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ORGANIC CARBON CONTENT AND STOCK IN THE RUBBER GROWING SOILS OF SOUTH INDIA

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Variations in soil organic carbon (OC) content and stock in the rubber growing soils in different states in South India were studied. Soil samples were collected from the traditionally rubber grown areas in Kerala and Tamil Nadu and also from recently cultivated areas in Karnataka, Goa and Maharashtra states. One composite sample (0-30 cm) of three sub samples from each unit of 50 ha rubber area were collected. Soil core samples also were taken to estimate the coarse fraction (gravel > 2 mm). Soil OC estimations and the volume and weight of gravel and fine earth (< 2mm) were determined following standard protocols. Based on the OC content (%) and weight of the fine earth portion, the stock OC present in the 0-30 cm soil layer was estimated on tonnes ha^{-1} basis and the samples from each district / state were categorized to low, medium, high and very high classes. It was observed that more than 90 per cent of the soil samples from rubber grown areas in all the districts / states belonged to the medium, high or very high status. Considerable variations were noticed in the percentage distribution of samples among the high and very high classes based on OC content and OC stock. However, as observed in the case of OC content, more than 90 per cent of the soil samples were adequate in stock OC also in all the districts / states, except in Thiruvananthapuram and Palakkad districts. The OC stock in rubber growing soils in South India ranged from 36.5 to 61.4 tonnes ha^{-1}.

Key words: Gravel volume, Rubber growing soils, Soil organic carbon, Soil organic carbon stock

INTRODUCTION

Soil organic matter or soil organic carbon (OC) as it is often reported is described as an important indicator of soil quality or productivity of an agricultural system (Bot and Benites, 2005; Wander, 2004). It is the only soil component that influences the entire soil properties *viz.* physical, chemical and biological. Most important soil functions such as infiltration, compaction, water holding capacity, erosion resistance, bulk density and nutrient retention are greatly regulated by the quantity and quality of soil organic matter (Weil and Magdoff,

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2004). In the past decade the perspective of the determination of soil OC has changed. Apart from its role in soil quality determination, the carbon storage or stock in soils are also assessed in the context of its greater role in global carbon cycle. In the context of climate change, land degradation and biodiversity loss, soils are considered as one of the most vulnerable resources in the world. Soils are a major carbon reservoir containing more carbon than the atmosphere and terrestrial vegetation combined (Batjes, 1996; IPCC WGI, 2001). Anthropogenic impacts on soil can turn it into either a net sink or a net source of greenhouse gases (Lefevre *et al.*, 2017). Thus determination of soil OC content and assessment of soil OC stock in any agricultural system is of great importance both in the agronomic and environment perspectives.

Natural rubber (NR) plantations were established in India about a hundred years back and are mainly concentrated in the state of Kerala and Kanyakumari district in the state of Tamil Nadu, where warm, humid tropical climate prevails. In the last few decades, the NR cultivation expanded to the Konkan region in the states of Karnataka, Goa and Maharashtra also. At present, NR cultivation is spread over about 6.3 lakh ha in South India of which about 5.51 lakh ha is in the state of Kerala while 21310, 51450, 1190 and 2680 ha are in the states of Tamil Nadu, Karnataka, Goa and Maharashtra, respectively (Rubber Board, 2020).

Soils under NR ecosystems are unique with respect to carbon sequestration potential. As the canopy of the rubber trees crosses over by the seventh or eighth year and the soil temperature is usually less than that in open fallow lands. Every year a substantial input of organic matter in the form of litter is added up in the soils under mature rubber plantations. The chemical nature of rubber leaf litter do not favor very fast decomposition in soil when compared to the litter of many other species and soils under continuous NR cultivation are reported to be rich in carbon stock (Abraham and Chudek, 2008). Though numerous reports on soil OC for the different districts and states (Karthikakuttyamma, 1995; NBSS & LUP, 1999; Abraham *et al.*, 2010; Abraham and Joseph, 2012; Abraham, 2015) are available, a systematic study based report on OC content and stock of soil OC for the rubber growing regions of entire South India is lacking. This study focus on the region wise variations in OC content and stock in rubber growing soils in South India and was part of the major project on fertility mapping of soils of traditional rubber growing tract in South India.

