STUDY OF SOIL CARBON SEQUESTRATION DUE TO LAND USE CHANGES AND ASSOCIATED SOIL MODIFICATION

POONAM KUMARI

DEPARTMENT OF CIVIL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY DELHI

SEPTEMBER 2018

STUDY OF SOIL CARBON SEQUESTRATION DUE TO LAND USE CHANGES AND ASSOCIATED SOIL MODIFICATION

by

Poonam Kumari

Department of Civil Engineering

Submitted

in fulfillment of the requirements for the degree of *Doctor of philosophy*

to the

INDIAN INSTITUTE OF TECHNOLOGY DELHI

SEPTEMBER 2018

To

My moter-in-law

Late.Kumud Kumari Singh

CERTIFICATE

This is to certify that the thesis entitled **"Study of Soil Carbon Sequestration due to Land Use Changes and Associated Soil Modification"** being submitted by **Ms. Poonam Kumari** to the Indian Institute of Technology Delhi is a record of bonafide research work carried out by her under my supervision and guidance. The thesis work, in my opinion, has reached the standard, fulfilling the requirements for the award of **Doctor of Philosophy** degree.

The research report and results presented in this thesis have not been submitted, in part or full, to any university or Institute for the award of any degree or diploma.

(Arvind K. Nema)
Professor,
Department of Civil Engineering,
Indian Institute of Technology Delhi
New Delhi-110016, India

Date:-
New Delhi

ACKNOWLEDGEMENTS

Firstly, I would like to express my special appreciation and thanks to my advisor **Dr. A. K. Nema** (Professor, Department of Civil Engineering, Indian Institute of Technology Delhi), for his invaluable guidance, cooperation, encouragement and for providing all assistance required for the completion of this work. His painstaking efforts in going through the manuscript and suggestions for its improvement are gratefully acknowledged. I would like to thank him for encouraging my research and for allowing me to grow as a research scientist. His advice on both research as well as on my career have been priceless.

Besides my advisor, I would like to thank Student Research Committee members: Prof. Mukesh Khare, Prof. K. K. Pant and Dr. Jagdish Telangrao Shahu for their insightful comments and encouragement. The hard questions raised from their sides incented me to widen my research from various perspectives.

I am also thankful to Environmental Engineering Laboratory staff members namely, Mr. Sanjay Kumar, Mr. Ishwar Singh and Mr. S. S. Shukla for their time-to-time support during my stay in the department. I would also like to mention other staff members who were a great support in this arduous journey of obtaining a Ph.D. from IIT Delhi, namely Mr. Rajveer Aggarwal, and Mr. Amal from Xerox Centre.

A special thanks to Mr. Bharat Bhushan Tyagi who is a renowned person in the Organic circles of India. After decades of experimentation with various types of agricultural techniques, and along with other farmers spread across the country, he is known to have been the pioneers of Organic farming with over 30 years of experience in organic farming. He has been working at various positions with Government associations like NCOF, ICCOA, Ministry of Agriculture, AFC, NABARD, Banks, Universities, etc, and has received numerous awards from multiple state and central bodies including a Progressive farmer award from Mr. Narendra Damodardas Modi, Honorable Prime Minister of India. He not only provided his organic farming land as one of the important sites of my research work but also helped to arrange the chemical farming land in the same locality which was in the demand of my work. I got an opportunity to learn a lot in the context of organic farming practices and their benefits which made my work easier.

I would like to thank my family: my father Mr. Sheoraksha Prasad Singh, mother Mrs. Krishna Singh and my father-in-law Mr. Surendra Sharma for their affection, continuous encouragement, moral and emotional support during the entire research programme.

I acknowledge and record my deep sense of love to the two little angel of my life, my son Aditya Kumar and Arnav Sharma, who gave me emotional support and their precious time to accomplish this task. At the end I would like express appreciation to my adored husband Mr. Rahul Kumar who not only gave me continuous motivation but also helped me in the sample collection from the various sites without expressing any obligations and burden in fact he made that work enjoyable and was always my support in the moments when there was no one to answer my queries. Without his encouragement and support, It would be impossible for me to achieve this assignment.

