

Original Research Article

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Soil Carbon Dynamics in Oil Palm - Cocoa Cropping System in Comparison to that of Oil Palm Sole Crop

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ABSTRACT

An investigation was conducted in oil palm sole crop and oil palm + cocoa cropping systems to study microbial diversity along with enzyme activities and understand soil carbon dynamics in oil palm based cropping system. Ten mature oil palm plantations (five each in oil palm sole crop and oil palm + cocoa) planted with *Tenera* hybrids with a spacing of 9 X 9 X 9 m in a triangular system were selected for the study. Cocoa var. Forastero is cultivated as an intercrop in oil palm plantations at 4.5 X 4.5 m spacing. Recommended package of practices for oil palm and cocoa cultivation were followed. Soil samples were collected in the two cropping systems (oil palm sole crop and oil palm + cocoa) at three consecutive depths from surface (0-15, 15-30 & 30-60 cm) and five distances from palm base (1, 2, 3, 4 & 5 meters) during the three seasons (summer, winter & rainy). The collected samples of soil were evaluated for soil carbon (C) dynamics viz., organic carbon (OC), potassium permanganate extractable C, readily mineralizable C, acid hydrolysable C, soluble C and microbial biomass C. Studies on soil carbon dynamics indicated that all the organic carbon fractions of two cropping systems varied significantly and highest values were recorded under oil palm + cocoa system. Higher carbon fractions were observed in summer, while lower fractions were seen during winter and rainy periods. Significant differences in soil carbon fractions were observed among three soil layers viz., 0 to 15, 15 to 30 & 30 to 60 cm. All the carbon fractions decreased from surface to bottom soil layers. A linear increment in soil carbon fractions was observed with increase in distance from palm base.

Keywords

carbon dynamics, cocoa, cropping system, oil palm, organic carbon

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Introduction

The role of plant and soils as a carbon sink is of vital significance in mitigating global warming effects and rising greenhouse gases in the atmosphere. Plantation crops offer tremendous scope for enhancing the carbon pool on the land surface. Among the plantation crops, oil palm is an important crop in India grown in 0.34 million ha. The crop is

being grown in India decrease the supply and demand of vegetable oils in the country.

Oil palm is being cultivated as a small holders' crop in India both under rainfed and irrigated conditions (Suresh and Kiran kumar, 2011). In order to supplement the income, cocoa is being grown as a successful intercrop in adult oil palm plantations (6-8 years) by majority of oil palm farmers.

Oil palm + cocoa cropping system is one of the finest models in terms of efficient utilization of horizontal and vertical space, profitability and sustainability under Indian conditions. Oil palm + cocoa cropping systems are effective in improving soil quality by continuous deposition of plant litter from cocoa and turnover of litter offers constant enrichment of organic matter to the soil through microbial activities (Bhagya and Suresh, 2018). However, studies on interactions among different biota in soil, organic C fractions along with enzymes in soils of oil palm + cocoa cropping system are very limited under irrigated conditions.

Knowledge of the dynamics between soil biota and microbial biomass carbon could play a vital role in understanding the oil palm + cocoa cropping system. Soil biota symbolizes a huge proportion of distribution in the earth's biodiversity. Deciphering the soil microbial activities has helped in getting valuable information of the ecosystems. Microorganisms in soils might be vital in affecting soil biological and chemical features (Shrinivas *et al.*, 2019).

The association concerning carbon fractions and microorganisms in soils are multi-faceted. This interaction is critical in gaining knowledge on carbon sequestration and stability in soils. Variations in spatial distribution of microorganisms in soils largely influences turnover of carbon by interacting with crops and soil chemical properties. Land use changes could affect the capacity of soil to sequester carbon as it affects a radical shift in yield and carbon turn over (Gileno V. Lacerda-Júnior *et al.*, 2019). Studies pertaining to soil carbon dynamics in oil palm + cocoa based cropping system are very scarce, the present research was undertaken to understand soil carbon dynamics in oil palm based cropping system.

