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Effect of Seasons on Sequestered Organic Carbon Pool in the Soils under different Land uses of Jhilmil Jheel Wetland, Haridwar-Uttrakhand, India

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Abstract: Jhilmil Jheel is a saucer shape wetland and is one of the most important wetland of Haridwar district (Uttrakhand, India) and also happens to be a conservation reserve for swamp deer (*Cervus duvauceli duvauceli*) declared in 2005. Consequently highly fragmented sections of swamp deer habitat remain few and far between, and Jhilmil Jheel happens to be the last refugee for this magnificent and highly endangered species. Wetlands are considered one of the highly productive ecosystems in the world and provide a potential sink for the atmospheric carbon. Therefore, a study was conducted to estimate the soil organic carbon (SOC) pool in Jhilmil Jheel wetland under different land uses *i.e.*, grassland, plantation and natural forest in different seasons *i.e.*, autumn, winter, spring and summer. The results revealed that in autumn season, SOC pool in grassland was maximum (81.38 t ha^{-1}) followed by natural forest (76.85 t ha^{-1}) and the least was in plantation (55.95 t ha^{-1}), in winter season, the SOC pool in natural forest was maximum (131.31 t ha^{-1}) followed by plantation (123.78 t ha^{-1}) and the least was in grassland (72.92 t ha^{-1}), in spring season, the SOC pool in natural forest was maximum (170.46 t ha^{-1}) followed by plantation (155.133 t ha^{-1}) and the least was in grassland (73.17 t ha^{-1}) and in summer season, the SOC pool in natural forest was maximum (123.89 t ha^{-1}) followed by plantation (114.61 t ha^{-1}) and the least was in grassland (64.73 t ha^{-1}) respectively. The average SOC pool under natural forest was maximum (125.61 t ha^{-1}) followed by plantation (112.37 t ha^{-1}) and the minimum was under grassland (73.05 t ha^{-1}). Statistical analysis showed that in autumn season, significant differences between SOC pool under grassland and plantation, natural forest and plantation were observed. In winter, spring and summer season, significant difference between SOC pool under natural forest and grassland, plantation and grassland were observed. The analysis also revealed that SOC pool was significantly different at (P 0.05 level) between all the three sites and also between different seasons.

Keywords: Grassland, Natural Forest, Plantation, Soil Organic Carbon pool & Wetland.

INTRODUCTION

Wetlands represent the largest component of the terrestrial biological carbon (C) pool (Dixon and Krankina, 1995) and thus play an important role in global C cycles (Sahagian and Melack, 1998). The great capacity of wetland soils to store C derives from the slow rate to which decomposition occurs under anaerobic conditions (Gorham, 1991; Hobbie *et al.*, 2000).

Carbon is the most important element which is essential for all the life forms and is commonly found in earth. Soils can act as sinks or as a source for carbon in the atmosphere depending on the changes happening to soil organic matter and one such important sink is wetland and as a matter of fact, wetland in India and elsewhere are facing great anthropogenic stress. To sustain the quality and productivity of soils, knowledge of SOC pool in terms of its amount and quality is essential. The first comprehensive study of organic carbon (OC) status in Indian soils was conducted (Jenny and Raychaudhuri, 1960) by collected 500 soil samples from different cultivated fields and forests with variable rainfall and temperature patterns. However, the study did not make any estimate of the total carbon reserves in the soils. The first attempt in estimating OC stock was also made based on a hypothesis of enhancement of OC level on certain unproductive soils and the first estimate of the organic carbon stock in Indian soils was 24.3 pg (1 Pg = 1015 g) based

on 48 soil samples (Gupta and Rao, 1984). Despite the important role attributed to wetland ecosystem in the global carbon cycle, little information exists on soil C quality and sensitivity of soil organic carbon (SOC) decomposition to climate change (Hill and Cardaci, 2004; Bridgham *et al.,* 2006). SOC losses from wetland ecosystem could then result in a large positive feedback to climate change (Davidson and Janssens, 2006). Soil organic matter can also increase or decrease depending on numerous factors, including climate, vegetation type, nutrient availability, disturbance land use and management practice (Six, 2002; Baker, 2007). Carbon accumulation in forested wetland soils is significantly greater than in upland forest soils due to the oxic/anoxic soil regime (Trettin and Jurgensen, 2003).

