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Organic Carbon Stock and its Relationship with Soil Properties in Coastal Agroecosystem of Puducherry, India

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This study in coastal agroecosystem was conducted to evaluate the soil organic carbon Stock (SOC) in different farm management practices (conventional, sustainable and organic) and to develop its relation to soil physical, chemical and biological parameters. Three composite soil samples were collected from each of the 9 farms from the surface (0-15 cm depth). Soil organic carbon (SOC) stock was significantly higher in organic farming (28.14 t ha^{-1}) compared to sustainable and conventional farming. Soils from organic farms had significantly higher level of moisture content (4.40 %(w/w)), water holding capacity (50.33%),clay (13%) total N (3.67 g kg^{-1}), total P (2.38 g kg^{-1}), soil respiration (6.33 mg CO_2 100 g of soil^{-1} day^{-1}), microbial biomass C (779.87 mg kg^{-1}) and N microbial biomass (74.90 mg kg^{-1}) compared to conventional and sustainable farming systems. SOC stock showed a significant positive correlation with soil moisture content (r = 0.80), volume of soil particle (r = 0.68), water holding capacity (r = 0.91), EC (r = 0.68), silt (r = 0.86), clay (r = 0.82), total N (r = 0.93), total P (r = 0.95), soil respiration (r = 0.67), microbial biomass C (r = 0.87) and N (r = 0.84). The highest amount of SOC stock was in organic farming due to continuous use of farm yard manure and organic fertilizers.

***(Key words:** Soil organic carbon stock, farming system, soil respiration, microbial biomass carbon)*

The soil organic carbon (SOC) not only influence the physical, chemical and biological properties of soils but also sustains its productivity in an agroecosystem. Important factors controlling SOC levels include climate, hydrology, parent material, soil fertility, biological activity, vegetation patterns and land use. SOC is extremely altered by human activities, viz. deforestation, biomass burning, land use changes and environmental pollution (Liu *et al.,* 2007). Most of the agricultural soils of India are low in soil organic carbon (SOC) and macro- and micronutrients. The agricultural system in India is typically a monsoon-driven low-input farming with limited use of organic amendments. Agriculture intensification and anthropogenic activities affect the soil quality at all levels, including the structure and function of soil microbial communities and plant available nutrients (Saha *et al*., 2008). Farm management systems alter soil microbial community structure through changes in carbon availability and its quality, pH, nutrient availability, or other chemical parameters (Cookson *et al*., 2007).

Crop rotation and farm management practices affects the physical, chemical, mineral, soil biological processes and biochemical properties of soil (Chinnadurai *et al.,* 2014). During the past few years, conventional agriculture management has relied on use of synthetic fertilizers and pesticides to improve crop productivity. This intensive use of agrochemicals is known to reduce biodiversity, increase irreversible erosion of soil and deplete soil organic matter (Sudhakaran *et al.,* 2013). However, only few studies have been conducted in coastal agroecosystem, India on the influence of farm management practices on the soil carbon stock and soil fertility (Behera *et al.,* 2016; Satpathy *et al.,* 2015; Padmavathy and Poyyamoli, 2011). Hence, the present study was undertaken to assess soil organic carbon stock and its relationship with soil properties in a coastal agroecosystem of Puducherry, India.

MATERIALS AND METHODS

Study area

Puducherry is located on the Coramandel coast 11°52′North, 79°45′East and 11°59′North and 79°52′East covering an area of 480 km^2. The mean annual rainfall of the study area is about 1311 mm. The mean number of annual rainy days is 55 and the mean monthly

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temperature ranges between 21°C and 30°C. The region gets more rainfall during north east monsoon. Humidity is also high as the area is nearer to the coast. In these study sites the texture of soils is sandy loam.

Soils from 9 farms following organic, sustainable and conventional farming were sampled from June 2014 to August 2015 (Table 1). Three farms were certified as organic farming and no synthetic fertilizer, pesticides and herbicides were used. They were located in Soriankuppam (organic-1, organic-2) and in Nallavadu (organic-3). The other three farms are classified as sustainable, in which synthetic fertilizers were used but synthetic pesticides were not used. These farms were located in Soriankuppam (sustainable-1, 2 & 3) (according to USDA, 2000). Remaining three conventional farms were also sampled. In these farms synthetic fertilizer and pesticides were used. These farms are located in Kalapet (conventional 1 and 3) and Soriankuppam (conventional 2).