MATERIALS AND METHODS

The study area comprised the traditional rubber growing tract extending from the Kanyakumari district in Tamil Nadu in the south to whole of Kerala and comparatively newer areas in Karnataka, Goa and Maharashtra in South India. The study area in Kerala and Tamil Nadu lies between 74° 48′ 33″ and 77° 38′ 35″ E longitudes and 7° 58′ 56″ and 12° 53′ 11″ N latitudes. In Karnataka, the study area is located between 74° 47′ and 77° 64′ E longitudes and 7° 98′ and 14° 90′ N latitudes. This study also covered the comparatively recently NR cultivated regions in Goa and Sindhudurg district in Maharashtra which lies between 72° 64′ to 74° 33′ E longitudes and 14° 89′ and 20° 21′ N latitudes.

The strategy of soil sampling was to collect at least one composite sample of three

sub samples from each unit of 50 ha NR plantation. Soil samples (0-30 cm) were collected from the entire NR growing regions and the details of area covered and number of samples collected is given in Table 1. Care was taken to collect samples in every panchayats where at least five per cent of the area is under NR cultivation. Another set of samples (0-30 cm) were collected using soil cores (710.10 cm^3) to estimate the volume of gravel (>2 mm) content and density of fine earth (<2 mm). The sampling process was carried out between December 2012 and May 2013.

Samples collected were air dried in shade, mixed thoroughly, sieved (2 mm) and used for OC estimation. A sub sample (10 g) of the dried sample was pulverized completely to pass through a 0.15 mm sieve and was used for OC estimations following the Walkley and Black (1934) protocol as modified and described by Nelson and Sommers (1996). All the soil samples were acidic in nature with pH values less than 5.5, hence no inorganic C was present and the C estimated is considered as organic carbon. A correction factor of 1.3 was used to account for the unrecovered C content when Walkley and Black protocol was followed.

The moisture content and dry weight of the core soil samples were determined. The air dried core samples were thoroughly washed through a sieve (2 mm) and gravel portions (mineral coarse fractions) were separated. The volume and weight of gravel and fine earth in each core sample were determined. The gravel volume was determined by water displacement method and the volume of fine earth content computed by deduction from the total core volume. Based on the OC per cent in fine earth portion and weight of fine earth, the stock OC present in the 0-30 cm soil layer in an ha was estimated on tonnes ha^{-1} basis.

The data on OC content (%), gravel volume (%), OC stock (volume basis; tonnes ha^{-1} 30 cm^{-1}) were grouped location wise *viz.* into 14 districts of Kerala, Tamil Nadu (Kanyakumari district alone), Karnataka (all districts together), Goa (South & North) and Maharashtra (Sindhudurg district alone) and were statistically analyzed. Percentage of soil samples with OC content ranged between <0.75, 0.75-1.5, 1.5-2.5 and >2.5 per cent were classified as low, medium, high and very high classes, respectively in each district / state. Similarly percentage of soil samples with OC stock ranged between <22.5, 22.5-45.0, 45.0-75.0 and >75.0 tonnes ha^{-1} were classified as low, medium, high and very high classes, respectively in each district / state. The classification to different classes is as per the present norms followed in Rubber Research Institute of India.

RESULTS AND DISCUSSION

Altogether, 10,448 soil samples were collected for the study from the entire rubber growing regions in South India and the number of samples collected from each district /state is given in Table 1. The range and mean values of OC content (%) under the NR growing soils in different districts / states are given in Table 2. The OC content in soil samples were widely varying in different regions and no specific pattern or trend was observed. Very low values for OC content such as 0.2 or 0.3 per cent were noted for a few samples in Kottayam and Thiruvananthapuram districts. The highest OC content of 10.1 per cent was noted for a sample from Kannur district. The average OC content among the 14 districts in Kerala was observed to be increasing in the order: Palakkad, Thrissur, Wayanad, Malappuram, Thiruvananthapuram, Kollam, Ernakulam, Kottayam, Alappuzha, Pathanamthitta,

Table 1. **Area under NR cultivation and number of samples collected from the NR growing regions of South India**

Districts / States	Area under NR (ha)	Number of samples
Thiruvananthapuram	27567	505
Kollam	38998	766
Pathanamthitta	55845	1101
Alappuzha	4421	52
Kottayam	110724	2099
Ernakulam	37348	693
Idukki	66155	949
Thrissur	15734	270
Palakkad	32119	514
Malappuram	38835	772
Kozhikode	20895	296
Wayanad	7567	157
Kannur	54292	953
Kasaragod	25424	423
Tamil Nadu	21948	306
Karnataka	31662	516
Goa	424	21
Maharashtra	1133	55

Idukki, Kozhikode, Kannur, Kasaragod. In other states it increased in the order, Maharashtra, Tamil Nadu, Karnataka and Goa. The average OC content (%) in all the districts in Kerala as well as in other states were found to be more than 1.5 per cent *viz.* fall in high or very high status.