In last decade, the greenhouse effect has been of great concern, and has led to several studies on the quality, kind, distribution and behavior of SOC (Eswaran *et al.,* 1993; Batjes, 1996; Velayutham *et al.,* 2000). According to Jha *et al.,* (2003) global warming and emission of CO_2 are of worldwide concern because these are creating environmental imbalance and are a long term threat to the well being of all life on earth. Equilibrium between the rate of decomposition and rate of supply of organic matter is disturbed when forests are cleared and land use is changed (Lal, 2004; Buringh,1984).

The study of wetland SOC pool was very scanty/meager particularly in Indian scenario. Therefore the present study was undertaken with the aim to estimate the SOC pool under different land uses of Jhilmil Jheel wetland because no systematic study had been undertaken so far in this area. As a result of this study, a comparative account will be available for the SOC pool of Jhilmil Jheel wetland.

STUDY AREA

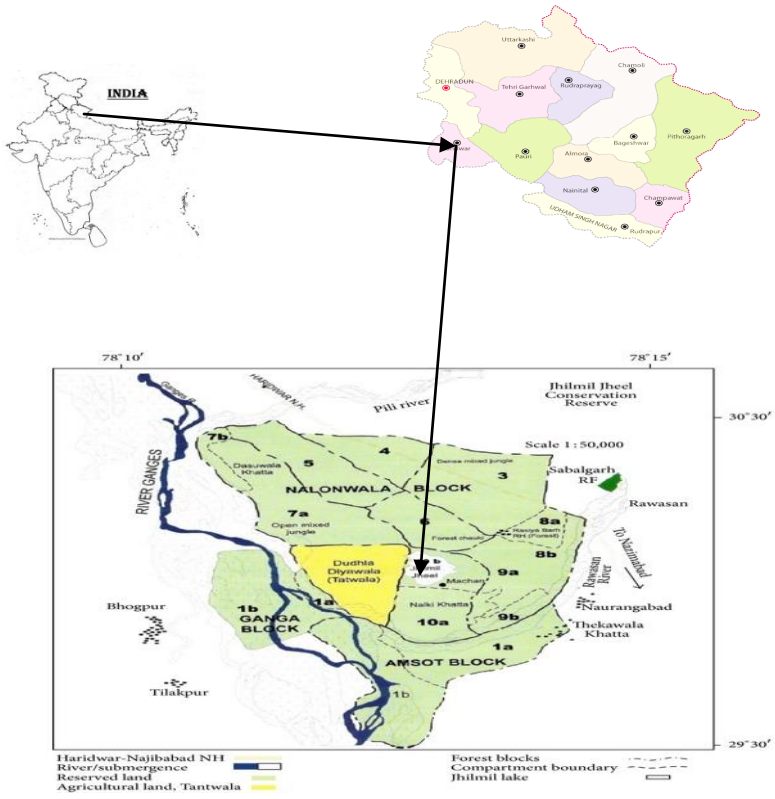

Figure 1. Map of the Study area (source unanimous)

METHOD & MATERIAL:

1. Study Site:

The study was conducted in Jhilmil Jheel Wetland located in Haridwar Forest Division and situated at the junction of the Bhabar and Terai formations extending up to the Ganges in Uttrakhand state and located between the Haridwar-Najibabad highway in Chidyapur range of Haridwar forest reserve. It was situated between longitude N 29^0 32 to 29^0 50' and latitude E 78^0 to 78^0 15' covering an area of 3783.50 ha of the reserve forest. The altitude of the area varies from 200-250 meters above msl. It is connected to river Ganga and is surrounded by reserve forest of chidyapur. It represents a very unique and species rich ecosystem which encompasses spectacular landscapes, tall grasses and tropical moist deciduous forests. Very few islands of natural habitat remain today in the flood plain of river Ganga as a major portion of the grasslands was also taken up for eucalyptus plantation by forest department. Consequently highly fragmented sections of swamp deer habitat remain few and far between, and Jhilmil Jheel happens to be the last refugee for this magnificent and highly endangered species.