Materials and Methods

The study was taken up in ten mature oil palm plantations (5 with oil palm sole crop and 5 with oil palm + cocoa) belonging to farmers of Pedavegi mandal, West Godavari Dt., Andhra Pradesh, India. Pedavegi is situated at 16.80 ° N latitude, 81.11° E longitude and 85 m above mean sea level. The average temperature ranged from minimum of 24-27⁰ C to maximum of 34-36⁰ C with an average rainfall of 648 mm. All the oil palm plantations were prior planted with tenera hybrids with a spacing of 9 X 9 X 9 m in a triangular system. Cocoa var. Forastero is cultivated as an intercrop in oil palm plantations at a spacing of 4.5 x 4.5 m. Plantations having uniform age, yield and management practices have been selected for the study. Recommended management practices for oil palm and cocoa cultivation were followed. The soils in the study area were alluvial soils. Soil samples were collected during 2010-12 in the two cropping systems (oil palm sole crop and oil palm + cocoa) at three consecutive depths from surface (0 to 15 cm, 15 to 30 cm and 30 to 60 cm) and at five distances from palm base (1 metre, 2 metre, 3 metre, 4 metre, and 5 metre) during the three seasons (summer, winter and rainy).

Soil sampling was done by triangular sampling method as per Tailliez (1971) by using an auger (Chan, 1976) in all the 10 plantations under study. The triangle was sub divided into 16 sub triangles with sides 2.20 meters and from each centre of sub triangle, one core of sample were taken with the help of auger (10 cm diameter). Circular soil cores were collected in the two cropping systems (oil palm sole crop and oil palm + cocoa) at three consecutive depths from surface (0 to 15 cm, 15 to 30 cm and 30 to 60 cm) and at five distances from palm base (1 to 5 m) during the three seasons (summer, winter and rainy).

Two sets of samples were collected by quartering technique from three triangles in each plantation. Immediately after sampling, excess water was drained off and visible root fragments were separated and stones removed manually. One set of fresh samples was used for estimating enzymes and microbial diversity studies and the other was air dried, sieved with 2 mm sieve and stored in polythene bags for estimation of Organic carbon (OC), KMnO_4 extractable carbon, Acid hydrolysable C, Microbial biomass C, Readily mineralizable C, and Water soluble C. The soil organic carbon content (%) was estimated as per Walkley and Black's, 1934. Readily mineralizable C (RMC) and Microbial biomass C (MBC) was estimated as per Vance *et al.*, 1987. WSC content was estimated as per W. B. McGill *et al.*, 1986. The potassium permanganate extractable carbon was estimated as per Blair *et al.*, 1995. Acid hydrolysable carbon was estimated as per Cheshire and Mundie, 1966. The statistical design used was four factorial completely randomised block design and data was analysed as per Gomez and Gomez, 1984.

Results and Discussion

The microbial carbon (MBC), WSC, organic carbon (SOC), AHC, readily mineralizable carbon (RMC) and POXC contents of two cropping systems (oil palm sole crop and oil palm + cocoa) varied significantly and highest values were recorded under oil palm + cocoa system (Tables 1-6). Different soil properties, climate, type of forest, litter quality and litter production by vegetation influence the soil carbon content (Don *et al.*, 2007). The average carbon contents in surface soil layers were less in cultivated environments compared to that of mixed and natural forest land use situations (Amanuel *et al.*, 2018). In alley cropping systems of tropical regions, significant changes of microbial biomass were

found (Stefan Seiter *et al.*, 1999). Mersch *et al.*, 1993 also reported larger amounts of microbial mass in alley systems compared to that of single cropping situations. Kachaka *et al.*, 1993 also recorded that higher biomass could be seen in alley situations compared to that of controlled environments. Forest soils possessed greater amounts of organic matter compared to that of paddy and dry environments (Jendoubi *et al.*, 2019).

During the seasons, higher contents of POXC, AHC, SOC, RMC, MBC and WSC were recorded during summer in comparison to that other seasons studied (Tables 1-6). Interaction among different seasons and cropping systems revealed that the organic carbon content differed significantly during different seasons in two cropping systems. Similar trend was observed in oil palm sole crop also.