The percentage distribution of soil samples in each district / state to different classes (low, medium, high and very high) based on OC content are given in Table 5. Based on the OC (%) ranges, <0.75, 0.75-1.5, 1.5-2.5 and >2.5 per cent, soil samples were classified to low, medium, high and very high status as per the present system of classification followed in Rubber Research Institute of India. There were no samples in low OC (%) status in Alappuzha, Ernakulam, Thrissur, Kozhikode Wayanad and Kasaragod districts. In all the districts / states, only less than five per cent of samples were in low OC (%) status except in Palakkad district in Kerala and the state of Maharashtra. In Palakkad district, 10.5 per cent samples were in low OC status while in Maharashtra it was 94.6 per cent. Fifty two per cent of the samples in Thrissur district belonged to medium OC (%) status and 30 to 50 per cent of the samples in Thiruvananthapuram, Palakkad, Malappuram, Wayanad districts and Tamil Nadu were also in medium status. In Karnataka, about 20 per cent of the samples fall under medium, OC (%) status. More than 90 per cent of the samples were either in high or very high status in terms of OC content in Alappuzha, Idukki, Kozhikode, Kannur and Kasaragod districts in Kerala and the state of Goa. Sixty to 90 per cent of the samples in Kollam, Pathanamthitta, Kottayam, Ernakulam, Malappuram, Wayanad districts and Tamil Nadu and Karnataka States also belonged to high or very high OC (%) status. Thus more than 90 per cent of the soil samples from rubber grown areas in all the districts / states in South India were adequate in OC content (%) or belonged to the medium, high or very high status.

Mean, minimum and maximum values of gravel volume (%) in the samples collected from NR growing soils in different districts/ states are given in Table 3. Huge variations (CV >60%) in gravel volume were observed in Wayanad, Palakkad, Thrissur and Kozhikode districts and in the state of Tamil Nadu. The variations were comparatively less (CV < 30%) in Alappuzha and Kasaragod districts. The average gravel volume was the highest (32.1 %) in Alappuzha district while it was more than 20 per cent in

Table 2. Range and mean values of soil OC content (%) in the NR growing regions of South India

Districts / States	Minimum	Maximum	Mean	CV (%)
Thiruvananthapuram	0.30	3.94	1.79	39.66
Kollam	0.44	4.15	1.82	30.89
Pathanamthitta	0.40	4.90	2.25	33.87
Alappuzha	1.34	3.45	2.06	25.37
Kottayam	0.20	4.40	1.99	31.12
Idukki	1.02	3.89	2.34	25.26
Ernakulam	0.17	3.90	1.83	35.80
Thrissur	1.00	3.78	1.60	31.26
Palakkad	0.15	3.80	1.54	40.95
Malappuram	0.80	3.68	1.78	27.26
Kozhikode	0.95	4.58	2.52	27.24
Wayanad	0.80	3.29	1.66	29.46
Kannur	0.52	10.11	2.86	34.98
Kasaragod	0.45	7.67	3.21	33.44
Tamil Nadu	0.67	4.21	1.88	35.14
Karnataka	0.49	4.82	2.12	34.18
Goa	0.72	3.65	2.38	31.35
Maharashtra	0.48	3.25	1.85	31.69

Thiruvananthapuram and Kollam districts and it was less than 10 per cent in Thrissur and Wayanad districts. In some samples in Kollam and Alappuzha districts the mean gravel volumes recorded were more than 50 per cent. The lowest gravel volume recorded in Alappuzha district was 9.9 per cent while in other districts / states it was less three per cent.

Traditionally the soil nutrient statuses are expressed on a weight basis *viz.* in ppm or mg kg^{-1}. However, realizing the importance of quantifying the nutrient reserve in soil volumes in assessing nutrient supplying capacity of a soil, the nutrients are expressed and considered on a volume basis also, *viz.* tonnes ha^{-1} 30 cm^{-1} or mg L^{-1} *etc.* (Sillanpad, 1982). The nutrient stock in certain volume of different soils may vary considerably depending on the nutrient content and on the volume of the gravel or coarse fragments contained. It has been reported that in the traditionally NR grown areas in India *viz.* in the state of Kerala, rubber yield was correlated with soil nutrients expressed in volume basis (Rao, 2013). Based on the data generated on soil OC content and fine earth density, the stock OC in the 30 cm soil layer was estimated on tonnes ha^{-1} basis. The range and mean values for stock OC based on each of the soil sample collected for the different districts and states are given in Table 4. There exists considerable variation among the stock OC values as observed in the case of OC content (%) in all the districts / states. The lowest average stock of soil OC in rubber growing soils (0-30 cm) in South India was observed in Thiruvananthapuram district (36.5 tonnes ha^{-1}) while the highest was recorded in Idukki district (61.4 tonnes ha^{-1}).