2. Climate:

The area experiences sub-tropical climate, coldest month being January when temperature drops as low as 2ºC and in summers, temperature soars up to 44ºC. The area experiences heavy rainfall during June to September (monsoon). Annual rainfall averages about 1300 mm (recorded between 1997 and 2007, Haridwar Forest Division). Relative humidity ranges between 45 - 80%.

3. Soil Sampling:

The site was categorized into three different land uses *i.e.*, natural forest, plantation and grassland. In the middle of the conservation reserve, a small part of the middle portion of the grassland is occupied by swamp. Sampling was done randomly in all the three parts of the wetland during the period of 2012 to 2014 in each season. A pit of 30 cm × 30 cm × 30 cm was dugout and soil was collected. Soil organic matter tends to concentrate in the upper soil horizons with roughly half of the soil organic carbon of the top 100 cm of mineral soil being held in the upper 30 cm layer (IPCC, 2003). Therefore, we have collected the soil samples from the upper 30 cm layer.

4. Estimation of Soil Attributes:

Soil samples were processed as per method described by (Jackson, 1965) and coarse fragment, bulk density was estimated as per (Wilde *et. al.*, 1964). Organic carbon was estimated by the method described by (Walkley and Black, 1934).

5. Equation for SOC pool Calculation:

The data for SOC pool was calculated by using the following equation as suggested by IPCC Good Practice Guidance (2003) for LULUCF:

$$\mathrm{SOC} = \sum_{Horizon=1}^{Horizon=n} \mathrm{SOC}_{\mathrm{Horizon}}$$

$$\mathrm{SOC} = \sum_{Horizon=1}^{Horizon=n} ([\mathrm{SOC}] * \mathrm{Bulk\ Density} * \mathrm{Depth} * (1 - \mathrm{C\ frag.}) * 10)_{\mathrm{Horizon}}$$

Where, SOC = Representative soil organic carbon content for the forest type and soil of interest, tones C ha^{-1}.

$SOC_{Horizon}$ = Soil organic carbon content for a constituent soil horizon, tones C ha^{-1}.

[SOC] = Concentration of SOC in a given soil mass obtained from analysis, g C $(kg\ soil)^{-1}$.

Bulk density = Soil mass per sample volume, tones soil m^{-3} (equivalent to Mg m^{-3}).

Depth = Horizon depth or thickness of soil layer, m

C Fragment =% volume of coarse fragments / 100, dimensionless.

RESULTS & DISCUSSION

Seasonal wise SOC pool in all the three different sites of Jhilmil Jheel wetland:

The SOC pool under different land uses of Jhilmil Jheel wetland was estimated and results were presented in table 1. The results indicated that during autumn season, the SOC pool was maximum under grassland (81.38 t ha^{-1}) followed by natural forest (76.85 t ha^{-1}) and minimum was under plantation (55.95 t ha^{-1}) (figure 2), in winter season, the SOC pool was maximum under natural forest (131.25 t ha^{-1}) followed by plantation (123.78 t ha^{-1}) and minimum was under grassland (72.92 t ha^{-1}) (figure 3), in spring season, the SOC pool was maximum under natural forest (170.46 t ha^{-1}) followed by plantation (155.13 t ha^{-1}) and minimum was under grassland (73.17 t ha^{-1}) (figure 4), in summer season, the SOC pool was maximum under natural forest was (123.89 t ha^{-1}) followed by plantation (114.61 t ha^{-1}) and minimum was under grassland (64.73 t ha^{-1}) (figure 5) respectively. Overall it was observed that the maximum SOC pool was in spring season under the natural forest (170.46 t ha^{-1}) and the minimum SOC pool was observed in autumn season under plantation (55.95 t ha^{-1}). The study revealed that the SOC pool in grassland was higher as compared to natural forest and plantation in the autumn season and decreased in winter followed by spring and then least was in summer. It may be because the above ground herbaceous biomass dies in autumn and regenerates in spring in the perennial grasslands and that their root systems also have a rapid turnover but on a longer time scale, an estimated 55% of temperate grassland root biomass turns over annually (Gill and Jackson, 2001; Gill *et al.*, 2002). The natural grassland locked in a significant amount of SOC and the presence of extensive root biomass of grass communities may be one of the reason for higher SOC pool content (Balesdent and Balabane, 1996) and since roots are considered to be more stable form of carbon supply to the soil than litter (Denef and Six, 2006). Residues and roots of grasses decomposes faster than the residues and roots of broadleaf trees, and likely due to lower lignin found in grasses (Pinno and Wilson, 2011). And comparative studies of meadows and forest soils in the forest zone of Russia (Yakimenko, 1998) have demonstrated the ability of grassland ecosystems to accumulate more SOC in a 50 cm soil layer then in forest ecosystems. It is generally accepted that within a year up to 50% of the biomass carbon (both roots and above ground biomass) dies, decomposes and as a result as residues in the SOC pool (Follet *et al.*, 2001). While in plantation and natural forest, the results revealed an increasing trend up to spring. It may be because forests have grater canopies and provide the litter in larger quantity as compare to grasslands therefore, accumulation of carbon was higher. About 40% of the total SOC stock of the global soils resides in forest ecosystem (Bhattacharyya *et al.*, 2008). The Himalayan zones, with dense forest vegetation, cover nearly 19% of India and contain 33% of SOC reserves of the country (Eswaran *et al.*,1999). Declining trend during the summer season may be because organic carbon content decreases with increase in temperature (Kirschbaum, 1995; Albrecht and Rasmussen, 1995), and decomposition rates (microbial respiration) doubles with every 10^{o}C increase in the temperature (Schlesinger, 1997; Hartel, 2005). Dick and Gregorich (2004) compared relative decomposition rates of organic matter in tropical (Nigeria) and cold dry climates (Canada), and found that decomposition rates were 10 times faster in the tropical site.

