

SOIL CARBON POOLS UNDER DIFFERENT LANDUSE AND MANAGEMENT SYSTEMS IN THE TERAI REGION OF WEST BENGAL (INDIA)

*Thesis
Submitted to
VISVA-BHARATI
in partial fulfillment of the requirement for the degree of
Doctor of Philosophy*

by

DIPANKAR PAL

Registration No.: VB-1640 of 2012-13



**DEPARTMENT OF ENVIRONMENTAL STUDIES
SIKSHA-BHAVANA (INSTITUTE OF SCIENCE), VISVA-BHARATI
SANTINIKETAN, WEST BENGAL-731235, INDIA
2017**

*Dedicated
to
my beloved parents*

आचार्य
श्री नरेंद्र मोदी

ACHARYA (CHANCELLOR)
SHRI NARENDRA MODI

उपाचार्य
प्रो. स्वपन कु. दत्ता

UPACHARYA (VICE-CHANCELLOR) (Offig.)
PROF. SWAPAN K. DATTA

विश्वभारती VISVA-BHARATI

(Established by the Parliament of India under
Visva-Bharati Act XXIX of 1951
Vide Notification No. : 40-5/50 G.3 Dt. 14 May, 1951)

संस्थापक
रबीन्द्रनाथ ठाकुर
FOUNDED BY
RABINDRANATH TAGORE



शान्तिनिकेतन - 731235
SANTINIKETAN - 731235
जि.वीरभूम, पश्चिम बंगाल, भारत
DIST. BIRBHUM, WEST BENGAL, INDIA
फोन Tel: +91-3463-262 451/261 531
फैक्स Fax: +91-3463-262 672
ई-मेल E-mail: visva-bharati@visva-bharati.ac.in
Website: www.visva-bharati.ac.in

सं./No. _____

दिनांक/Date. _____

CERTIFICATE

This is to certify that the research work embodied in the thesis titled "**Soil Carbon Pools under Different Landuse and Management Systems in the Terai Region of West Bengal (India)**" submitted for the degree of Doctor of Philosophy in Environmental Science, to the Visva-Bharati has entirely been carried out by Mr. Dipankar Pal (Registration no. VB-1640 of 2012-13) on his own. The work is an original one and has not been submitted in part or in full, for any other Degree or Diploma.

The results reported in the thesis are genuine, script of the thesis has been written by the candidate himself and the help and assistance received various sources during the course of this investigation have been duly acknowledged.

This is also certified that Mr. Dipankar Pal presented his Pre-Ph.D Seminar on 10.02.2017 and the points raised by the external experts and the members of the Board of Studies in the Department of Environmental Studies, Siksha-Bhavana, Visva-Bharati, Santiniketan have been incorporated in the thesis.

Dibyendu Mukhopadhyay
Dr. Dibyendu Mukhopadhyay
(Co-supervisor)
Professor
Department of Soil Science and
Agricultural Chemistry
Uttar Banga Krishi Viswavidyalaya
Pundibari, Cooch Behar

Pulak Kumar Patra
Dr. Pulak Kumar Patra
(Supervisor)
Assistant Professor
Department of Environmental Studies,
Visva-Bharati

Shibani Chaudhury
Prof. Shibani Chaudhury
Head, Department of Environmental Studies
Visva-Bharati

DECLARATION

I hereby declared that the thesis entitled “**Soil carbon pools under different landuse and management systems in the Terai region of West Bengal (India)** ” which I am submitting for the partial fulfillment of Doctor of Philosophy to the Visva-Bharati, Santiniketan is an original work carried out by me, at the Department of Environmental Studies, Siksha Bhavana (Institute of Science), Visva-Bharati, Santiniketan and at Uttar Banga Krishi Viswavidyalaya, Pundibari, Coochbehar under the supervision of Dr. Pulak Kumar Patra, Assistant Professor, Department of Environmental Studies, Visva-Bharati and co-supervision of Dr. Dibyendu Mukhopadhyay, Professor, Department of Soil Science and Agricultural Chemistry, Uttar Banga Krishi Viswavidyalaya. I further declare that this work has not been submitted earlier to this or to any other University and does not form the basis for the award of any other degree or diploma.

Place: Santiniketan

Date: 21.09.2017

Dipankar Pal
Dipankar Pal

PREFACE

Carbon sequestration is of great importance to sustainable agriculture and for controlling global climate change. Conversion of land can change Soil Organic Carbon (SOC) due to the perturbation of soil. Increasing SOC storage in the subsoil layers constitutes a major portion of C-sequestration in the soil profile. Soil can act as source and sink of the atmospheric C depending on landuse, cropping system and management practices. Loss of SOC often occurs under tillage practices for mixing in surface residues and by raising the turnover rates. The SOC in the top soil is prone to rapid perturbations and decomposition by the increased near surface microbial activity and high fluctuations in soil temperature and moisture, whereas, the amount of SOC stored in deeper layers is the most important fraction for long term SOC sequestration.