Lastly, I would also like to thank God almighty for everything.

(Poonam Kumari)

ABSTRACT

The rapid rate of urban expansion due to a rise in population and economic growth is causing land use and land cover changes in Delhi NCR region. The present study assesses the impact of land use change on climate by estimating the reduction in the soil carbon sequestration capacity and emission of carbon dioxide (CO_2), a major component of greenhouse gas, into the atmosphere. Soil, the huge pool of earthly carbon retains almost 1500 Pg. organic carbon in its outermost top one meter. Any small changes in this huge pool may lead to great impacts on the biogeochemical cycle of carbon (C). Modelling of soil organic carbon (SOC) is an appropriate method to evaluate the effect of land use and its management on soil carbon sequestration which one could not assess through the experimental work. The present study aimed: 1) to evaluate how land use change and season influences soil organic carbon (SOC) stocks, 2) Simulation of SOC in different land use for next 30 years from the year 2015, with the help of Rothamsted Carbon Model (RothC) by Coleman and Jenkinson (1996) and 3) to determine the effect of different fertilizer treatment on SOC retaining capacity in different soil texture by controlled experiment. To achieve these objectives four different land use, falling under same climatic area of Delhi NCR region, the Protected forest (PF) and Unprotected forest (UPF) of the South Central Ridge of Aravallis (28°32′00″N 77°10′40″E) near Vasant Kunj and Mehrauli in Delhi and the Organic Farming (OF) and Chemical Farming (CF) fields located in Bulandsahar (Uttar Pradesh state in northern India having coordinates $28^0$26’N 77^0 50;E), Ghaziabad, UP of India were selected for analysis of soil organic carbon (SOC) and soil inorganic carbon (SIC) in the upper layer of soil (0-30 cm) in three seasons of a year. Soil samples were collected in the summer (March), monsoon (July) and winter (December) seasons of the year 2015 from various depths 0-5, 5-10, 10-15, 15- 20 & 20-30cm. The result showed that statistically significant difference exists among SOC of

the four land use and it follows the order of PF> UPF > OF > CF in all the seasons. Statistically, an insignificant difference was observed between SIC of organic and chemical farming fields but SIC in the protected forest was found significantly higher than the unprotected forest in all the seasons. The statistically significant difference in C/N ratio was observed in the soil of all land use in all seasons and it follows the order of PF> UPF > OF > CF. The average SOC (t/ha) in 2015 in PF, UPF, OF & CF were found as 97.78, 72.92, 65.40 & 40.15 respectively. Net emission of CO_2 in the atmosphere per hectare of land was calculated in terms of the difference in SOC (t/ha) in different land uses. It was observed that if one hectare of PF gets converted into UPF, 91.24 tons of CO_2 would be released into the atmosphere and if it gets converted into agricultural land then depending on management practices either as OF or CF field amount of CO_2 released in the atmosphere would be 118 tons and 211.50 tons respectively. Similarly if one hectare of unprotected forest gets converted into agricultural field then according to management practices of OF and CF management practices the amount of CO_2 released in atmosphere in tons would be 27.60 and 120.26 respectively and if one hectare of OF field gets converted into CF field the amount of CO_2 released in atmosphere would be 92.67 tons. But no significant differences were observed across the three seasons (summer, monsoon, and winter) in the SOC, TN and C/N ratio in all the four selected land use. The simulated values of SOC correlated well with measured data (R^2 = 0.96 to 0.97) for all the four land use, the modelling error (root mean square error, %RMS) were observed as 2.65, 5.08, 3.90 to 5.32 in surface layer of protected forest PF, UPF, OF and CF sites respectively indicating a good efficiency of the Roth C model. The Nash-Sutcliffe model efficiency coefficient (E) which matches predicted and observed values and varies from "–infinity" to "1", with the best performance at "E=1" were found as 0.64, -0.35, 0.65, 0.63 respectively for all four land use. Negative values of 'E' for unprotected forest indicates fewer similarities of predicted values with the mean of the