Season-wise SOC pool under different land uses of Jhilmil Jheel wetland

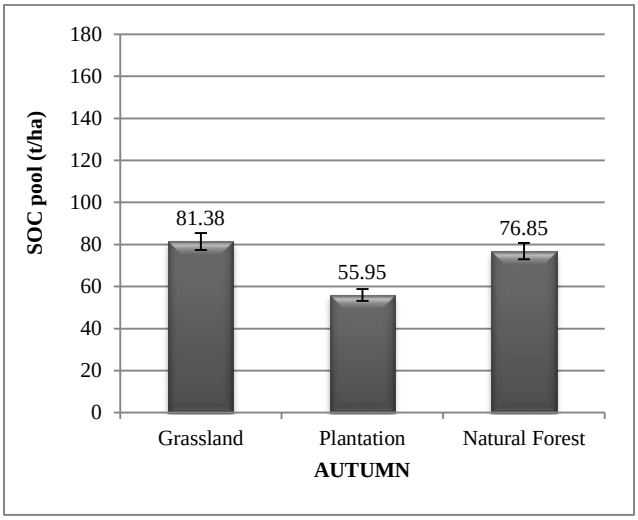

Figure 2

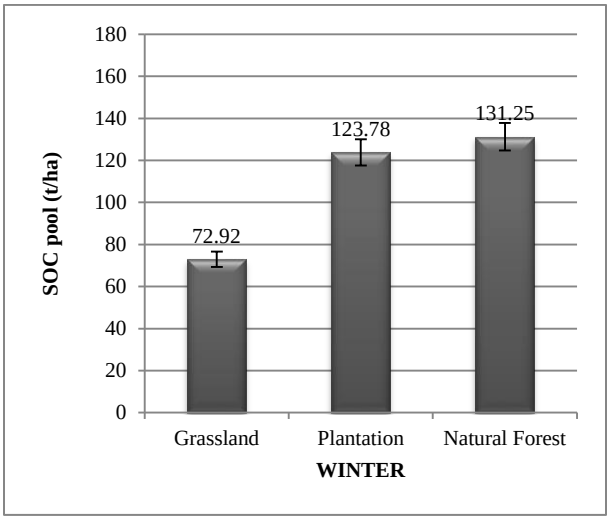

Figure 3

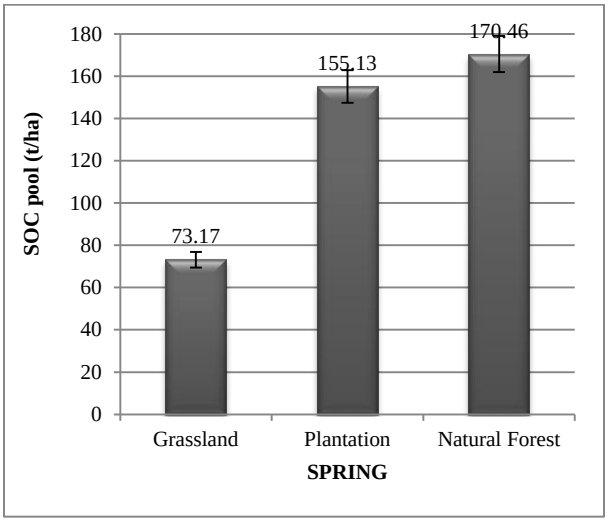

Figure 4

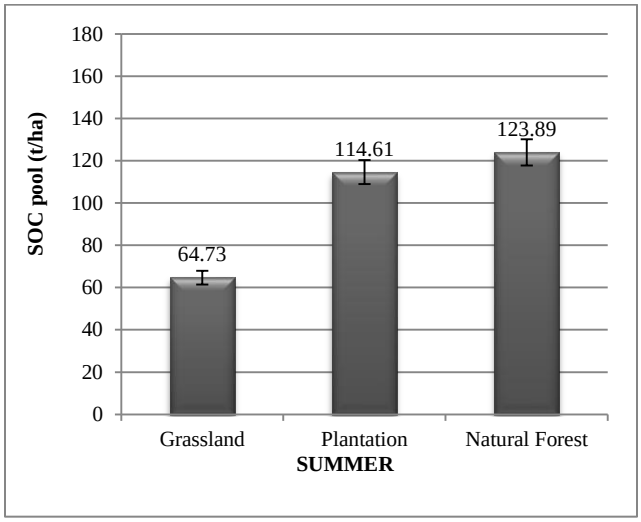

Figure 5

Table 1. Seasonal wise SOC pool under Grassland, Plantation and Natural Forest of Jhilmil Jheel wetland

Sl. No.	Seasons	Sites	SOC Pool (t/ha)	Std. Deviation	Std. Error
1	Autumn	Grassland	81.38[a]	± 20.957	4.68
2		Natural Forest	76.85[a]	± 17.268	3.86
3		Plantation	55.95[b]	± 16.759	3.74
4	Winter	Natural Forest	131.25[a]	± 23.803	5.32
5		Plantation	123.78[a]	± 22.093	4.94
6		Grassland	72.92[b]	± 20.948	4.68
7	Spring	Natural Forest	170.46[a]	± 31.518	7.04
8		Plantation	155.13[a]	± 37.223	8.32
9		Grassland	73.17[b]	± 19.616	4.38
10	Summer	Natural Forest	123.89[a]	± 19.093	4.26
11		Plantation	114.61[a]	± 18.130	4.05
12		Grassland	64.73[b]	± 19.829	4.43

Same alphabets represent the at par groups.