Table 3. **Range and mean values of soil gravel volume (%) in the NR growing regions of South India**

Districts / States	Minimum	Maximum	Mean	CV (%)
Thiruvananthapuram	1.4	49.3	21.7	31.3
Kollam	1.4	50.7	23.1	36.5
Pathanamthitta	1.4	42.3	16.3	36.2
Alappuzha	9.9	50.7	32.1	25.2
Kottayam	1.4	43.7	15.3	36.6
Idukki	1.4	40.8	12.3	35.1
Ernakulam	1.4	39.4	13.7	39.4
Thrissur	1.4	31.0	7.7	59.1
Palakkad	1.0	39.4	12.1	69.7
Malappuram	1.4	46.5	16.7	42.0
Kozhikode	1.4	40.8	12.5	57.6
Wayanad	1.4	26.8	4.8	81.1
Kannur	1.4	43.7	18.3	36.2
Kasaragod	2.8	42.3	17.5	26.6
Tamil Nadu	1.4	39.4	14.5	60.0
Karnataka	1.4	42.3	17.7	41.0
Goa	2.8	28.2	13.7	45.1
Maharashtra	4.2	25.4	15.1	38.7

The stock OC values among the NR growing soils in South India ranged from 0.3 tonnes ha^{-1} observed for a sample in Kollam district to 264.9 tonnes ha^{-1} for another sample in Kannur district (Table 4). Stock soil OC under NR systems was reported from other nations also (Sun *et al.*, 2017). Bridhikitti (2017) reported that in Thailand under rubber plantations, the stock OC in the top soil layer (0-30 cm) ranged between 34.2 - 54.6 tonnes ha^{-1}.

The percentage distribution of samples in each district / state to low, medium, high and very high status of stock OC (kg ha^{-1}, 30 cm) are given in Table 5. Based on the range in stock OC values, <22.5, 22.5-45.0, 45.0-75.0 and >75.0 tonnes ha^{-1}, samples were classified to low, medium, high and very high status, respectively. The variations observed in the case of stock OC is similar to that in the case of soil OC content (%) in many cases. However, certain prominent changes were observed in Thiruvananthapuram and Kollam districts in Kerala and in Maharashtra State. The percentage of samples in low status were 4.9 and 2.1 based on the OC content in Thiruvananthapuram and Kollam districts which considerably increased to 19.6 and 9.0, respectively based on stock OC (tonnes ha^{-1}). In Maharashtra, though 94.6 per cent of samples were in low status based on OC content. However, based on stock OC, only 3.5 per cent samples were in low status. Except for some districts such as Kottayam, Palakkad, Malappuram and Wayanad districts in Kerala and Tamil Nadu, in most of the other districts and states, very drastic changes were observed in the number of samples in medium status based on OC (%) and stock OC. Considerable variations in

Table 4. **Range and mean values of soil organic carbon stock (tonnes ha^{-1} 30 cm^{-1}) in the NR growing regions of South India**

Districts / States	Minimum	Maximum	Mean	CV (%)
Thiruvananthapuram	8.0	91.3	36.5	43.2
Kollam	0.3	110.3	42.6	38.6
Pathanamthitta	12.1	138.8	56.0	33.6
Alappuzha	22.7	105.1	48.2	39.8
Kottayam	4.4	119.0	52.4	34.4
Idukki	10.6	128.4	61.4	28.8
Ernakulam	5.2	116.1	48.1	40.1
Thrissur	15.1	91.4	40.5	31.5
Palakkad	4.2	131.8	48.5	42.2
Malappuram	17.1	116.3	52.6	30.2
Kozhikode	18.2	109.2	57.0	31.6
Wayanad	27.1	112.9	51.6	28.8
Kannur	7.7	264.9	61.1	33.3
Kasaragod	8.6	115.5	60.6	29.3
Tamil Nadu	16.2	146.3	57.6	40.9
Karnataka	10.9	156.9	58.7	34.5
Goa	20.4	87.8	54.0	31.6
Maharashtra	16.2	80.5	46.0	31.8