observed value, this may be due to over disturbance of the selected sites due to concrete work all around the unprotected forest area which is surrounded from all sides by Jawaharlal Nehru University, Delhi that may leads to disturbance of natural biological balance of the forest soil. On the basis of simulated SOC stock for the next 30 years, the PF showed 14.63% increase and UPF 4.82% increase, the OF 3.729% increase but the CF showed 9.06% decrease, in SOC stock in 2045 from 2015 stock. The result of controlled experiments shows that if we shift from Organic manure to Chemical fertilizer treatment in sandy loam, loam or silty clay soil, the potential of an additional amount of CO_2 release in the atmosphere from one-hectare agriculture land would be 40.10, 40.21, 40.62 tons respectively. These data give the quantitative estimation of how land use and land management affects the conversion of soil from sink to source of carbon in the atmosphere.

Keyword: - Soil carbon sequestration, Soil organic carbon, Soil Inorganic Carbon, Carbon cycle, Organic manure, chemical fertilizer.

सार

जनसंख्या और आर्थिक विकास में वृद्धि के कारण शहरी विस्तार की तीव्र दर दिल्ली एनसीआर क्षेत्र में भूमि उपयोग और भूमि कवर में परिवर्तन का कारण बन रही है। वर्तमान अध्ययन मिट्टी कार्बन अनुक्रमण क्षमता में कमी और कार्बन डाइऑक्साइड (CO_2), ग्रीनहाउस गैस का एक प्रमुख घटक, वायुमंडल में कमी का अनुमान लगाकर जलवायु पर भूमि उपयोग परिवर्तन के प्रभाव का आकलन करता है। मृदा, सांसारिक कार्बन का विशाल पूल लगभग 1500 Pg बनाए रखता है। कार्बनिक कार्बन अपने बाहरी शीर्ष एक मीटर में। इस विशाल पूल में किसी भी छोटे बदलाव से कार्बन (C) के जैव-रासायनिक चक्र पर बहुत अधिक प्रभाव पड़ सकता है। मिट्टी कार्बनिक कार्बन (SOC) का मॉडलिंग मिट्टी कार्बन अनुक्रमण पर भूमि उपयोग और उसके प्रबंधन के प्रभाव का मूल्यांकन करने के लिए एक उपयुक्त तरीका है, जिसे प्रयोगात्मक काम के माध्यम से आकलन नहीं किया जा सकता है। वर्तमान अध्ययन का लक्ष्य है: 1) यह मूल्यांकन करने के लिए कि भूमि उपयोग में परिवर्तन और मौसम मिट्टी कार्बनिक कार्बन (SOC) के शेयरों को कैसे प्रभावित करता है, 2) रोथमस्टेड कार्बन मॉडल की मदद से वर्ष 2015 से अगले 30 वर्षों के लिए विभिन्न भूमि उपयोग में एसओसी का सिमुलेशन (RothC) कोलमैन और जेनकिन्सन (1996) और 3) द्वारा नियंत्रित प्रयोग द्वारा विभिन्न मिट्टी बनावट में एसओसी बनाए रखने की क्षमता पर विभिन्न उर्वरक उपचार के प्रभाव को निर्धारित करने के लिए। इन उद्देश्यों को प्राप्त करने के लिए चार अलग-अलग भूमि उपयोग, दिल्ली एनसीआर क्षेत्र के समान जलवायु क्षेत्र, संरक्षित वन (PF) और अरावली के दक्षिण केंद्रीय रिज के असुरक्षित वन (UPF) के तहत गिरने (28 डिग्री 32'00 "एन 77 डिग्री 10 ' 40 "ई) दिल्ली में वसंत कुंज और मेहरौली के पास और बुलंदहार में स्थित कार्बनिक खेती (OF) और केमिकल फार्मिंग (CF) क्षेत्र (उत्तरी भारत में उत्तर प्रदेश राज्य 28026'एन 770 50; ई), गाजियाबाद, यूपी के समन्वय में है भारत को एक वर्ष के तीन सत्रों में मिट्टी (0-30 cm) की ऊपरी परत में मिट्टी कार्बनिक कार्बन (SOC) और मिट्टी अकार्बनिक कार्बन (SIC) के विश्लेषण के लिए चुना गया था। मृदा