When the seasons were integrated, the SOC pool under natural forest was maximum (125.61 t ha^{-1}) followed by plantation (112.37 t ha^{-1}) and the minimum was under grassland (73.05 t ha^{-1}) which was the lowest among the three different sites. The total average SOC pool of Jhilmil Jheel wetland was (103.68 t ha^{-1}) shown in (table 2). SOC pool was higher under natural forests as compared to planted forests. This may be due to production and return of higher amount of litter in natural forests. The release of nutrients from litter decomposition is a fundamental process in the internal biogeochemical cycle of an ecosystem, and decomposers recycle a large amount of carbon that was bounded in the plant or tree to the atmosphere (Sevgi and Tecimen, 2008).

Table 2. Overall Mean SOC pool under different Land uses of Jhilmil Jheel wetland

Sl. No	Site	Mean SOC pool (t/ha)	Std. Deviation	Std. Error
1	Natural Forest	125.61	± 40.675	4.55
2	Plantation	112.37	± 43.593	4.87
3	Grassland	73.05	± 20.818	2.33
Average		103.68	± 42.645	2.75

STATISTICAL ANALYSIS

Table 3. Statistically significant mean difference on the basis of CD (LSD) in different seasons

Sl. No.	Season	Vegetation	Mean Difference	P Value
1	Autumn	Grassland Vs. Plantation	25.4315*	0.000
2		Natural Forest Vs. Plantation	20.9025*	0.001
3	Winter	Plantation Vs. Grassland	50.8570*	0.000
4		Natural Forest Vs. Grassland	58.3310*	0.000
5	Spring	Plantation Vs. Grassland	81.9630*	0.000
6		Natural Forest Vs. Grassland	97.2855*	0.000
7	Summer	Plantation Vs. Grassland	49.8790*	0.000
8		Natural Forest Vs. Grassland	59.1625*	0.000

SPSS model was used to analyze the data for One-way ANOVA to compare SOC pool in all the three different sites. The analysis showed (table 3) that in autumn season, there was a significant difference between SOC pool under grassland and plantation as well as under natural forest and plantation. In winter season, the analysis showed significant difference between SOC pool under plantation and grassland as well as between natural forest and grassland. In spring season, the analysis showed significant difference between SOC pool under plantation and grassland as well as between natural forest and grassland. Finally there was significant difference between SOC pool under plantation and grassland as well as between natural forest and grassland at (P 0.05 level).

CONCLUSION

The study showed that in Jhilmil Jheel wetland area, under natural forest soils had the higher amount of OC pool followed by plantation and grassland was having the least amount of SOC pool. The higher SOC pool was observed in spring season followed by winter, summer and least amount was observed in autumn season. Overall results from the study showed a considerable high amount of SOC pool levels which signifies fewer disturbances in the well protected area. There is a great measure of biodiversity in the Jhilmil Jheel wetland, this factor also adds to the well maintained SOC pool level. Wetlands have the potential to remove large quantities of carbon from the atmosphere and to reduce the concentration of atmospheric CO_2 which will help abate global warming. If the wetland carbon stock might be destroyed, a large amount of carbon accumulation could be discharged from wetland soils in a short period of time.

This study was the first attempt to assess the seasonal changes in the SOC pool under different land uses of Jhilmil Jheel wetland. This study will be helpful in preparing carbon inventory of the wetland for the policy makers for preparing an effective management plan as well as to take effective measures for managing soil organic carbon efficiently in Haridwar district and the declaration of Jhilmil Jheel as conservation reserves and conserve the habitat which will ultimately remain as a safe heaven for this species in Uttrakhand.