Based on the background as mentioned, the experiments were undertaken with the following objectives-

1. To determine the forms of carbon pools of the soils of different landuse system under *Terai* region of West Bengal.
2. To delineate the distribution of forms of carbon under different land use pattern by the Geographical Information System (GIS) tools.
3. To determine soil nutrients, carbon pools and yields under different treatment and practices in experimental field.
4. To assess the important environmental factors governing the forms of carbon in soils.

A study under four different eco-systems (forest, agricultural land, tea garden and fallow land) was conducted under *Terai* situation of West Bengal to characterise the soils with important physico-chemical properties, and determining the fractions of soil carbon (Labile Carbon, Particulate Organic Carbon, Oxidisable Organic Carbon etc.) with the increasing soil depth (0-20 cm, 20-40 cm, 40-60 cm) by using the standard methods.

It was observed that the available N-P-K and the exchangeable (Ca^{2+} , Mg^{2+}), electrical conductivity (EC), carbon fractions in soils significantly varied with the depth of soil as well as landuse patterns in most of the cases.

It was also found that Oxidisable Organic Carbon was relatively higher in forest soils compare to that of agricultural lands. The labile carbon (LC) content of forest soils was also

higher compare to other soils collected from various landuse/ land cover. The particulate organic carbon (POC) and labile carbon fractions of tea garden soils were in between that of forest soils and agricultural soils. It was also identified that there were differences in depthwise distribution of the same carbon fractions under various landuse.

Mapping of forms of carbon under different landuse pattern in *Terai* region of West Bengal have been computed using ArcGIS,R software packages. Assessment of the important environmental factors like temperature, humidity, rainfall governing the forms of carbon in soils were also studied during field experiments.

Besides these, a study was undertaken at the Instructional farm of Uttar Banga Krishi Viswavidyalaya, Pundibari, Coochbehar with wheat (Cv. K1006) to determine the different pools of carbon, N-P-K, yield attributes and yield with respect to two different (Zero-tillage and Conventional tillage) management practises under different inputs (paddy straw, farm yard manure, control) during 2014-15 to 2015-16.

Because of the logarithmic nature of carbon with depth, the majority of the carbon fractions were found above 40 cm depth containing most of the labile carbon sources for more accessible to microbial decomposition, while the soil at depth being relatively old were least influenced by management practices as found at the surface. The carbon fractions were dominant at forest and tea garden than the cultivated and fallow land areas.

In a separate experiment with wheat (*Triticum aestivum* L.), it was observed that the continuous rice-wheat cropping with balanced fertilisation(N-P-K) along with carbon input caused significant carbon build-up in the soil in both tillage system. The relative efficacy of the amendments for SOC building was more in Farm Yard Manure (FYM) than the paddy straw (PS). Organic carbon and labile pool of OC input supplemented through FYM and PS played significant role on the crop yield. The results indicates that of all treatments tested, balanced N-P-K fertilisation along with an adequate amount of FYM following zero tillage management was most suitable for the continuous rice-wheat cropping system for improving the SOC stock and sustaining crop productivity.

Soil carbon, available nutrients and yield were higher (61.52 kg ha⁻¹) in zero tillage system compare to conventional tillage (59.02 kg ha⁻¹) system. Application of decomposed paddy straw and farmyard manure showed higher carbon and nutrient addition in both tillage system.

Rainfall, temperature and relative humidity were minimum during cropping period (November to March) comparison to May to July in both the year of experiment.

Balance of CO₂ under different treatment (T₁ to T₉) was different on leaf temperature and relative humidity. It was observed that zero tillage operation had better balance in CO₂-in and CO₂-out from leaf during photosynthesis compare to conventional tillage.

Results from the study showed that carbon sequestration and yields were higher in zero-tillage practices than that of conventional tillage practices indicating the management practices to be adopted for better carbon sequestration in soils.

This research work will also help farmers to motivate and to adopt conservation tillage or reduced tillage practices with organic inputs in the agricultural field to achieve sustainable agriculture. Mapping on soil fractions under conservation tillage will enlight in the global carbon stock under different eco systems.

ACKNOWLEDGEMENT

With profound sense of gratitude I place my regards to all my teachers and all my family members who stand with their belief in me with constant love and affection.