नमूने गर्मियों (मार्च), मॉनसून (जुलाई) और सर्दियों (दिसंबर) के मौसम में वर्ष 2015 के विभिन्न गहराई से 0-5, 5-10, 10-15, 15-20 और 20-30 cm में एकत्र किए गए थे। नतीजे से पता चला कि चार भूमि उपयोग के एसओसी के बीच सांख्यिकीय रूप से महत्वपूर्ण अंतर मौजूद है और यह सभी मौसमों में PF> UPF > OF > CF के आदेश का पालन करता है। सांख्यिकीय रूप से, कार्बनिक और रासायनिक खेती के क्षेत्रों के एसआईसी के बीच एक महत्वहीन अंतर देखा गया था लेकिन संरक्षित जंगल में एसआईसी सभी मौसमों में असुरक्षित जंगल की तुलना में काफी अधिक पाया गया था। सभी मौसमों में सभी भूमि उपयोग की मिट्टी में C/N अनुपात में सांख्यिकीय रूप से महत्वपूर्ण अंतर देखा गया था और यह PF> UPF > OF > CF के आदेश का पालन करता है। PF, UPF, OF & CF में 2015 में औसत SOC (t / ha) क्रमशः 97.78, 72.9 2, 65.40 और 40.15 के रूप में पाया गया था। भूमि के प्रति हेक्टेयर वातावरण में कार्बन डाइऑक्साइड का शुद्ध उत्सर्जन विभिन्न भूमि उपयोगों में एसओसी (t/ha) में अंतर के संदर्भ में गणना की गई थी। यह देखा गया था कि यदि PF का एक हेक्टेयर UPF में परिवर्तित हो जाता है, तो 91.24 टन कार्बन डाइऑक्साइड वायुमंडल में जारी किया जाएगा और यदि यह कृषि भूमि में परिवर्तित हो जाता है तो प्रबंधन प्रथाओं के आधार पर या तो CF क्षेत्र की मात्रा वायुमंडल में जारी की जाती है क्रमशः 118 टन और 211.50 टन होगा। इसी प्रकार यदि असुरक्षित वन का एक हेक्टेयर कृषि क्षेत्र में परिवर्तित हो जाता है तो OFऔर CF प्रबंधन प्रथाओं के प्रबंधन प्रथाओं के मुताबिक टन में वायुमंडल में जारी कार्बन डाइऑक्साइड क्रमशः 27.60 और 120.26 होगा और अगर एक हेक्टेयर क्षेत्र CF क्षेत्र में परिवर्तित हो जाता है वायुमंडल में जारी कार्बन डाइऑक्साइड की मात्रा 92.67 टन होगी। लेकिन सभी चार चयनित भूमि उपयोग में एसओसी, टीएन और सी / एन अनुपात में तीन मौसम (गर्मी, मानसून और सर्दी) में कोई महत्वपूर्ण अंतर नहीं देखा गया। एसओसी के अनुरूपित मूल्य सभी चार भूमि उपयोग के लिए मापा डेटा (R^2 = 0.96 से 0.97) के साथ अच्छी तरह से संबंधित हैं, मॉडलिंग त्रुटि (रूट माध्य वर्ग त्रुटि,% आरएमएस) को सतह परत में 2.65, 5.08, 3.90 से 5.32 के रूप में देखा गया था संरक्षित वन