Sample collection

Three composite soil samples from 0-15cm depth were collected from each of the 9 farms from June 2014 to August 2015. All the samples were collected after the crop was harvested and before the soil was tilled, to avoid interference by recent application of fertilizers and agronomic practices. Bulked samples were kept separately according to the location within each field for replication maintenance. Composite soil samples were stored in deep freezer to control microbial activities for biochemical analysis. The soils were transferred to storage room and were stored at 4°C until the time of analysis.

Analysis of soil properties

Soil moisture content was determined by gravimetric method (Hesse, 1971). Soil particle density, bulk density and volume of soil particle were determined by volumetric flask method (Bashour and Sayegh, 2007). Soil texture was determined by international pipette method (Piper, 1966). Water holding capacity was determined by gravimetric method (Margesin and Schinner, 2005). Soil pH (1:2 soil water suspension) was determined by potentiometry (Waring and Bremner, 1964). Soil salinity (EC) (1:2 soil water suspension) was determined by conductometry (Waring and Bremner, 1964). Soil organic carbon (SOC) was determined by Chromic acid wet digestion (Walkley and Black, 1934). Total nitrogen (Total N) was determined by Macro-Kjeldahl digestion (Piper, 1966). Total phosphorus (Total P) was analyzed by WD-XRF instrument (Becckhoff *et al.,* 2006). Soil respiration was determined by trapping CO_2 evolved during the incubation of soil in NaOH solution. The amount of alkali used for trapping CO_2 was calculated after titration with HCl solution and results were expressed as mg CO_2 100 g of soil^{-1} day^{-1} (Stotzky, 1965). Microbial biomass C and N were analyzed by fumigation extraction method (Vance *et al.,* 1987).

Data analysis

All the experimental data were analyzed using SPSS version 16. Statistically significant difference between the farm management practices was analyzed by using one way ANOVA test. The relationship among soil properties and carbon stock were analyzed by Pearson correlation.

RESULTS AND DISCUSSIONS

Influence of farming systems on soil physico-chemical properties

Our results showed that soil moisture content (4.40%) and water holding capacity (50.33%) were significantly higher in organic farming soils (Table 1). Soil moisture content was positively correlated with water holding capacity (r = 0.718 *), clay content (r = 0.775*), total phosphorus (r = 0.726*), soil organic carbon (r = 0.767*), soil respiration (r = 0.770*), carbon stock (r = 0.792*), microbial biomass C (r = 0.797*) and microbial biomass N (r = 0.882**) (Table 3).

Soil bulk density (BD) was higher in sustainable farming (1.28 g/cm^3) compare than other two farming systems and were not significantly different among farm management practices. Volume of soil particle (19.89 cm^3) was higher in organic farming soil (Table 1). Electrical conductivity (r = 0.752*) and amount of carbon stock (r = 0.667*) showed significant positive correlation with volume of soil particle (Table 2). pH was higher in conventional farms (6.59) compared than

