
| Integrated | 95.26$^{c}$ | 105.94$^{b}$ | 104.16$^{b}$ | 65.02$^{f}$ | 92.595$^{b}$ |
| Mean | 93.63$^{b}$ | 119.28$^{a}$ | 77.32$^{c}$ | 60.42$^{d}$ | |
| | | | *Depth 30-45 cm* | | |
| Organic | 91.26$^{a}$ | 83.25$^{a}$ | 44.56$^{f}$ | 41.89$^{f}$ | 65.24$^{a}$ |
| Inorganic | 31.66$^{g}$ | 73.47$^{bcd}$ | 32.55$^{g}$ | 40.55$^{fg}$ | 44.56$^{c}$ |
| Integrated | 81.47$^{bc}$ | 57.01$^{e}$ | 68.57$^{d}$ | 36.10$^{fg}$ | 60.79$^{b}$ |
| Mean | 68.13$^{a}$ | 71.24$^{a}$ | 48.56$^{b}$ | 39.51$^{c}$ | |
| | | | *Depth 45-60 cm* | | |
| Organic | 61.46$^{d}$ | 51.23$^{g}$ | 88.15$^{a}$ | 45.00$^{h}$ | 61.46$^{a}$ |
| Inorganic | 39.22$^{i}$ | 56.12$^{ef}$ | 57.9$^{de}$ | 26.32$^{j}$ | 44.89$^{b}$ |
| Integrated | 52.56$^{g}$ | 81.92$^{b}$ | 73.91$^{c}$ | 30.32$^{j}$ | 59.68$^{a}$ |
| Mean | 51.08$^{c}$ | 63.09$^{b}$ | 73.32$^{a}$ | 33.88$^{d}$ | |

*Values within a column, followed by different letters are significantly different at P<0.05 by Duncan's multiple range tests. CS1: Basmati rice-wheat-*Sesbania* - (green manuring), CS2: Basmati rice-lentil-*Sesbania* (green manuring), CS3: Basmati rice-vegetable pea- *Sesbania* (green manuring) and CS4: Basmati rice-*Brassica napus*- *Sesbania* (green manuring).

vegetable pea-*sesbania* system, all other systems recorded numerically higher yield under organic management. The yield difference of Basmati rice-wheat-*Sesbania* (CS1), Basmati rice-lentil-*Sesbania* (CS2), Basmati rice-*Brassica napusSesbania* (CS4) under organic management over inorganic were 9.00, 14.01 and 18.94% respectively, where as the yield difference of integrated practice over inorganic practice were 7.52, 2.94 and 12.23 % respectively, indicating role of organic manures in enhancing the yield of all the crops and systems.

Table 6 Long term effect of organic, inorganic and integrated production systems on system equivalent (Basmati rice) yield (kg/ha)

| Cropping system | Organic | Inorganic | Integrated | Mean |
|---|---|---|---|---|
| CS1 | 6963 | 6388 | 6869 | 6740 |
| CS2 | 7865 | 6898 | 7101 | 7288 |
| CS3 | 6284 | 6306 | 6382 | 6324 |
| CS4 | 7408 | 6228 | 6990 | 6875 |
| Mean | 7130 | 6455 | 6836 | |

CS1: Basmati rice-wheat-*Sesbania* (green manuring), CS2: Basmati rice-lentil-*Sesbania* (green manuring), CS3: Basmati rice-vegetable pea- *Sesbania* (green manuring) and CS4: Basmati rice-*Brassica napus*- *Sesbania* (green manuring)

*Carbon balance and turnover rate*

After 10 years, all the cropping systems under organic, inorganic and integrated management practice, contributed towards C sequestration. SOC content of the soil (0-15 cm) was improved by 84% under Basmati rice-*Brassica napus*-*Sesbania* with organic management, whereas it increased by 28.8% and 68.3% with inorganic and integrated management respectively compared to initial level (2004). The application of organic source of fertilizer significantly increased SOC content over the other management practices. This might be attributed to greater amount of organic input with higher lignin content (FYM) and the increased plant biomass addition resulting in a greater accumulation per unit of C input (Paustian *et al.* 1992). Among the cropping systems, lowest amount of SOC (16.26%) increase was found under basmati rice-wheat and *sesbania* system with inorganic management (Table 7). Among the different cropping systems, basmati rice-*Brassica napus*-*sesbania* sequestered

Table 7 Long term effect of organic, inorganic and integrated production systems on Carbon sequestration in soil

| Treatments | Soil organic carbon pool (Mg/ha) | | | | Carbon sequestration (Mg/ha.) | | | | Carbon sequestration rate (Mg/ha/year ) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | CS1 | CS2 | CS3 | CS4 | CS1 | CS2 | CS3 | CS4 | CS1 | CS2 | CS3 | CS4 |
| Organic | 24.738 | 23.994 | 22.878 | 25.296 | 14.62 | 13.63 | 12.14 | 15.36 | 1.46 | 1.36 | 1.21 | 1.54 |
| Inorganic | 15.984 | 19.008 | 17.928 | 17.712 | 2.97 | 7.00 | 5.56 | 5.27 | 0.30 | 0.70 | 0.56 | 0.53 |
| Integrated | 23.94 | 20.748 | 23.3415 | 23.142 | 13.56 | 9.31 | 12.76 | 12.49 | 1.36 | 0.93 | 1.28 | 1.25 |

CS1 Basmati rice-wheat-*Sesbania* - (green manuring) , CS2 Basmati rice-lentil-*Sesbania* (green manuring), CS3 Basmati ricevegetable pea- *Sesbania* (green manuring) and CS4 Basmati rice-*Brassica napus*- - *Sesbania* (green manuring).

maximum amount of carbon (15.36 Mg/ha) in soil followed by Basmati rice–wheat-*Sesbania* systems. The balanced application of nutrients with FYM significantly improved the SOC pool of soil as compared to chemical fertilizer treatments, irrespective of cropping systems. Similar trend was also reported by Brar *et al*. (2013) for rice-wheat cropping systems. The Basmati rice-wheat-*Sesbania*, Basmati rice-lentil-*Sesbania*, Basmati rice-vegetable pea-S*esbania* and Basmati rice-mustard-*Sesbania* cropping systems with organic management contributed positively toward carbon sequestration. The ratios of carbon sequestration over initial carbon were more or less at par among organic and integrated management in all the cropping systems except in Basmati rice-lentil-*Sesbania*. The value of carbon sequestration ratio varied from 0.88 to 1.11 under organic and integrated management system whereas the ratio varied from 0.22 to 0.51 under inorganic management in different cropping systems. Carbon sequestration rate was higher in Basmati rice- *Brassica napus*-*Sesbania* as a result of higher labile carbon, water soluble carbon and yield compared to other cropping systems.

The explicitly study concludes that management practice including the cropping systems contributes significantly for improving the soil organic carbon and its associated factors. It can be concluded that either Basmati rice-wheat-*Sesbania* or basmati rice- *Brassica napus*-*Sesbania* cropping system with organic or integrated management is better for sequestering higher C in the soil than the present rice-wheat system with inorganic management.

## ACKNOWLEDGEMENT

The authors are highly thankful to Indian Council of Agricultural Research, New Delhi for proving financial support in the form of Network Project on Organic Farming, National Innovations on Climate Resilient Agriculture Project and G B Pant University of Agricultural Technology, Pantnagar, Uttarakhand for providing infrastructure facilities for conducting the field experiments. The authors are also thankful to Director, ICAR-Indian Institute of Farming Systems Research, Modipuram for providing facilities for analysis of soil samples.

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