This is in tune with that of Singh and Yadava, 2006, who reported higher amounts during May and lower amounts during September. During summer season high organic nutrients and moderate temperature promote the microbial activity. This is in tune with that of Srivastava & Singh, 1991, who have reported higher amounts in summer in grasslands of tropical conditions of India. The samples collected during May usually record high bacterial biomass values which might be due to peak microbial growth that occurs in spring. Bacterial biomass will be higher during May to July (Stefan Seiter 1999).

Ryan *et al.*, 2009 noticed higher organic matter and permanganate-oxidizable carbon in fall and winter. It has been reported that biomass carbon has been greater in summer (wet) compared to that of winter (dry) season in rubber plantations, (Pan *et al.*, 2000). Significant variations in C fractions estimated were seen in soil layers. The amounts of C fractions were greatest in surface layers and lower contents were recorded in bottom most soil layers (Tables 1-6).

Table.1 Variations in organic carbon (units) in soils of Oil Palm sole crop and Oil Palm + Cocoa plantations at different depths and distances from palm base during various seasons

Treatments/ → Seasons	Soil depth (cm)	Oil Palm (sole crop)						Oil Palm + Cocoa					
		Distance from palm base (m) (D)					Mean	Distance from palm base (m) (D)					Mean
		1	2	3	4	5		1	2	3	4	5	
Summer	0-15	0.80	0.67	0.49	0.41	0.36	0.55	1.39	1.58	1.71	1.75	1.94	1.67
	15-30	0.54	0.43	0.40	0.31	0.22	0.38	1.04	1.17	1.35	1.60	1.79	1.39
	30-60	0.37	0.27	0.25	0.21	0.20	0.26	0.38	0.41	0.50	0.75	0.97	0.60
	Mean	0.57	0.46	0.38	0.31	0.26	0.39	0.94	1.05	1.19	1.37	1.57	1.22
Winter	0-15	0.58	0.42	0.40	0.33	0.27	0.40	0.98	1.00	1.15	1.36	1.58	1.21
	15-30	0.43	0.38	0.32	0.29	0.19	0.32	0.52	0.74	0.96	1.19	1.32	0.95
	30-60	0.29	0.27	0.28	0.18	0.14	0.23	0.21	0.36	0.51	0.56	0.76	0.48
	Mean	0.43	0.36	0.33	0.27	0.20	0.32	0.57	0.70	0.87	1.04	1.22	0.88
Rainy	0-15	0.44	0.38	0.31	0.28	0.21	0.32	0.73	0.98	1.08	1.17	1.29	1.05
	15-30	0.31	0.25	0.22	0.18	0.14	0.22	0.39	0.55	0.42	0.61	1.10	0.61
	30-60	0.25	0.18	0.22	0.11	0.10	0.17	0.15	0.19	0.23	0.46	0.58	0.32
	Mean	0.33	0.27	0.25	0.19	0.15	0.24	0.42	0.57	0.58	0.75	0.99	0.66
Grand Mean		0.45	0.36	0.32	0.26	0.20	0.32	0.64	0.77	0.88	1.05	1.26	0.92

Source of variation	LSD (p=0.05)	Source of variation	LSD (p=0.05)
Treatment	0.023	Treatment * Palm distance	0.035
Season	0.028	Season * Palm distance	0.062
Treatment * Season	0.039	Treatment * Season * Palm distance	0.088
Soil depths	0.028	Soil depths * Palm distance	0.062
Treatment * Soil depths	0.039	Treatment * Soil depths * Palm distance	0.088
Season * Soil depths	0.048	Season * Soil depths * Palm distance	0.108
Treatment * Season * Soil depths	0.068	Treatment * Season * Soil depths * Palm distance	0.153
Palm distance	0.021		

Table.2 Variations in Microbial Biomass Carbon (MBC-2) in soils of Oil Palm sole crop and Oil Palm + Cocoa plantations at different depths and distances from palm base during various seasons