*With profound privilege I say my sincere thanks to my supervisor and guide **Dr. Pulak Kumar Patra**, Assistant Professor, Department of Environmental Studies, Siksha-Bhavana, Visva-Bharati, Santiniketan, Birbhum, West Bengal for his noble supervision, valuable suggestions, ever encouraging inspirations and reverence to fall in judiciously with him for his full dedication to my work. His diverge knowledge and keen interest in research has always encouraged and motivated to work with.*

*It is of immense pleasure to me to express my deepest sense of gratitude to the co-supervisor, advisor, mentor **Professor Dibyendu Mukhopadhyay**, Professor, Department of Soil Science and Agricultural Chemistry, Uttar Banga Krishi Viswavidyalaya, Pundibari, Coochbehar, West Bengal for his sagacious guidance, full dedication to my work and pain staking efforts. His close monitoring and encouragement made the work complete in time and with perfection. I feel proud being a scholar under the guidance of such a learned person.*

*I am highly grateful to **Dr. Shibani Chaudhury**, Professor, **Dr. Pratap Kumar Padhy**, Associate Professor, **Dr. S. Balachandran**, Assistant Professor, Department of Environmental Studies, Siksha-Bhavana, Visva-Bharati, Santiniketan, Birbhum, West Bengal for their support and encouragement.*

*I render my heartfelt thanks and obligation to **Dr. Amarendra Nath Dey**, Associate Professor, Department of Forestry and **Professor Apurba Kumar Chowdhury**, Department of Plant Pathology, Uttar Banga Krishi Viswavidyalaya, Pundibari, Coochbehar for their inexplicable support.*

*I consider this opportunity to express my sincere and profound gratitude to **Dr. Mrigendra Ghosh**, Director of Farms (Actg.) and **Mr. Prafulla Kumar Paul**, Incharge, Central Library, Uttar Banga Krishi Viswavidyalaya, Pundibari, Coochbehar for providing uncountable help for the success of my thesis.*

*I sincerely acknowledge **Professor Sumit Chakravarty**, **Dr. Gopal Shukla** and **Dr. Nazir Ahmed Pala**, Assistant Professor, Department of Forestry and **Mr. Niles Bhowmick**, Department of Pomology and Post Harvest*

Technology, Uttar Banga Krishi Viswavidyalaya, Pundibari, Coochbehar for their kind co-operation and helpful suggestions all the way to my thesis.

I would like to thank **Dr. Prahlad Deb** (Assistant Professor, Department of CEHAB, Palli Siksha Bhavana, Visva-Bharati) for his help during the course of study and research work.

I also sincerely acknowledge **Professor Ashok Choudhury**, Director of Research (Actg.) and **Professor Subhendu Bandyopadhyay**, Department of Agronomy, Uttar Banga Krishi Viswavidyalaya, Pundibari, Coochbehar for their kind support all the way of my thesis.

I consider this opportunity to express my sincere gratitude to the **Chief Conservator of Forests, Wildlife & Biodiversity & Chief Wildlife Warden, Director of Forests, Govt. of West Bengal** for according permission to conduct the research work in the forests of Terai region of West Bengal.

I will be happy to mention the support and co-operation received from **Anarul Hoque, Parimal Panda, Kausik Mandal, Subhendu Das, Mijanur Rahaman, Bappa Pramanik, Biswajit Majumdar, Suman Samanta, Indranil Bhui, Suraj Ghosh, Sk. Mahim Ali**, who have always been beside me whenever I needed them and also I would like to thank them for being a part of my life.

I would like to thank all support staff of Department of Environmental Studies, Visva-Bharati, all support staff of Farm and Examination section of Uttar Banga Krishi Viswavidyalaya, Pundibari, Coochbehar for their contribution.

I would like to thank my whole family for their love and prayer throughout the period of my study. I am obliged for their motivation, sacrifice and support during the course of this endeavour and to remember the faces behind the task with a sense of gratitude to my mother, **Smt. Basanti Pal**, my wife **Smt. Shibani Pal** and my son **Debapratim Pal** who always gave my efforts necessary support and encouragement.

I am indebted to so many people that a complete acknowledgement would be an encyclopedia and hence is not possible in this short circumstances but none has been forgotten.

Lastly, I want to thank Almighty God for blessing me.