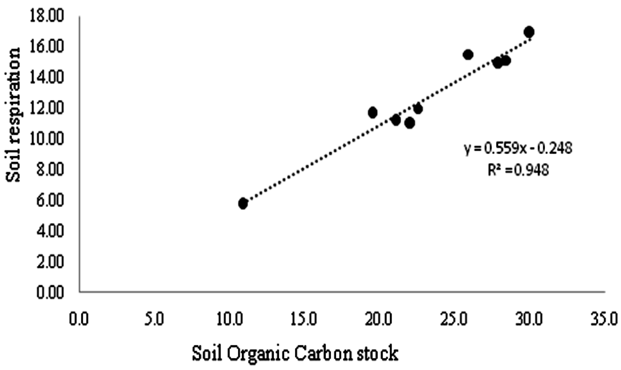

***Fig. 1**. Relationship between Soil respiration and SOC*

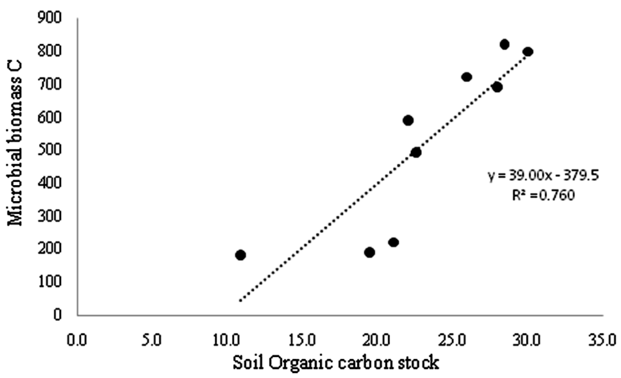

Fig. 2. *Relationship between Microbial biomass C and SOC*

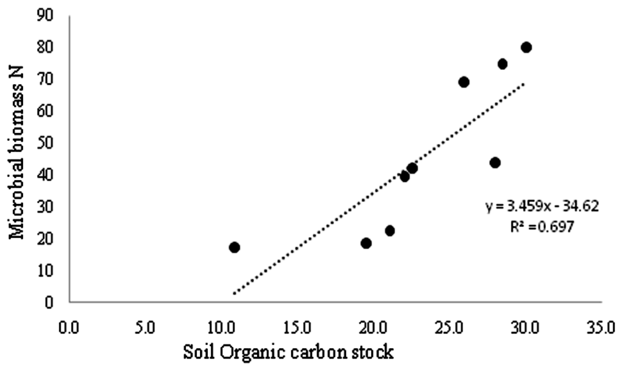

Fig. 3*. Relationship between Microbial biomass N and SOC*

other two farms and did not significantly differ with farm management practices. EC was higher in organic farming system soils and showed significant positive correlation with volume of soil particle (r = 0.752*), water holding capacity (r = 0.732*), total N (r = 0.715*) and SOC (r = 0.683*) (Table 3).

Sand content (78.33 %) was higher in conventional farming system soils. Silt (15.67 %) and clay (13 %) were higher in organic farming soil. Amount of clay showed significant differences among the farm management practices (Table1). Clay content of farming system soils was positively correlated with water holding capacity (r =0.812**), soil moisture content (r = 0.775*), total nitrogen (r = 0.870**), total phosphorus (r = 0.723*), SOC (r = 0.905**), soil respiration (r = 0.681*), Carbon stock (r = 0.867**), microbial biomass C (r = 0.881**) and N (r = 0.903**) (Table 3).

Our study revealed that soils from organic farms exhibited improved soil quality. Soil physical factors including increased soil moisture content, water holding capacity, volume of soil particle and lower bulk density were evident in organically managed farm soils. These effects were due to application of variety of organic amendments, FYM and vermicomposts applied by organic farmers in every crop rotation compared to other farmers. Several other studies have also shown that

Table 1*. Management practices and cropping pattern of three farming systems*

Farms and location	Cropping pattern			INM	IPM	Weed management
	2011-12	2012-13	2013-14			
Conventional farming	1. Groundnut (JLR)+Chilli+ Bhendi 2. Rice (White Ponni) 3. Black gram	1.Groundnut (JLR) + Black gram 2. Tapioca	1. Bhendi (hybrid) 2. Finger millet and bottle gourd 3. Rice (White Ponni)	FYM, DAP, Urea and Gypsum	Methomyl 40 % SP, Lambadacyhalothirn 5%, Hexaconazole 5%, Cypermethrin and Chlorpyrifos	Hand hoe and Spade
Sustainable farming	1. Groudnut (JLR) + Tapioca 2. Rice (White Ponni) 3. Green gram	1.Groundnut (JLR) + Black gram 2. Green gram	1. Groundnut (JLR)+Black gram 2. Gingelly and Mesta 3. Rice (White Ponni)	FYM, Green manure, Urea, Gypsum and Muriate of Potash	Neem oil spraying and NPV(Nuclear Poly headral Virus) for leaf roller caterpillar control	Hand hoe and Spade
Organic farming	1. Groundnut (JLR)+Brinjal+ Chilli 2. Rice (ADT 36) +Fodder crop (CO3)+Black gram 3. Gingelly (SVPR) 4. Rice	1. Groundnut (JLR) + Tapioca 2. Bhendi 3. Rice (White Ponni)	1. Groundnut (JLR) + Brinjal + Chilli 2. Black gram 3. Gingelly (SVPR) 4. Rice (ADT 36)	FYM, Green manure, Vermi compost, Rhizobium, Potash Mobilizing Bacteria and Panchakavya	Five leaf extract + Ginger and garlic extract and cultural methods of control	Hand hoe and Spade