Treatments /→ Seasons	Soil depth (cm)	Oil Palm (sole crop)						Oil Palm + Cocoa					
		Distance from palm base (m) (D)					Mean	Distance from palm base (m) (D)					Mean
		1	2	3	4	5		1	2	2	3	4	
Summer	0-15	49.54	46.82	42.45	38.05	30.15	41.40	154.00	159.44	167.48	169.58	178.02	165.71
	15-30	44.86	40.45	39.30	37.50	29.98	38.42	129.30	138.17	143.44	154.30	145.76	142.19
	30-60	38.13	32.77	27.86	23.34	22.66	28.95	80.33	84.01	88.33	92.46	99.65	88.96
	Mean	44.18	40.01	36.54	32.96	27.60	36.26	121.21	127.21	133.08	138.78	141.14	132.29
Winter	0-15	43.74	42.89	38.11	30.17	29.45	36.87	129.96	140.76	147.37	150.67	162.44	146.24
	15-30	39.20	35.04	31.23	28.34	28.11	32.38	100.67	111.45	119.67	122.60	125.30	115.94
	30-60	31.80	28.82	26.57	22.00	20.00	25.84	64.82	76.60	89.28	91.32	95.02	83.41
	Mean	38.25	35.58	31.97	26.84	25.85	31.70	98.48	109.60	118.77	121.53	127.59	115.20
Rainy	0-15	40.67	38.32	33.65	29.54	28.45	34.13	109.45	114.65	132.83	136.22	137.40	126.11
	15-30	34.50	32.20	30.56	25.45	23.00	29.14	92.89	98.41	100.53	100.91	118.33	102.21
	30-60	29.56	25.00	19.45	17.04	10.65	20.34	58.76	71.43	75.55	80.43	89.12	75.06
	Mean	34.91	31.84	27.89	24.01	20.70	27.87	87.03	94.83	102.97	105.85	114.95	101.13
	Grand Mean	39.11	35.81	32.13	27.94	24.72	31.94	102.24	110.55	118.28	122.05	127.89	116.20

Source of variation	LSD (p=0.05)	Source of variation	LSD (p=0.05)
Treatment	0.461	Treatment * Palm distance	1.030
Season	0.564	Season * Palm distance	0.430
Treatment * Season	0.798	Treatment * Season * Palm distance	1.785
Soil depths	0.564	Soil depths * Palm distance	1.262
Treatment * Soil depths	0.798	Treatment * Soil depths * Palm distance	1.785
Season * Soil depths	0.977	Season * Soil depths * Palm distance	2.186
Treatment * Season * Soil depths	1.382	Treatment * Season * Soil depths * Palm distance	3.091
Palm distance	0.200		

Table.3 Variations in Water Soluble Carbon (WSC) in soils of Oil Palm sole crop and Oil Palm + Cocoa plantations at different depths and distances from palm base during various seasons

Treatment s/→ Seasons	Soil depth (cm)	Oil Palm (sole crop)						Oil Palm + Cocoa					
		Distance from palm base (m) (D)					Mean	Distance from palm base (m) (D)					Mean
		1	2	3	4	5		1	2	3	4	5	
Summer	0-15	32.66	29.34	26.31	26.49	21.98	27.36	31.00	37.00	39.65	42.68	60.34	42.13
	15-30	28.12	24.55	22.50	25.22	19.18	23.92	31.68	35.62	38.77	37.45	55.00	39.70
	30-60	20.75	19.57	18.43	15.28	11.34	17.07	29.56	30.55	31.05	30.16	38.45	31.95
	Mean	27.18	24.49	22.41	22.33	17.50	22.78	30.75	34.39	36.49	36.76	51.26	37.93
Winter	0-15	26.00	24.00	23.62	21.27	18.32	22.64	27.31	30.66	34.00	44.34	46.34	36.53
	15-30	17.53	17.48	15.73	13.47	12.55	15.35	20.21	24.30	26.45	37.82	37.87	29.33
	30-60	15.84	13.34	11.61	12.33	10.33	12.69	19.11	20.14	22.30	33.68	36.18	26.28
	Mean	19.79	18.27	16.99	15.69	13.73	16.90	22.21	25.03	27.58	38.61	40.13	30.71
Rainy	0-15	18.99	16.75	16.05	17.47	10.68	15.99	31.02	37.81	36.39	37.09	39.33	36.33
	15-30	16.80	15.67	14.46	12.30	10.00	13.85	15.01	15.08	19.08	25.01	28.44	20.52
	30-60	13.54	10.66	12.67	10.66	9.56	11.42	12.04	12.89	15.77	20.15	27.19	17.61
	Mean	16.44	14.36	14.39	13.47	10.08	13.75	19.36	21.93	23.75	27.42	31.65	24.82
Grand Mean		21.14	19.04	17.93	17.17	13.77	17.81	24.10	27.12	29.27	34.26	41.02	31.15