Date: 21.09.2017
Place: Santiniketan

Dipankar Pal
Dipankar Pal

CONTENTS

Chapter	Particulars	Page No.
1.	INTRODUCTION	1-9
1.1	Introduction	1-1
1.2	Objectives	7-7
2.	REVIEW OF LITERATURE	10-60
2.1	Carbon Pools	10-11
2.2	Soil Carbon Pools	11-13
2.3	Soil Carbon and landuses	13-15
2.3.1	Soil Carbon in forest soils	15-17
2.3.2	Soil carbon in agricultural soils	17-19
2.3.3	Soil carbon in fallow land	19-21
2.3.4	Soil carbon in tea garden	21-25
2.4	Factors affecting soil carbon pools	25-25
2.4.1	Tillage practices and change in soil carbon	25-25
2.4.2	Soil aggregate and soil carbon	25-26
2.4.3	Influence of cropping system	26-27
2.5	Physicochemical properties	27-28
2.6	Soil carbon in relation to soil depth	28-30
2.7	Carbon fractions of soil	30-32
2.7.1	Soil Organic Carbon	32-35
2.7.2	Particulate Organic Carbon	35-37
2.7.2.1	Management effects on particulate organic matter	37-38
2.7.3	Soil Mineralisable Carbon	38-39
2.7.3.1	Carbon fractions and soil respiration	40-41
2.7.3.2	Land use and C-mineralization	41-42
2.7.4	Labile Carbon	42-43
2.7.5	Soil Inorganic Carbon	44-45
2.7.6	Total Organic Carbon	45-45
2.8	Distribution of Soil Carbon	45-45
2.8.1	GIS mapping of Carbon pools	46-47
2.8.2	Spatial distribution of soil carbon	47-49
2.9	Management Influence on Carbon Storage	49-51
2.9.1	Tillage effect on Carbon sequestration	51-53
2.9.2	Carbon storage under different Treatment	53-54
2.10	Soil Carbon Pools and environmental effect	54-54
2.10.1	Temperature effect	55-57
2.10.2	Humidity effect	58-58
2.10.3	Rainfall effect	59-60
3.	MATERIALS AND METHODS	61-79
3.1	Materials	61-61
3.1.1	Soils under study and their collection	61-64
3.1.2	Soil sampling	64-65
3.1.3	Laboratory Instruments/Equipments:	65-66
3.1.4	Chemicals	66-66
3.2	Methods	66
3.2.1	Physico-chemical properties of soil	66-67
3.2.2	Carbon Fractions	67-67

Chapter	Particulars	Page No.
3.2.2.1	Oxidisable Organic Carbon (SOC)	67-67
3.2.2.2	Particulate Organic Carbon (POC)	68-68
3.2.2.3	Soil Inorganic Carbon (SIC)	68-68
3.2.2.4	Mineralizable Carbon (MC)	68-68
3.2.2.5	Labile Carbon (LC)	68-68
3.2.2.6	Total Organic Carbon (TOC)	69-69
3.3	Carbon Mapping	69
3.4	Field Experiment	69-70
3.4.1	Materials	70-70
3.4.1.1	Experimental site	70-70
3.4.1.2	Experimental soil	70-70
3.4.1.3	Cropping History of Experimental Plot	70-70
3.4.1.4	Test crop and varieties	70-70
3.5	Details of Experiment	71-71
3.5.1	Details about experiment	71-71
3.5.2	Calendar of operations	73-75
3.5.3	Collection of soil samples	76-76
3.5.4	Details of operation	76-77
3.5.4.1	Collection of soil samples	77-77
3.5.4.2	Methods of recording biometric observations	77-77
3.6	Growth parameters	77-77
3.7	Yield attributing characteristics	77-78
3.8	Yield	78-79
3.9	Meteorological observation	79-79
3.10	Observation of IRIGA	79-79
4.	RESULTS AND DISCUSSION	80-158
4.1	Characterization of soils under study	80-80
4.1.1	Forest ecosystems	80-81
4.1.2	Agricultural land	81-82
4.1.3	Tea garden	82-82
4.1.4	Fallow land	82-83
4.2	Carbon fractions under different landuse systems	92-92
4.2.1	Carbon fractions at forest soils	92-92
4.2.2	Carbon fractions at cultivated lands	92-92
4.2.3	Carbon fractions at fallow lands	92-92
4.2.4	Carbon fractions at Tea gardens	92-92
4.3	Effect of Land-use on Different Carbon Fractions in Soils	97-98
4.4	Distribution of soil carbon fractions and GIS mapping	98-99
4.5	Effect of tillage and organic residues on carbon fractions of soil and yield of wheat	107-116
4.5.1	Yield attributing characteristics	141-142
4.5.2	Uptake of N-P-K in plant	145
4.5.3	Changes of temperature and relative humidity during the crop growth period	152
4.5.4	Effect of treatment on CO ₂ balance	152
5.	Summary and Conclusion	159-163
6.	Future Scope of Research	164
7.	References	I-XLIII