पीएफ, यूपीएफ, ऑफ और सीएफ़ साइट क्रमशः RothC मॉडल की एक अच्छी दक्षता का संकेत देते हैं। नैश-सटक्लिफ मॉडल दक्षता गुणांक (E) जो मूल्यों का अनुमान लगाता है और मनाया जाता है और "-इफिनिटी" से "1" में भिन्न होता है, "E = 1" में सर्वश्रेष्ठ प्रदर्शन क्रमशः 0.64, -0.35, 0.65, 0.63 के रूप में पाया जाता है। सभी चार भूमि उपयोग के लिए। असुरक्षित वन के लिए 'ई' के नकारात्मक मूल्य अनुमानित मूल्य के अर्थ के साथ अनुमानित मूल्यों की कम समानता दर्शाते हैं, यह सभी पक्षों से घिरे असुरक्षित वन क्षेत्र के आसपास ठोस काम के कारण चयनित साइटों की गड़बड़ी के कारण हो सकता है जवाहरलाल नेहरू विश्वविद्यालय, दिल्ली द्वारा जो वन मिट्टी के प्राकृतिक जैविक संतुलन में अशांति का कारण बन सकता है। अगले 30 वर्षों के लिए अनुरूपित SOC स्टॉक के आधार पर, PF ने 14.63% की वृद्धि और UPF 4.82% की वृद्धि दर्ज की, 3.72 9% की वृद्धि हुई, लेकिन CF ने 2015 स्टॉक से 2045 में SOC स्टॉक में 9.06% की कमी देखी। नियंत्रित प्रयोगों के परिणाम से पता चलता है कि यदि हम रेतीले लोम, लोम या रेशमी मिट्टी की मिट्टी में कार्बनिक खाद से रासायनिक उर्वरक उपचार में स्थानांतरित करते हैं, तो एक हेक्टेयर कृषि भूमि से वायुमंडल में कार्बन डाइऑक्साइड रिलीज की अतिरिक्त मात्रा की संभावना 40.10, 40.21 होगी क्रमश: 40.62 टन। ये आंकड़े मात्रात्मक अनुमान देते हैं कि कैसे भूमि उपयोग और भूमि प्रबंधन मिट्टी के वातावरण में कार्बन के स्रोत के लिए मिट्टी के रूपांतरण को प्रभावित करता है।

कीवर्ड: - मृदा कार्बन अनुक्रम, मृदा कार्बनिक कार्बन, मृदा अकार्बनिक कार्बन, कार्बन चक्र, कार्बनिक खाद, रासायनिक उर्वरक।

Contents

	Certificate	I
	Acknowledgements	Iii
	Abstract	V
	List of Figures	Xii
	List of Tables	Xv
	Acronyms and Abbreviations	Xviii
CHAPTER 1	INTRODUCTION	1
1.1	Background	1
1.2	Carbon Sequestration Potential of Soil	2
1.3	Basic Mechanism behind increasing Carbon residence time	4
1.4	Promising Technologies and Methodology for Soil carbon sequestration	5
1.4.1	Improvement of Soil Carbon Sequestration by adding Fly Ash	5
1.4.2	By Recommended Management Practices of agriculture	5
1.4.3	Through adopting Biotechnology	7
1.4.4	Biomass Carbonization	8
1.4.5	Deep-Soil Sequestration	9
1.5	Motivation for the Study	10
1.6	Objective of the study	11
1.7	Thesis organization	12