Source of variation	LSD (p=0.05)	Source of variation	LSD (p=0.05)
Treatment	0.443	Treatment * Palm distance	0.679
Season	0.543	Season * Palm distance	0.125
Treatment * Season	0.768	Treatment * Season * Palm distance	1.716
Soil depths	0.543	Soil depths * Palm distance	1.214
Treatment * Soil depths	0.768	Treatment * Soil depths * Palm distance	1.716
Season * Soil depths	0.940	Season * Soil depths * Palm distance	2.102
Treatment * Season * Soil depths	1.001	Treatment * Season * Soil depths * Palm distance	2.973
Palm distance	0.444		

Table.4 Variations in Permanganate soluble carbon (POSC) in soils of Oil Palm sole crop and Oil Palm + Cocoa plantations at different depths and distances from palm base during various seasons

Treatments/ → Seasons		Oil Palm (sole crop)						Oil Palm + Cocoa					
		Distance from palm base (m) (D)					Mean	Distance from palm base (m) (D)					Mean
	Soil depth (cm)	1	2	3	4	5		1	2	3	4	5	
Summer	0-15	388.44	378.34	371.09	364.00	340.99	368.57	429.76	453.78	461.04	467.95	478.39	458.18
	15-30	369.67	363.65	360.00	355.87	336.76	357.19	427.00	446.00	450.76	454.98	459.55	447.66
	30-60	208.00	200.00	195.44	191.65	185.89	196.20	324.09	331.22	335.43	340.000	348	335.75
	Mean	322.04	314.00	308.84	303.84	287.88	307.32	393.62	410.33	415.74	420.98	428.65	413.86
Winter	0-15	376.45	367.31	360.09	353.00	329.61	357.29	380.00	404.31	411.09	418.03	428.44	408.37
	15-30	357.87	352.76	348.43	345.01	324.98	345.81	377.23	396.34	400.65	404.11	409.45	397.56
	30-60	197.54	189.22	184.56	180.88	173.02	185.04	225.44	231.98	235.28	240.24	248.00	236.19
	Mean	310.62	303.10	297.69	292.96	275.87	296.05	327.56	344.21	349.01	354.13	361.96	347.37
Rainy	0-15	263.44	253.00	246.09	239.00	215.32	243.37	260.03	284.78	291.09	298.26	308.31	288.49
	15-30	244.87	239.05	235.78	230.64	212.00	232.47	257.31	276.15	280.00	284.25	289.33	277.41
	30-60	143.08	135.91	130.00	126.04	119.08	130.82	204.00	211.56	215.20	220.98	228.00	215.95
	Mean	217.13	209.32	203.96	198.56	182.13	202.22	240.45	257.50	262.10	267.83	275.21	260.62
	Grand Mean	283.26	275.47	270.16	265.12	248.63	268.53	320.54	337.35	342.28	347.64	355.27	340.62

Source of variation	LSD (p=0.05)	Source of variation	LSD (p=0.05)
Treatment	1.761	Treatment * Palm distance	1.956
Season	2.141	Season * Palm distance	0.100
Treatment * Season	2.998	Treatment * Season * Palm distance	2.147
Soil depths	2.141	Soil depths * Palm distance	1.762
Treatment * Soil depths	2.998	Treatment * Soil depths * Palm distance	1.378
Season * Soil depths	3.655	Season * Soil depths * Palm distance	2.076
Treatment * Season * Soil depths	2.018	Treatment * Season * Soil depths * Palm distance	1.621
Palm distance	0.024		