INM: Integrated Nutrient Management; IPM: Integrated Pest Management

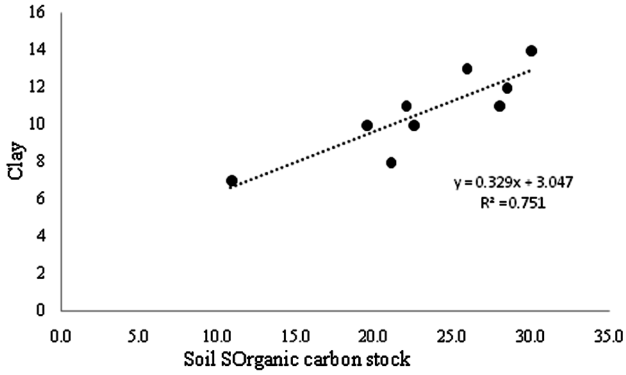

Fig. 4. *Relationship between Clay and SOC*

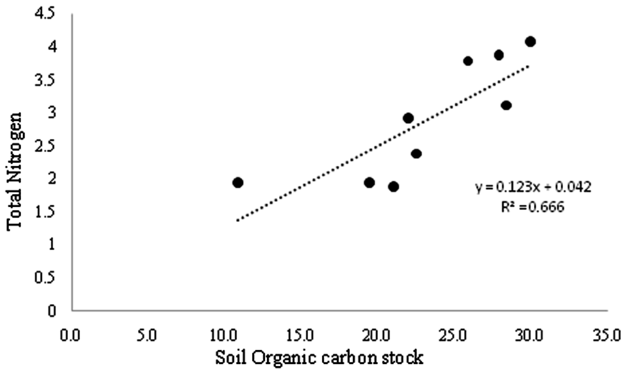

Fig. 6. *Relationship between Total N and SOC*

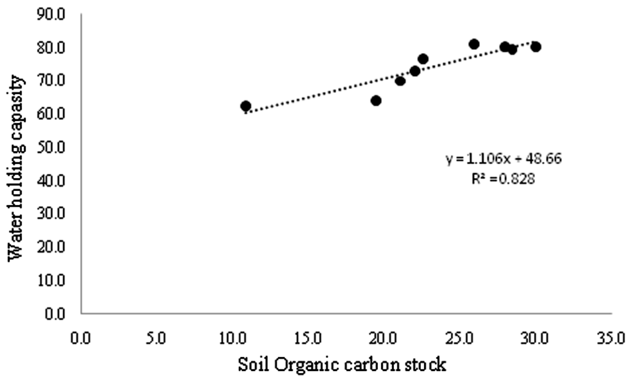

Fig. 5. *Relationship between water holding capacity and SOC*

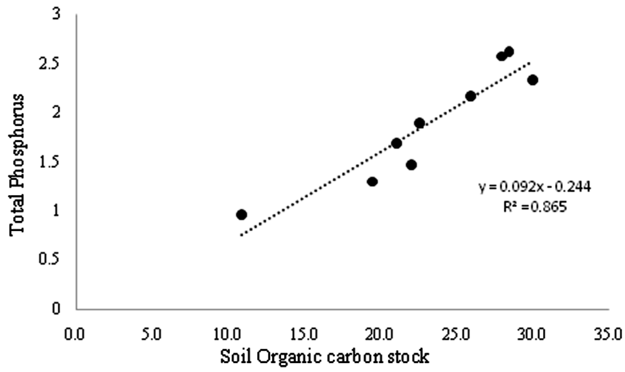

Fig. 7. *Relationship between Total P and SOC*

Table 2. *Physico-chemical and biological properties of soils in different farming systems*