CHAPTER 2	LITERATURE REVIEW	13
2.1	Overview of Literature	13
2.2	Sequestration of Carbon	13
2.3	Sequestration of carbon in Soil	16
2.4	Carbon Cycle in Soil	17
2.5	Carbon pool in Indian soil	18
2.6	Land-use change and Soil carbon dynamics	20
2.7	Root Activity and Soil Carbon Sequestration	24
2.8	Soil Carbon Fractions and Stability	25
2.9	Soil carbon modelling	27
2.10	RothC model and its performance in short-term and long term experiments	34
2.11	Effects of different fertilizer treatment on SOC retaining capacity	36
2.12	Gap in previous studies	40
CHAPTER 3	STUDY OF EFFECT OF LAND USE CHANGES ON SOIL ORGANIC CARBON RETAINING CAPACITY IN DELHI NCR	41
3.1	Introduction	41
3.2	Material and Methods	43
3.2.1	Study Area	43
3.2.2	Climate	46
3.2.3	Soil Sampling and Analysis	47
3.3	Result and Discussion	52
3.3.1	Effect of Land Use and Soil Depth on SOC Stock	52
3.3.2	Effect of Land Use and Soil Depth on SIC Stock	60

3.3.3	Effect of Land Use and Soil Depth on TN and C/N ratio	65
3.3.4	Effect of Land Use and Soil Depth on pH and EC	74
3.3.5	Effect of Land use changes on emission of carbon dioxide gas from soil	82
3.3.6	Effect of Seasons on soil pH in different land use	83
3.3.7	Effect of Seasons on soil EC in different land use	88
3.4	Conclusions	92
CHAPTER 4	SIMULATION OF SOIL ORGANIC CARBON STOCK AS AFFECTED BY LAND USE AND MANAGEMENT PRACTICE: A CASE STUDY OF DELHI NCR	93
4.1	Introduction	93
4.2	Methodology	94
4.2.1	Description of the area of study	94
4.2.2	Model description and evaluation	94
4.2.3	Initialization and Calibration of the model	96
4.2.4	Estimation of model execution	98
4.3	Result and Discussion	99
4.3.1	Model performance in all four selected land use sites of Delhi NCR	99
4.3.2	Development of SOC stock on four selected land use sites	103
4.4	Conclusion	109
CHAPTER5	EFFECT OF DIFFERENT FERTILIZER TREATMENT AND SOIL TEXTURE ON THE EMISSION OF CO2 IN THE ATMOSPHERE FROM THE SOIL	111
5.1	Introduction	111

5.2	Material and methods	112
5.2.1	Experimental setup	112
5.2.2	Fertilization treatment and management	113
5.2.3	Soil sampling and analysis	114
5.2.4	Statistical analysis	114
5.3	Result and discussion	115
5.3.1	Influence of different fertilization modes and soil texture on the percentage change of TOC	115
5.3.2	Influence of different fertilization modes on the percentage change of TN pool	121
5.3.3	Relationship between change of TOC and change in TN	124
5.3.4	Influence of Different Fertilizer Treatment and TN on percentage change in TOC	128
5.4	Experimental Limitation	130
5.5	Conclusion	130
CHAPTER 6	SUMMARY AND MAJOR FINDINGS	133
6.1	Summary and Conclusions	133
6.2	Scope of Future Work	134
6.3	Contribution of the work to overall body of knowledge for the profession	134
	REFRENCES	135
	PUBLICATION	
	BIO DATA	

LIST OF FIGURES

Figure no.	Title	Page no
1.1	Total global annual flux of carbon in gigatons (billions of tons) through the most biologically active pools (as compared to the deep-ocean and lithosphere)	3
2.1	The global annual carbon cycle	16
2.2	Carbon cycle in soil	17
2.3	Paths engrossed in soil organic carbon dynamics	22
2.4	Combined density fractionation procedure of SOC	27
2.5	Structure of an organism-oriented model (detrital food-web model, the model exemplifies the food-web at the Lovinkhoeve experimental farm	28
2.6	Conceptual pools and fluxes often used in process-oriented SOM models	29
3.1	Pictures of the Study area: a) chemical farming field (CF), b) organic farming field (OF), c) protected forest and d) unprotected forest (UPF) in Delhi NCR.	46
3.2	Sampling and collections of soil samples from the site of study area.	48
3.3	Soil texure chart	49
3.4	Instruments (a) Shimadzu solid sample module, Model: SSM-5000A; TOC analyser; (b) TKN analyser	50
3.5	Average percentages SOC in different Land use in different soil depth in the three seasons: (a) Summer season, (b) Monsoon season and (c) Winter season in the year 2015.	58
3.6	Average percentage SIC in different Land use in different soil depth in the three seasons: (a) Summer season, (b) Monsoon season and (c) Winter season.	65