Table.5 Variations in Acid Hydrosoluble carbon (AHC) in soils of Oil Palm sole crop and Oil Palm + Cocoa plantations at different depths and distances from palm base during various seasons

Treatments/→ Seasons	Soil depth (cm)	Oil Palm (sole crop)						Oil Palm + Cocoa					
		Distance from palm base (m) (D)					Mean	Distance from palm base (m) (D)					Mean
		1	2	3	4	5		1	2	3	4	5	
Summer	0-15	188.44	178.34	171.09	164.00	140.99	168.57	229.76	253.78	261.04	267.95	278.39	258.18
	15-30	169.67	163.65	160.00	155.87	136.76	157.19	227.00	246.00	250.76	254.98	259	247.55
	30-60	108.00	100.00	95.44	91.65	85.89	96.20	174.09	181.22	185.43	190.000	198	185.75
	Mean	155.37	147.33	142.18	137.17	121.21	140.65	210.28	227.00	232.41	237.64	245.13	230.49
Winter	0-15	176.45	167.31	160.09	153.00	129.61	157.29	180.00	204.31	211.09	218.03	228.44	208.37
	15-30	157.87	152.76	148.43	145.01	124.98	145.81	177.23	196.34	200.65	204.11	209.45	197.56
	30-60	97.54	89.22	84.00	80.88	73.02	84.93	125.44	131.98	135.28	140.24	148.00	136.19
	Mean	143.95	136.43	130.84	126.30	109.20	129.34	160.89	177.54	182.34	187.46	195.30	180.71
Rainy	0-15	163.44	153.00	146.09	139.00	115.32	143.37	160.03	184.78	191.09	198.26	208.31	188.49
	15-30	144.87	139.05	135.78	130.64	112.00	132.47	157.31	176.15	180.00	184.25	189.33	177.41
	30-60	93.08	85.91	80.00	76.00	69.08	80.81	104.00	111.56	115.20	120.00	128.00	115.75
	Mean	133.80	125.99	120.62	115.21	98.80	118.88	140.45	157.50	162.10	167.50	175.21	160.55
Grand Mean		144.37	136.58	131.21	126.23	109.74	129.63	170.54	187.35	192.28	197.54	205.21	190.58

Source of variation	LSD (p=0.05)	Source of variation	LSD (p=0.05)
Treatment	1.688	Treatment * Palm distance	3.776
Season	2.068	Season * Palm distance	1.256
Treatment * Season	2.925	Treatment * Season * Palm distance	2.074
Soil depths	2.068	Soil depths * Palm distance	1.689
Treatment * Soil depths	0.689	Treatment * Soil depths * Palm distance	1.305
Season * Soil depths	3.582	Season * Soil depths * Palm distance	2.003
Treatment * Season * Soil depths	1.945	Treatment * Season * Soil depths * Palm distance	1.548
Palm distance	2.670		

Table.6 Variations in Readily mineralizable carbon (RMC) in soils of Oil Palm sole crop and Oil Palm + Cocoa plantations at different depths and distances from palm base during various seasons