the percentage distribution of samples among the high and very high categories based on OC content (%) and OC stock also were observed. These variations are expected and could be due to the variable level of influence of OC content and gravel volume, which were varying in different districts and states in South India (Table 2, 3 and 4). However, as observed in the case of OC content, more than 90 per cent of the soil samples were adequate in OC stock or belonged to the medium, high or very high status in all the districts / states except Thiruvananthapuram and Palakkad districts. The data on soil OC content and stock in the NR growing regions in South India indicate the soil carbon sequestration potential of the crop.

Soil organic matter is a soil component which can directly or indirectly influences physical, chemical and biological properties of soil and is one of the key factors that determine soil health (Wander, 2004; Bot and Benites, 2005). The inherent factors to a particular soil such as slope, depth of solum or texture are not amenable to changes and the influence of these factors on soil quality of the agricultural system is not manageable also. Apparently, the soil quality is better or comparatively easily manageable through regulating the quantity of quality of soil organic matter in an agricultural system (Wander, 2004; Bot and Benites, 2005). These soils though located in the tropics and under the same crop, NR experience wide variation in climate. The reason for the variation in stock OC in different regions

Table 5. **Percentage distribution of soil samples based on OC content (%) and OC stock (tonnes ha^{-1} 30 cm^{-1}) to different classes**

Districts /States	Low		Medium		High		Very High	
	OCC	OCS	OCC	OCS	OCC	OCS	OCC	OCS
Thiruvananthapuram	4.9	19.6	36.0	52.3	43.8	25.3	15.3	2.8
Kollam	2.1	9.0	27.0	47.7	61.6	40.2	9.4	3.1
Pathanamthitta	0.8	1.5	17.7	28.1	50.6	55.4	30.9	15.0
Alappuzha	0.0	0.0	9.1	45.5	70.9	43.6	20.0	10.9
Kottayam	1.9	3.9	21.9	32.5	57.8	52.8	18.5	10.8
Ernakulam	0.0	0.3	7.6	19.4	53.6	57.3	38.8	23.0
Idukki	4.7	8.6	24.0	36.3	57.4	46.8	13.8	8.3
Thrissur	0.0	5.5	52.0	66.1	41.6	25.9	6.3	2.6
Palakkad	10.5	12.0	37.9	35.5	44.5	43.0	7.0	9.6
Malappuram	0.9	1.8	31.6	31.9	60.1	57.7	7.4	8.6
Kozhikode	0.0	0.3	5.0	26.1	46.8	58.9	48.2	14.7
Wayanad	0.0	0.0	37.5	38.1	56.9	54.4	5.6	7.5
Kannur	0.2	1.0	4.2	19.0	35.2	58.5	60.3	21.4
Kasaragod	0.0	0.7	3.6	17.7	21.3	59.7	75.1	22.0
Tamil Nadu	0.7	0.7	33.0	29.0	52.4	48.8	13.9	21.5
Karnataka	2.2	2.2	19.8	24.9	49.9	51.9	28.1	21.1
Goa	4.8	4.3	4.8	26.1	38.1	60.9	52.4	8.7
Maharashtra	94.6	3.5	5.4	49.1	0.0	43.9	0.0	3.5

OCC-Organic carbon content OCS-Organic carbon stock

under the same crop, NR could be due to the drastic variation in the amount and pattern of rainfall in these regions and its influence on the organic matter decomposition pattern (Abraham and Jessy, 2018). Suitable agronomic management options for improving OC content may be adopted in districts such as Thiruvananthapuram, Kollam or Thrissur to improve the comparatively lower soil OC stock.

CONCLUSION

The soil OC content, gravel volume and stock OC in the 0-30 cm soil layer under rubber plantations in different districts of Kerala and the states of Tamil Nadu, Karnataka, Goa and Maharashtra were estimated through extensive sampling and analysis. Wide variations in OC content and gravel volume were observed in the different rubber growing regions in South India. The stock OC under rubber plantations in South India ranged from 36.5 to 61.4 tonnes ha^{-1} in the top 0-30 cm soil layer. More than 80 per cent of the soils under rubber in South India, stock OC falls under medium, high or very high status. The soil OC status in NR growing regions indicates the carbon sequestration potential of the crop.