3.7	Average percentage TN and C/N ratio in different Land use in different soil depth in the three seasons: (a) Summer season (b) Monsoon season and (c) Winter season in 2015	70
3.8	Average pH and EC in the various land use in 0-5cm, 5-10cm, 10-15cm, 15-20cm, 20-30cm depth in the three seasons: (a) Summer season, (b) Monsoon season and (c) Winter season in the year 2015.	80
3.9	Seasonal variations in Soil pH in different land use in different soil depth. (a) Organic Farming (OF), (b) Chemical Farming (CF), (c) Protected Forest (PF) and (d) Unprotected Forest (UPF) in the year 2015.	86
3.10	Seasonal variations in soil EC in different land use in different soil depth. (a)Organic Farming (OF), (b) Chemical Farming (CF), (c) Protected Forest (PF) and (d) Unprotected Forest (UPF) in the year 2015.	91
4.1	Variation in the amount of soil organic carbon (0–30 cm) between observed and modeled values by the Roth C model at the different land use of Delhi NCR. (a) Organic farming, (b) Chemical Farming, (c) Protected forest and (d) Unprotected forest.	103
4.2	Development of average values of simulated SOC stock (tons/hectare) during modeling period on the selected four land use sites of Delhi NCR	106
5.1	Steps showings the experimental setup of the controlled experiments	113
5.2	Average percentage changes in TOC in different fertilizer treatment in different soil depth in (a) Loamy soil, (b) Sandy Loam soil and (c) Silty Clay soil. Error bars represent standard deviation. Each value refers to mean +/- SD (n=3).	120

5.3 Average percentage changes in TOC in different soil texture in different soil depth. Each value refers to mean +/- SD (n=3). 120

5.4 Average percentage change in TN (g/kg) in different fertilizer treatment in different soil depth in (a) Loamy soil, (b) Sandy Loam soil and (c) Silty Clay soil. 123

5.5 Average percentage change in TN in different soil texture in different soil depth 124

5.6 Regression Analysis of Change in TN in relation with percentage change in TOC(a) OM treatment, (b) CF treatment, (c) 7OM:3CF treatment, (d) 5OM:5CF treatment, (e) 3OM:7CF treatment and (f) CK treatment. Each value refers to mean +/- SD (n=15). 127

List of Tables

Table no.	Title	Page no.
2.1	Methods of SOC fractionation	26
2.2	Main characteristics of processes-oriented versus organism-oriented models	30
2.3	Main characteristics of the most frequently referred to models in the scientific literature	32
3.1	Average monthly air temperature, monthly rainfall, and evaporation in the year 2015 in the study area of Delhi NCR	51
3.2	Soil Characteristics of four selected land use sites of Delhi NCR in the year 2015	52
3.3	Average percentage SOC in various land use in 0-5, 5-10, 10-15, 15-20, and 20-30cm depth in the summer, monsoon and winter season in 2015	56
3.4	Analysis of ANOVA Two-Factor without Replication for variation in SOC in various Land use and in various depth in summer, monsoon and winter seasons in the year 2015	58
3.5	Average value of SOC (t/ha) in various Land use of Delhi NCR region in the year 2015	60
3.6	Average percentage SIC in various land use in 0-5cm, 5-10cm, 10-15cm, 15-20cm, 20-30cm depth in the summer, monsoon and winter season in the year 2015.	62
3.7	Analysis of ANOVA Two-Factor without Replication for variation in SIC in various land use and in various depth in summer, monsoon and winter Seasons	63
3.8	Average TN (g/kg) in various lands in various depth in the summer, monsoon and winter season in the year 2015	71