Treatments /→ Seasons	Soil depth (cm)	Oil Palm (sole crop)						Oil Palm + Cocoa					
		Distance from palm base (m) (D)					Mean	Distance from palm base (m) (D)					Mean
		1	2	3	4	5		1	2	3	4	5	
Summer	0-15	45.73	43.04	38.68	34.27	26.38	37.62	65.38	73.28	77.68	83.12	84.77	76.85
	15-30	41.14	36.62	35.54	34.25	26.19	34.75	64.20	73.23	74.53	75.68	80.09	73.55
	30-60	34.33	28.93	24.06	19.57	18.86	25.15	57.89	58.57	63.09	68.00	73.36	64.18
	Mean	40.40	36.20	32.76	29.36	23.81	32.51	62.49	68.36	71.77	75.60	79.41	71.53
Winter	0-15	39.56	39.06	34.31	26.37	25.65	32.99	60.68	61.40	69.34	74.12	74.57	68.02
	15-30	35.40	31.26	27.43	24.56	24.31	28.59	55.45	58.68	62.46	66.27	70.43	62.66
	30-60	28.00	25.02	22.77	18.20	16.22	22.04	52.00	53.23	57.80	60.05	63.03	57.22
	Mean	34.32	31.78	28.17	23.04	22.06	27.87	56.04	57.77	63.20	66.81	69.34	62.63
Rainy	0-15	36.89	34.52	29.85	25.74	24.65	30.33	60.68	61.77	65.88	70.55	72.90	66.36
	15-30	30.70	28.41	26.77	21.65	19.20	25.35	45.33	57.68	62.79	64.43	66.73	59.39
	30-60	25.76	21.27	15.65	13.24	6.98	16.58	33.55	49.27	51.68	57.23	61.79	50.70
	Mean	31.12	28.07	24.09	20.21	16.94	24.08	46.52	56.24	60.12	64.07	67.14	58.82
Grand Mean		35.28	32.01	28.34	24.21	20.94	28.16	55.02	60.79	65.03	68.83	71.96	64.33

Source of variation	LSD (p=0.05)	Source of variation	LSD (p=0.05)
Treatment	0.603	Treatment * Palm distance	1.347
Season	0.738	Season * Palm distance	1.650
Treatment * Season	1.044	Treatment * Season * Palm distance	1.876
Soil depths	0.738	Soil depths * Palm distance	1.650
Treatment * Soil depths	1.044	Treatment * Soil depths * Palm distance	1.564
Season * Soil depths	1.278	Season * Soil depths * Palm distance	1.540
Treatment * Season * Soil depths	1.808	Treatment * Season * Soil depths * Palm distance	0.245
Palm distance	0.035		

Similar patterns were detected in oil palm sole crop and oil palm + cocoa system. At different soil depths, all C fractions were greater in oil palm + cocoa system than oil palm sole crop. Similarity of results could be seen with that of vanStraaten O *et al.*, 2015. In soil layers studied, OM has been significantly higher in cover crops compared to no cover crops (Lalith M. Rankoth *et al.*, 2019). The amounts of C fractions were higher in surface soils compared to that bottom soil layers, which is in tune with Zhang *et al.*, 2019. The top 30 cm of soil surface hold approximately 52 per cent of carbon pool and subjected to changes with change in land use pattern and deforestation.

A linear increment with respect to C fractions was observed with increase in distance from palms (Tables 1-6). Maximum contents of C fractions content was noticed at 5 m distance from palms and decreased gradually with decrease in distance from palms. Highest SOC, WSC was at 5 m distance from palm base in oil palm + cocoa system, while lowest was in oil palm sole crop at 1 m distance, which is in agreement with Haron *et al.*, 1998. MBC, RMC in oil palm sole crop soil significantly decreased with increase in distance from palm base.

But in oil palm + cocoa soils, MBC, RMC was more in soils, which were farther away from palm base. However, the content of POXC varied with various distance from palm base, though, the variation was not significant. The soil AHC distribution was highest at 2 m distance from palm base. There was a significant difference between 1 and 4 m distance from palm base irrespective of seasons and soil depths. Our results agree with that of findings of Haron *et al.*, 1998, who opined that dynamics of C fractions vary with time and space. The organic carbon in frond piles has been same in alleys and basins because of harvested leaves in alleys.

Studies on soil carbon dynamics indicated that the soil organic C, water soluble C, readily mineralizable C, microbial C, KMnO₄ extractable C, and acid hydrolysable carbon contents of two cropping systems varied significantly and highest values were recorded under oil palm + cocoa system. Higher contents of all the C fractions were observed in summer, while lower contents were seen during other seasons. Significant differences in soil carbon fractions were observed among three soil depths (0 to 15, 15 to 30 and 30 to 60 cm). All the carbon fractions decreased from surface to bottom soil layers. A linear increment in soil carbon fractions was observed with increase in distance from palm base.

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