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REFERENCES

[1] S.L. Albrecht, "Soil quality and soil organic matter". 1995, pp. 101-104. *In* Columbia Basin Agricultural Research Annual Report. Spec. Rpt. 946. Oregon State University in cooperation with USDA-Agricultural Research Service, Pendleton, OR.

[2] D.F. Baker, "Reassessing carbon sinks". 2007, *Science*. 316:1708-1709.

[3] J. Balesdent, "Major contribution of roots to soil carbon storage inferred from maize cultivated soils". 1996, *J Soil Biol. Biochem*. 28: 1261-1263.

[4] T.C. Baruah, "A Text Book of Soil Analysis", Vikas publishing house Pvt. Ltd., 1999, pp 13-14.

[5] N.H. Batjes, "Total C and N in soils of the world".1996, *Eur J Soil Sci*, 47:151-163.

[6] T. Bhattacharyya, "Soil carbon storage capacity as a tool to prioritize area for carbon sequestration", 2008, *Current Science*, 95 (4): 482 – 484.

[7] W.D. Billings, "Increasing atmospheric carbon dioxide: possible effects on artic tundra". 1983, *Oecologia* 58: 286-289.

[8] S.D. Bridghm, "The carbon balance of North American wetlands". 2006, *Wetlands* 26: 889-916.

[9] P. Buringh, "Organic carbon in soils of world". In The Role of Terrestrial Vegetation in Global Carbon Cycle: Measurement by Remote Sensing (Ed): Woodwell GM. 1984, John Wiley: 91-109.

[10] J.K. Cronk, "Wetland Plants: Biology and Ecology". Lewis Publishers , CRC Press. Boca Raton, Florida, 2001.

[11] E.A. Davidson, "Temperature sensitivity of soil carbon decomposition and feedbacks to climate change". 2006, *Nature* 440: 165-173.

[12] K. Denef, "Contributions of incorporated residue and living roots to aggregate associated and microbial carbon in two soils with different clay mineralogy", 2006, *Eur. J. Soil Sci*. 57: 774-786

[13] S.K. Dey, "A preliminary estimation of carbon stock sequestrated through rubber (*Hevea brasiliensis*) plantation in North Eastern regional of India". 2005, *Indian Forester*, 131(11):1429-1435.

[14] W.A. Dick, "Developing and maintaining soil organic matter levels". 2004, pp. 103-120. *In* Managing Soil Quality: Challenges in Modern Agriculture. P. Schjønning, S. Elmholt and B. T. Christensen, Eds. CABI Publishing, CAB International. Cambridge, Massachusetts.

[15] R.K. Dixon, "Can the terrestrial biosphere be managed to conserve and sequester carbon? In: Carbon sequestration in the biosphere: Processes and products". NATO ASI Series. Series 1. 1995, *Global Environmental Change*, 33: 153 – 179.

[16] H. Eswaran, "Global Climate Change and Pedogenic Carbonates (Ed.)", Lal R, et al. 1999, Lewis Pub-lishers, Fl, USA, 15-25.

[17] H. Eswaran, "Organic carbon in soils of the world". 1993, *Soil Sci Soc Am J*, 57:192-194.

[18] R.F. Follett, "*The Potential of U.S. Grazing Lands to Sequester Carbon and Mitigate the Greenhouse Effect"*. 2000, CRC Press, Boca Raton, FL.

[19] R.A. Gill, "Global patterns of root turnover for terrestrial ecosystems". 2000, New Phytol 147:13–31

[20] E. Gorham, "Northern peatlands: role in the carbon cycle and pribable responses to climate warming". 1991, *Ecological Applications* 1: 182-195.

[21] R.K. Gupta, "Potential of wastelands for sequestering carbon by reforestation". 1984, *Current Science*. 66:378-380.

[22] P.G. Hartel, "The soil habitat". 2005, pp. 26-53. *In* Principles and Applications of Soil Microbiology. 2nd edition. D. M. Sylvia, J. J. Fuhrmann, P. G. Hartel, and D. A. Zuberer, Eds. Pearson Prentice Hall. Upper Saddle River, New Jersey.