3.9	Average C/N ratio in the summer, monsoon and winter season in various land in the year 2015	72
3.10	Analysis of ANOVA Two-Factor without Replication for variation in TN in various land use and in various depth in summer, monsoon and winter seasons in the year 2015	73
3.11	Analysis of ANOVA Two-Factor without Replication for variation in C/N ratio in various land use and in various depth in summer, monsoon and winter seasons in the year 2015	74
3.12	Average pH in the various land use in 0-5, 5-10, 10-15, 15-20, and 20-30cm depth in the summer, monsoon and winter seasons in the year 2015	76
3.13	Average EC in the various land use in 0-5, 5-10, 10-15, 15-20, and 20-30cm depth in the summer, monsoon and winter season in the year 2015	77
3.14	Analysis of ANOVA Two-Factor without Replication variation in pH in various land use and in various depth in summer, monsoon and winter Seasons in the year 2015	81
3.15	Analysis of ANOVA Two-Factor without Replication for variation in EC in various land use and in various depth in summer, monsoon and winter seasons in the year 2015	82
3.16	CO2 emission from soil due to land use changes	83
3.17	Analysis of ANOVA Two-Factor without Replication for seasonal variation in pH in various Land use and in various depth of soil in the year 2015	87
3.18	Analysis of ANOVA Two-Factor without Replication for seasonal variation in EC in various Land use and in various depth in the year 2015	91
4.1	Initial Soil Condition of the all four land use in March 2015	98
4.2	Model performance in simulating SOC (t/ha) of four land use of Delhi NCR.	101
4.3	Simulated SOC (t/ha)of four land use sites of Delhi NCR	104
4.4	Percentage change in SOC in first, second and third decades	104

4.5	Degradations of SOC (tons/hectare) by land use conversion in coming 30 years	105
4.6	Model output representing total SOC (t/ha) from the year 2015 to 2045	107
4.7	Different fraction of SOC (t/ha) in the four land use site during the simulation period	108
5.1	Physical characteristics of three texture of the soil	115
5.2	pH and EC of soil subjected to different fertilizer treatment	115
5.3	Anova: Two-Factor with replication showing variation in TOC due to soil texture and fertilizer treatment	117
5.4	Fertilization induced changes in the percentage of Total Organic Carbon (TOC) in the various depth of soil in three soil texture	118
5.5	Two-Factor With Replication showing variation in TN due to soil texture and Fertilizer treatment	121
5.6	Fertilization induced percentage changes in the of Total Nitrogen (TN) in g/kg in various soil depth in three soil texture	122
5.7	Table of regression model showing the relationship of TN with respect to TOC in the soil	128
5.8	Table of the regression model with eight explanatory variables taking Manure treatment as the reference in Fertilizer treatment variables and Sandy Loam soil in texture variable	129
5.9	Tons of CO_2 released in atmosphere per hectare of farm if we shift from Manure	130

ACRONYMS AND ABBREVIATIONS

Abbreviation/Acronym	Definition
Avg :	Average
C :	Carbon
CF :	Chemical Fertilizer
CK :	Check, without any fertilizer treatment
CO_2 :	Carbon di Oxide
E :	The Nash-Sutcliffe model efficiency coefficient
FAO :	Food and Agriculture Organization
GHG :	Green House Gas
INM :	Integrated Nutrient Management
NCR :	National Capital Region
OM :	Organic Manure
PF :	Protected Forest
RothC :	Rothamsted Carbon
SD :	Standard Deviation
SE :	Standard Error
SIC :	Soil Inorganic Carbon

SOC :	Soil Organic Carbon
TN :	Total Nitrogen
TOC :	Total Organic Carbon
UPF :	Unprotected Forest