	Conventional	Sustainable	Organic	P-value
Soil moisture (%)	2.70 ±0.32	3.20 ±0.17	4.40 ±0.32	0.013 c
Soil bulk density (Mg m^{-3})	1.20 ±0.05	1.28 ±0.03	1.18 ±0.04	0.262
Volume of soil particle (cm^3)	19.26 ±0.27	19.39 ±0.40	19.89 ±0.33	0.443
Water holding capacity (%)	35.67 ±2.27	46.77 ±2.08	50.33 ±0.49	0.003 b
pH	6.59 ±0.57	6.12 ±0.13	6.18 ±0.19	0.615
EC (dS m^{-1})	0.14 ±0.08	0.27 ±0.04	0.31 ±0.08	0.261
Sand (%)	78.33 ±2.68	77.67±1.2	71.33 ±2.03	0.143
Silt (%)	14.33 ±1.6	12.67 ±0.67	15.67 ±1.5	0.383
Clay (%)	8.33 ±0.72	10.67 ±0.33	13.00 ±0.6	0.006 b
Total nitrogen (g kg^{-1})	1.93 ±0.02	3.07 ±0.44	3.67 ±0.29	0.018 c
Total phosphorous (g kg^{-1})	1.32 ±0.21	1.98 ±0.32	2.38 ±0.13	0.049 c
Organic carbon (g kg^{-1})	9.56 ±1.90	12.65 ±1.16	15.90 ±0.54	0.041 c
C:N (%)	5±0.12	4.12±0.09	4.34±0.13	0.701
Carbon stock (t ha^{-1})	17.22 ±1.34	24.3 ±0.97	28.14 ±1.89	0.035 c
Soil Respiration (mg $CO_2$100 g of $soil^{-1}day^{-1}$)	3.49 ±0.45	3.70 ±0.084	6.33 ±0.30	0.007 c
Microbial biomass C (mg kg^{-1})	198.10 ±11.64	590.80 ±89.58	779.87±31	0.001 a
Microbial biomass N (mg kg^{-1})	19.43 ±1.59	41.87 ±13	74.90 ±4	0.001 a

a: significantly different at $p \leq 0.001$, b: significantly different at $p \leq 0.01$ and c: significantly different at $p \leq 0.05$

organic farming improved the soil quantity (Denef, 2006; Acosta-Martinez *et al.,* 2003; Reganold *et al.,* 2001).

Soil organic carbon (15.90 g kg^{-1}), total nitrogen (3.67 g kg^{-1}), total phosphorus (2.38 g kg^{-1}), C:N (4.34%) concentration and soil carbon stock (28.14 t ha^{-1}) were significantly higher in organic farming soil (Table 1). SOC was positively correlated with soil moisture content (r = 0.767*), volume of soil particle

Table 3. *Correlation among various soil properties*

.	SM	SBD	VSP	WHC	pH	EC	Sand	Silt	Clay	TN	TP	SOC	SR	MC	MN	CN	C stock
SM	1	ns	0.385	0.718 *	ns	0.432	ns	0.176	0.775*	0.566	0.726*	0.767*	0.770*	0.797*	0.882**	0.149	0.792*
SBD		1	ns	ns	ns	ns	0.652	-0.842**	ns	ns	ns	ns	ns	0.032	ns	ns	ns
VSP			1	0.570	ns	0.752*	ns	0.199	0.600	0.747*	0.575	0.688*	0.413	0.528	0.532	ns	0.667*
WHC				1	ns	0.732*	ns	0.020	0.812**	0.865**	0.921	0.872**	0.700*	0.930**	0.869**	ns	0.910**
pH					1	ns	ns	0.293	ns	ns	ns	ns	ns	ns	ns	ns	-0.683*
EC						1	ns	0.059	0.649	0.715*	0.543	0.683*	0.531	0.601	0.554	ns	0.677
Sand							1	-0.877**	-0.793*	ns	ns	ns	ns	ns	ns	ns	ns
Silt								1	0.487	0.199	0.004	0.372	0.373	0.066	0.287	0.236	0.190
Clay									1	0.870**	0.723*	0.905**	0.681*	0.881**	0.903**	ns	0.867**
TN										1	0.784*	0.818**	0.548	0.906**	0.834**	ns	0.816**
TP											1	0.890**	0.632	0.861**	0.810**	0.020	0.930**
SOC												1	0.698*	0.826**	0.841**	0.171	0.947**
SR													1	0.641	0.841**	0.077	0.625
MC														1	0.936**	ns	0.872**
MN															1	ns	0.835**
CN																1	0.130
C stock																	1