LIST OF TABLES

Table No.	Title	Page No.
1	Geographical Locations of the collected soil samples	62
2	Important properties of soils under the Forest ecosystem	84
3	Important properties of soils under the Agro- ecosystem	85
4	Important properties of soils under the Fallow land situation	86
5	Important properties of soils under the Tea gardens	87
6	Interactions among soil properties and different ecosystems	88
7	Correlation coefficients among different soil properties and nutrient pools	90
8	Oxidizable organic carbon of soils under the forest ecosystem	93
9	Oxidizable organic carbon of soils under the cultivated ecosystem	94
10	Oxidizable organic carbon of soils under the fallow land ecosystem	95
11	Oxidizable organic carbon of soils under the tea gardens ecosystem	96
12	Labile and recalcitrant carbon pools of soils under the fallow land ecosystem	100
13	Labile and recalcitrant carbon pools of soils under the cultivated ecosystem	100
14	Labile and recalcitrant carbon pools of soils under the forest ecosystem	101
15	Labile and recalcitrant carbon pools of soils under the tea gardens ecosystem	101
16	The Physico-Chemical properties of the field experimental soils	117
17	Effect on treatment on available nitrogen in soil at CRI stage of wheat under different tillage methods	118
18	Effect on treatment on available nitrogen (pool over practice) in soil at CRI stage of wheat under different tillage methods	118
19	Effect on treatment on available phosphorus in soil at CRI stage of wheat under different tillage methods	119
20	Effect on treatment on available phosphorus(pool over practice) in soil at CRI stage of wheat under different tillage methods	119
21	Effect on treatment on available potassium in soil at CRI stage of wheat under different tillage methods	120
22	Effect on treatment on available potassium(pool over practice) in soil at CRI stage of wheat under different tillage methods	120
23	Effect on treatment on available nitrogen in soil at flowering stage of wheat under different tillage methods	121
24	Effect on treatment on available nitrogen (pool over practice) in soil at flowering stage of wheat under different tillage methods	121
25	Effect on treatment on available phosphorus in soil at flowering stage of wheat under different tillage methods	122
26	Effect on treatment on available phosphorus (pool over practice)in soil at flowering stage of wheat under different tillage methods	122
27	Effect on treatment on available potassium in soil at flowering stage of wheat under different tillage methods	123
28	Effect on treatment on available potassium (pool over practice) in soil at flowering stage of wheat under different tillage methods	123
29	Effect on treatment on available nitrogen in soil at milking stage of	124

Table No.	Title	Page No.
	wheat under different tillage methods	
30	Effect on treatment on available nitrogen (pool over practice) in soil at milking stage of wheat under different tillage methods	124
31	Effect on treatment on available phosphorus in soil at milking stage of wheat under different tillage methods	125
32	Effect on treatment on available phosphorus (pool over practice) in soil at milking stage of wheat under different tillage methods	125
33	Effect on treatment on available potassium in soil at milking stage of wheat under different tillage methods	126
34	Effect on treatment on available potassium (pool over practice) in soil at milking stage of wheat under different tillage methods	126
35	Effect on treatment on available nitrogen in soil at harvest stage of wheat under different tillage methods	127
36	Effect on treatment on available nitrogen (pool over practice) in soil at harvest stage of wheat under different tillage	127
37	Effect on treatment on available phosphorus in soil at harvest of wheat under different tillage methods	128
38	Effect on treatment on available phosphorus (pool over practice) in soil at harvest of wheat under different tillage methods	128
39	Effect on treatment on available potassium in soil at harvest of wheat under different tillage methods	129
40	Effect on treatment on available potassium (pool over practice) in soil at harvest of wheat under different tillage methods	129
41	Effect on treatment on organic carbon in soil at CRI stage of wheat under different tillage methods	130
42	Effect on treatment on organic carbon (pool over practice) in soil at CRI stage of wheat under different tillage methods	130
43	Effect on treatment on labile carbon in soil at CRI stage of wheat under different tillage methods	131
44	Effect on treatment on labile carbon (pool over practice) in soil at CRI stage of wheat under different tillage methods	131
45	Effect on treatment on organic carbon in soil at flowering stage of wheat under different tillage methods	132
46	Effect on treatment on organic carbon (pool over practice) in soil at flowering stage of wheat under different tillage methods	132
47	Effect on treatment on labile carbon in soil at flowering stage of wheat under different tillage methods	133
48	Effect on treatment on labile carbon (pool over practice) in soil at flowering stage of wheat under different tillage methods	133
49	Effect on treatment on organic carbon in soil at milking stage of wheat under different tillage methods	134
50	Effect on treatment on organic carbon (pool over practice) in soil at milking stage of wheat under different tillage methods	134
51	Effect on treatment on labile carbon in soil at milking stage of wheat under different tillage methods	135
52	Effect on treatment on labile carbon (pool over practice) in soil at milking stage of wheat under different tillage methods	135
53	Effect on treatment on organic carbon in soil at harvest of wheat	136

Table No.	Title	Page No.
	under different tillage methods	
54	Effect on treatment on organic carbon (pool over practice) in soil at harvest of wheat under different tillage methods	136
55	Effect on treatment on labile carbon in soil at harvest of wheat under different tillage methods	137
56	Effect on treatment on labile carbon (pool over practice) in soil at harvest of wheat under different tillage methods	137
57	The status of nutrients (N-P-K) under different tillage operations of plant	138
58	Residual status of N-P-K, Organic Carbon and Labile Carbon in soil under different tillage operations	140
59	Effect of different treatments on yield attributes(CT) of wheat crop at first and second year	143
60	Effect of different treatments on yield attributes(ZT) of wheat crop at first and second year	143
61	Effect of different treatments on yield attributes (CT) of wheat crop at first and second year	144
62	Effect of different treatments on yield attributes (ZT) of wheat crop at first and second year	144