[23] A.R. Hill, "Denitrification and organic carbon availability in riparian wetland soils and subsurface sediments". 2004, *Soil Sci. Soc. Am. J* 68: 320-325.

[24] S.E. Hobbie, "Controls over carbon storage and turnover in high altitude soils". 2000, *Global Change Biology* 6: 196-210.

[25] IPCC, "*Good Practice Guidance for Land Use, Land Use Change and Forestry"*. Published by the Institute for Global Environmental Strategies (IGES) for the IPCC. Publishers Institute for Global Environmental Strategies, Japan 2003.

[26] M.L. Jackson, "Soil Chemical Analysis–Advance Course. Published by the author, Wisconsin University, Madison, Wisconsin, 1965.

[27] H. Jenny, "Effect of Climate and Cultivation on Nitrogen and Organic Matter Reserves in Indian Soils". 1960, *ICAR, New Delhi, India* :126.

[28] M.N. Jha, "Soil organic carbon store in different forests of India". 2003, *Indian Forester* 129 (6): 714 – 724

[29] M.U.F. Kirschbaum, "The temperature dependence of soil organic matter decomposition, and the effect of global warming on soil organic storage". 1995, *Soil Biology and Biochemistry* 27: 753-760.

[30] R. Lal, "Soil carbon sequestration to mitigate climate change". 2004, Geoderma. 123:1-22.

[31] S.S. Negi, "Sequestered organic carbon pool in the forest soils of Uttrakhand state, India". 2013, *Int. J. Sci. & Env.* 2, (3): 510 - 520.

[32] S.W. Pacala, "Consistant land and atmospheric based U.S carbon estimates". *Science* 2001, 292:2316 - 20.

[33] B.D. Pinno, "Ecosystem carbon changes with woody encroachment of grassland in the northern Great Plains". 2011, *Ecoscience*, 18 (2): 157–163

[34] D. Sahagian, "Global wetland distribution and functional characterization": trace gases and the hydrologic cycle, 1998, IGBP report 46.

[35] K.E. Savage, "Interannual variation of soil respiration in two New England forests". *Global Biogeochemical Cycles*, 2001, 1-14.
[36] O. Sevgi, "Changes in Austrian Pine forest floor properties in relation with altitude in mountainous areas", J. Forest Science, 2008, 54 : 306-313.

[37] W.H. Schlesinger, "Biogeochemistry: An Analysis of Global Change". 2nd ed. Academic Press. 1997, San Diego, California.

[38] J. Six, "Organic matter turnover". *Encycl Soil Sci.* 2002, 936-942.

[39] C.C. Trettin,. Carbon cycling in wetland forest soils. In the potential of U.S forest soil to sequester carbon and mitigate the greenhouse effect. Lewis Publisher, CRC Press. Boca Raton, Florida, 2003, pp.311-331.

[40] M. Velayutham, "Global Climate Change and Tropical Ecosystems", Edited by: Lal R, Kimble JM, Stewart BA. Lewis Publishers, Boca Raton, 2000, FL:71-96.

[41] A. Walkley, "An Examination of Degtjareff Method for Determining Soil Organic Matter and a Proposed Modification of the Chromic Acid Titration Method". Soil Sci. 1934, 37, 29-37.

[42] K.M. Watt, "Organic matter dynamics in seasonally inundated forest wetlands of the Gulf Coastal Plain". Wetlands. 1999, 19: 139-148.

[43] S.A. Wilde, "Soil and Plant Analysis for Tree Culture". Oxford Publishing House, Calcutta, India.

[44] E.Y. Yakimenko, "Soil Comparative Evolution under Grasslands and Woodlands in the forest zone of Russia". In Lal, R., Kimble, J.M., Follet, R. F., and Stewart, B.A. (eds): Management of Carbon Sequestration in Soil. CRC Press, Boca Raton, New York, 1998, pp. 391 - 420.

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