*correlation is significant at the 0.05 level of interval, **correlation is significant at the 0.01 level of interval, Ns: Not significant,

SM: Soil moisture, SBD: Soil bulk density, VSM: Volume of soil particle, EC: Electrical conductivity, TN: Total nitrogen, TP: Total phosphorus, SOC; Soil organic carbon, SR: Soil respiration, MC: Microbial biomass carbon, MN: Microbial biomass nitrogen, CN: Carbon nitrogen ratio, Cstock : Carbon stock.

(r = 0.688*), water holding capacity (r = 0.872**), EC (r = 0.683*), clay (r = 0.905**), total N (r = 0.818**), total P (r = 0.890**), soil respiration (r = 0.698*), carbon stock (r = 0.947**), microbial biomass C (r = 0.826**) and N (r = 0.841**). Total nitrogen was positively correlated with volume of soil particle (r = 0.747*), water holding capacity (r = 0.865**), clay (r = 0.870**), total P (r = 0.784*), SOC (r = 0.818**), carbon stock (r = 0.816**), microbial biomass C (r = 0.906**) and N (r = 0.834**). Soil respiration (6.33 mg CO_2 100 g of soil^{-1} day^{-1}), microbial biomass C (779.80 mg kg^{-1}) and N (74.90 mg kg^{-1}) were higher in organic farming soil and they showed significant difference among the farm management practices (Table 2). These results agrees with findings from several other studies (Lagomarsino *et al.,* 2009; Liu *et al.,* 2007; Bending *et al.,* 2000).

Carbon stock and their relationship among soil properties

Our study showed SOC stock has significant positive correlation with soil moisture content (r = 0.80), volume of soil particle (r = 0.68), water holding capacity (r = 0.91), EC (r = 0.68), silt (r = 0.86), clay (r = 0.82), total N (r = 0.93), total P (r = 0.95), soil respiration (r = 0.67), microbial biomass C (r = 0.87) and N (r = 0.84) (Table 2) (Figs. 1, 2, 3, 4, 5, 6 & 7). Microbial biomass C and N are very sensitive to change in SOC. Compared to mineral fertilizers, organic manures (microbial inoculants, FYM, vermicompost and green manures) are more effectively increased soil organic carbon (Meng *et al.,* 2005). Organic farming system had improved the SOC and soil nutrients as compared to sustainable and conventional farming. It indicated that long-term usage of green leaf manures, organic amendments and cropping systems are increasing the SOC in organic farming system soils (Balota and Chaves, 2010). SOC in conventional farming soils was very low compare to other two farming system soils. It might be due to intensive monocropping and inadequate application of organic amendments (Meng *et al.,* 2005). SOC is an important attribute of soil quality. It influences soil physical, chemical and biological process (Padmavathy and Poyyamoli, 2011). SOC regulate the soil enzymatic activities, energy nutrients for soil biota, aggregate stability and water holding capacity. The large differences in SOC among farm management practices exhibit that green manure cultivation and application of organic manures change the pool of SOC (Chinnadurai *et al.,* 2014). Our results agree with previous study by Balota *et al*. (2004). The SOC, microbial biomass C and N mineralization showed clearly that variations in soil management caused different decomposition rates of organic matter and affected microbial biomass and its activity, with consequent differences in substrate availability.

Farm management practices is a major determinant factor that affects soil carbon storage in coastal agroecosystem. Our results illustrated that organic farming system had improved the SOC and soil nutrients as compared to sustainable and conventional farming. A significant relationship between the soil carbon stock with the soil moisture content, volume of soil particle, water holding capacity, EC, silt, clay, total N, total P, soil respiration, microbial biomass C and N was noted. The highest amount of SOC stock was in organic farming due to continuous use of farm yard manure and organic fertilizers.

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