LIST OF FIGURES

Figure No.	Title	Page No.
1	Layout of the experiment	72
2	Change in available N-P-K with different ecosystems	91
3	Inorganic Carbon fractions in soils under different landuse systems.	102
4	Mineralisable carbon fractions in soils under different landuse systems.	102
5	The GIS mapping of the carbon fractions under different land use situation showing the distribution of the oxidisable organic carbon .	104
6	The GIS mapping of the carbon fractions under different land use situation showing the distribution of the inorganic, active carbon and POC of soils.	105
7	The GIS mapping of the mineralisable carbon fractions under different land use situation.	106
8	The status of nutrients (N-P-K) under different tillage operations of plant	139
9	Residual status of N-P-K, Organic Carbon and Labile Carbon in soil under different tillage operations	139
10	Total organic carbon during second year under conventional and zero tillage at harvest of wheat	146
11	Uptake of nitrogen in stem of wheat at CRI stage under conventional and zero tillage practices.	146
12	Uptake of phosphorus in stem of wheat at CRI stage under conventional and zero tillage practices.	146
13	Uptake of potassium in stem of wheat at CRI stage under conventional and zero tillage practices.	147
14	Uptake of nitrogen in stem of wheat at flowering stage under conventional and zero tillage practices.	147
15	Uptake of phosphorus in stem of wheat at flowering stage under conventional and zero tillage practices.	147
16	Uptake of potassium in stem of wheat at flowering stage under conventional and zero tillage practices.	148
17	Uptake of nitrogen in stem of wheat at milking stage under conventional and zero tillage practices.	148
18	Uptake of phosphorus in stem of wheat at milking stage under conventional and zero tillage practices.	148
19	Uptake of potassium in stem of wheat at milking stage under conventional and zero tillage practices.	149
20	Uptake of nitrogen in stem of wheat at harvest under conventional and zero tillage practices.	149
21	Uptake of phosphorus in stem of wheat at harvest under conventional and zero tillage practices.	149
22	Uptake of potassium in stem of wheat at harvest under conventional and zero tillage practices.	150
23	Uptake of nitrogen in stem of wheat at harvest under conventional and zero tillage practices.	150
24	Uptake of phosphorus in stem of wheat at harvest under conventional and zero tillage practices.	150

Figure No.	Title	Page No.
25	Uptake of potassium in stem of wheat at harvest under conventional and zero tillage practices.	151
26	Changes of temperature and relative humidity during the crop growth period	154
27	Effects of treatment on CO ₂ -in balance under conventional tillage (1 st year) operations	154
28	Effects of treatment on CO ₂ -out balance under conventional tillage (1 st year) operations	155
29	Effects of treatment on CO ₂ -in balance under conventional tillage (2 nd year) operations	155
30	Effects of treatment on CO ₂ -out balance under conventional tillage (2 nd year) operations	156
31	Effects of treatment on CO ₂ -in balance under zero-tillage (1 st year) operations	156
32	Effects of treatment on CO ₂ -out balance under zero-tillage operations (1 st year)	157
33	Effects of treatment on CO ₂ -in balance under zero-tillage (2 nd year) operations	157
34	Effects of treatment on CO ₂ -out balance under zero-tillage (2nd year) operations	158

LIST OF ABBREVIATION

C	Carbon	OA	Organic Amendments
Ca	Calcium	OC	Organic Carbon
CEC	Cation Exchange Capacity	OM	Organic Matter
C_{mic}	Microbial Carbon	OOC	Oxidisable Organic Carbon
CRI	Crown Root Initiation	PCM	Potential Carbon Mineralization
CT	Conventional Tillage/ Conservation Tillage	POC	Particulate Organic Carbon
DOC	Dissolved Organic Carbon	POM	Particulate Organic Matter
EC	Electrical conductivity	POM-C	Particulate Organic Matter Carbon
FL	Fallow land	PS	Paddy Straw
FLF	Free Light Fraction	RT	Reduced Tillage
FYM	Farm Yard Mannure	WSC	Water Soluble Carbon
GHG	Green House Gas	SC	Soil Carbon
GIS	Geographical Information System	SCS	Soil Carbon Stocks
HC	Carbon	SIC	Soil Inorganic Carbon
IPCC	Intergovernmental Panel on Climate Change	SMBC	Soil Microbial Biomass Carbon
LC	Labile Carbon	SMC	Soil Microbial Carbon
LF	Light Fraction	SOC	Soil Organic Carbon
MBC	Microbial Biomass Carbon	SOM	Soil Organic Matter
MC	Mineralisable Carbon	SON	Soil Organic Nitrogen
Mg	Magnesium	SSA	Sub Saharan Africa
N	Nitrogen	STN	Soil Total Nitrogen
N-P-K	Nitrogen-Phosphorus-Pottasium	TN	Total Nitrogen
NT	No-till	TOC	Total Organic Carbon
		VPD	Vapour Pressure Deficit
		ZT	Zero Tillage

LIST OF PUBLICATIONS

Published Full Paper:

Pal, D., P. K. Patra, D. Mukhopadhyay. 2015. Characterizing soils under different land use patterns in Terai region of West Bengal. Asian J. Soil Sci. 142-148.