REFERENCES

Abraham, J. and Joseph, P. (2012). Under flora in rubber plantations: Its effect on soil properties. *Placrosym XX Plantation Crops Symposium XX*, 12-15 December, 2012, Coimbatore, India, Abstracts. p. 69.

Abraham, J., Jose, V.T., Joseph, K. and Thankamony, S. (2010). Organic and soluble forms of carbon and faunal and microbial population in soils under plantation crops (rubber and teak), cassava and natural forest in Kerala. Abstracts, *Placrosym XIX. 19th Biennial Symposium on Plantation Crops*. 7-10 December, 2010, Kottayam, India, Abstracts. p. 126-127.

Abraham, J. and Jessy, M.D. (2018). Soil CO_2 flux measurements from a mature natural rubber plantation. *Rubber Science*, **31**(3): 196-207.

Abraham, J. (2015). Soil health in different land use systems in comparison to a virgin forest in a tropical region of Kerala. *Rubber Science*, **28**(1): 8-21.

Abraham, J. and Chudek, J.A. (2008). Studies on litter characterization using ^{13}C NMR and assessment of microbial activity in natural forest and plantation crops' (teak and rubber) soil ecosystems of Kerala, India. *Plant and Soil*, **303**: 265-273.

Bridhikitti, A. (2017). Soil and biomass carbon stocks in forest and agricultural lands in tropical climates. *Songklanakarin Journal of Science Technology*, **39**(6): 697-707.

Batjes, N.H. (1996). Total carbon and nitrogen in the soils of the world. *European Journal of Soil Science*, **47**(2): 151-163.

Lefevre, C., Rekik, F., Alcantara, V. and Wiese, L. (2017). *Soil organic carbon: The hidden potential*. Food and Agriculture Organization of the United Nations, Rome, Italy.

Bot, A. and Benites, J. (2005). *The importance of soil organic matter: Key to drought-resistant soil and sustained food and production*. Food and Agriculture Organization of the United Nations, Rome, Italy.

IPCC WGI (2001). *'Climate Change 2001: The scientific basis'*. Cambridge University Press, Cambridge, UK.

Karthikakuttyamma, M. (1995). *Effect of continuous cultivation of rubber (Hevea brasiliensis) on soil properties*. Ph.D Thesis, University of Kerala, Trivandrum, India, 176 p.

NBSS & LUP. (1999). *Resource soil survey and mapping of rubber growing soils of Kerala and Tamil Nadu on 1:50,000 scale*. National Bureau of Soil Survey and Land Use Planning (Indian Council of Agricultural Research), Nagpur, India.

Nelson, D.W. and Sommers, L.E. (1996). Total carbon, organic carbon and organic matter. In: *Methods of Soil Analysis. Part 3. Chemical Methods* (Eds. D.L. Sparks *et al.*). *Soil Science Society of America, Wisconsin, USA*, pp. 961-1010.

Rao, D.V.K.N. (2013). Volume based expression of soil variables: Good descriptor of soil-plant interrelationships. *Scientific Research and Essays*, **8**(29): 1380-1388.

Rubber Board (2020). *Indian Rubber Statistics*, Rubber Board, Kottayam, India, **41**: 2.

Sillanpäa, M. (1982). Micro nutrients and the nutrient status of soil: A global study. FAO Soils Bulletin 48. Food and Agricultural Organization of United Nations, Rome, Italy.

Sun, Y.C., Ma, Y.X., Cao, K.F., Li, H.M., Shen, J.X., Liu, W.J., Di, L., Mei, C.C. (2017). Temporal changes of ecosystem carbon stocks in rubber plantations in Xishuangbanna, Southwest China. *Pedosphere*, **27**(4): 737-746.

Walkley, A. and Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science*, **37**(1): 29-38.

Wander, M. (2004). Soil organic matter fractions and their relevance to soil function. In: *Soil Organic Matter in Sustainable Agriculture*. (Eds. F. Magdoff and R.R. Weil), CRC Press, Boca Raton, pp. 67-102.

Weil R.R, Islam, K.R., Stine, A.M., Gruver, J.B. and Samson Liebig, S.E. (2003). Estimating active carbon for soil quality assessment: A simplified method for laboratory and field use. *American Journal of Alternative Agriculture*, **18**(1): 3-17.

Weil, R.R. and Magdoff, F. (2004). Significance of soil organic matter to soil quality and health. In: *Soil Organic Matter in Sustainable Agriculture*, (Eds. F. Magdoff and R.R. Weil), CRC Press LLC, Florida, USA, pp. 1-43.