Presented Paper: Extended Abstract

Distribution of Selected Soil Preparations under Different Land Use Patterns in *Terai* Region of West Bengal (India) 2016, D. Pal, P.K. Patra and D. Mukhopadhyay. International Symposium on Agriculture and Environment, 2016, University of Ruhuna, Sri Lanka, page 130-132.

Seminar Presentation :

Effect on Soil Health and Environment for Excessive Use of Chemical Fertilizers in some Agricultural Soils of Terai Region of West Bengal. D. Pal, D. Mukhopadhyay and P. K. Patra, page 26-27, National Seminar on Environmental Issues; Protection, Conservation and Management. 22-23 November 2013. Department of Environmental Studies, Visva-Bharati, Santiniketan.

Full Paper Communicated:

Effect of Land-use on Different Carbon Fractions in Soils . D. Pal, P.K. Patra, D. Deb, R. Bhattacharyya , D. Mukhopadhyay. 2017. Soil Science.

Chapter 1

INTRODUCTION

1.1 Introduction

Carbon may be considered as fundamental unit of all life on earth. It was found as the six-most abundant element in the plant and animal life, atmosphere, non-living organic matter, rocks etc. Carbon is found in five main pools namely Lithosphere, ocean, soil organic matter, atmosphere and biosphere. Soil played a key role as sink and fluxes in the soil-plant- atmosphere cycle in the terrestrial system.

In soils, carbon is present both in inorganic and organic forms. In arid soils carbon resides in soil mostly in the organic form. Being a component of the soil organic matter, carbon changes the physical, chemical and biological properties of the soil by improving the soil quality to sustain plant growth.

Soil organic matter (SOM) improves aggregation of soil particles, reduces bulk densities, holds soil water, increase water infiltration. These effect can enhance plants' productivity. On the other hand, soil organic carbon (SOC) increases cation

exchange capacity of soil chemically. Organically bound nitrogen, phosphorous and sulphur associated with SOC provides nutrients for plants through slow release for plant and growth yield. Besides, the main source of energy for maximum number of microorganisms and fauna comes from SOC, which is composed mainly of plant tissues and soil microorganisms in both living and decomposed forms along with decomposing by-products.

It was observed that soils are the largest terrestrial C pool having approximately two-thirds of the C in ecosystems (Schimel *et al.*, 1994). Soil organic C is the prime component of soil organic matter and it has been recognized as a key component of soils both in natural and in managed cultivated lands (Manlay *et al.*, 2007).

The SOC pool is a dynamic component of the C cycle which is closely linked to the atmospheric CO₂ pool (Schlesinger, 1997). This emission to the atmosphere is eight times greater than fossil fuel combustion inputs. Even small changes in the magnitude of the SOC pool or the input–output rates associated with it could have large consequences for the global C cycle, the concentration of CO₂ in the atmosphere, and the climate (Lal *et al.*, 1995).

Soil management influences the change in carbon stock efflux in soils. Due to plowing of soil and poor return of crop residues to the soils affect of soil degradation and retarding soil health occurred. Change in landuse results alteration of soil carbon at various depth. In the agricultural practices for higher yields, return of crop residues and conservation tillage system increased soil carbon. This organic carbon management is considered to be the key environmental management system for sustainable soil health as well as agricultural productivity.

An accurate quantification of SOC stocks is of fundamental interest to develop inventories related to emission and sinks of carbon dioxide concentrations influenced by landuse change and agricultural management.

Soil carbon pools change rapidly in response to landuse pattern. Globally, soil contains three times as much as carbon as plant biomass. Landuse change has been repeatedly shown to have large impacts on soil carbon stock which decreases when forests are converted to agricultural land (Chapman *et al.*, 2012).

Study on Australian soil demonstrated the key role of climate (rainfall and maximum temperature) and vegetation covers in controlling SOC stocks. It was observed that due to the influence of temperature and landuse/vegetation cover, SOC decreases with depth (Grey *et al.*, 2016).

Reforestation and afforestation of agricultural land can lead to increase storage of carbon. Experimental results in Ohio under the temperate climate, with warm, humid summers and mild winters deciduous forest vegetation revealed, that the SOC increased with time through the partial and full reforestation in top soils (10 cm), but less in deeper soil, while SOC/N ratio increased with time in partial and full reforestation in deeper soil (Kolbe *et al.*, 2016).

It was observed that on replacement of arable land to forest plantation in the Loess Hill region of China, there was increase in storage of soil organic carbon (Tong *et al.*, 2016).

Study in black locust forest in China showed that, the concentration of carbon fractions in forest soil were higher than crop land in the 0-30 cm soil profile. The concentration of microbial carbon and N were higher by an average of 29.6- 232.9 and 9.2-179 mg kg⁻¹ respectively compared to cropland at 0-30 cm depth (Zhao *et al.*, 2016).

While observing the SOC dynamics in India (Banger *et al.*, 2015) under land cover and landuse change, it was observed that the majority of SOC stock (ranged from 20.5 to 23.4 Pg C) is stored in the forested areas of north-east, north and few scattered region in southern India. Land cover and landuse-change increased SOC stocks by the 1.7 Pg C by conversion of low productivity fallow land to crop lands with the support by irrigation and N fertilisation.

Crop rotation has significant effect on soil organic matter and their relationship with soil physical attributes. Total C level in soil increases due to rotation of crops. Fractions of Particulate Organic Carbon (POC), Microbial Biomass Carbon (MBC) and Carbon (C) in macro aggregates were mostly affected by crop rotation (Garcia *et al.*, 2013).

Tillage practices effect the soil organic carbon (SOC) pools. Results revealed on long term conventional tillage (CT) and no-till (NT) practices on SOC and its fractions over the winter wheat growing season in surface and sub surface soils. It was

observed that SOC was increased slowly in surface soils with NT practice and less fluctuations with CT treatment. Seasonal variations in MBC and POC were similar under NT and CT and showed a maximum value prior to the winter anthesis stage. The POC, MBC and Dissolved Organic Carbon (DOC) were significantly higher with NT than with CT in upper 10 cm. The depth of soil influenced the SOC and its fractions, which decreased from surface to sub surface soil. The POC, MBC and DOC were highly correlated with SOC (Enke *et al.*, 2015).

Active fractions of soil carbon such as POC and short term soil microbial carbon (SMC) responded faster than total organic carbon (TOC) to management induced change in soil-C (Ladoni *et al.*, 2015).

Soil physical and biochemical properties were enhanced with reduced tillage (RT) which induced a more stable soil with increased porosity and improved microbial activity. Sharp changes in soil quality occurs at CT while smooth changes with depth were observed in RT, while, the SOC increased with RT. Changes in physical properties and microbial activity were due to mechanical stress in CT as compare to RT (Fontana, 2015).

Long term conservation tillage improves soil quality by enhancing soil structure, improving water availability and reducing soil erosion. Study on the effect on tillage intensity on SOC, organic carbon fractions, particulate organic matter (POM) showed that the POM-C associated with NT and RT accounted for 17% of SOC where POM-C accounted for 12% of SOC with CT at 0-20 cm depth. Results showed that the application of conservation tillage practices is crucial for maintaining soil quality and soil C stock (Mikha *et al.*, 2013).

Global estimates indicate that the world soil C pool is about 1500 to 2000 Pg, which is approximately two times larger than the atmospheric pool and three times the land biomass pool (IPCC, 2007). Soil organic C stocks under native and undisturbed vegetation were usually considered to be in dynamic equilibrium with other terrestrial C pools. Original SOC stocks are controlled by climate, terrain, vegetation, soil mineralogy, and interactions between these factors.

There is a growing interest in assessing the role of soil as a sink for carbon under different landuse practices, as increase in soil organic carbon content by 0.01% could lead to sequestration of carbon that can compensate the annual increase of

atmospheric carbon dioxide concentration. Sequestering 1 ton carbon in humus can conserve nutrients to the tune of 83.3 kg N, 20 kg P and 14.3 kg S per hectare. Thus, carbon management is essential for the environmental management and sustainability of soil health *vis-a-vis* agricultural productivity (Trumbore, 1997).

It was observed that SOC pools had the slowest turnover rates in terrestrial ecosystems and thus C sequestration in soils had the potential to mitigate CO₂ emission to the atmosphere. Important ecosystem functions, such as improved soil structure and fertility, increased water and nutrient holding capacity and greater provision of energy for soil biota were considered as higher soil C stabilization (Lal, 2004; Robertson and Swinton, 2005).

It was reported that agroecosystem management practices such as reduced tillage disturbance, increased N input and residue incorporation to soil can significantly increase the soil C (Thomsen and Christensen, 2004).

Intensive and regular tillage practices had caused huge losses of SOC and N pools as for the greenhouse gases emission (e.g., CO₂, CH₄, N₂O) to the atmosphere. It was identified that about 60% of SOC in temperate regions and 75% in the tropics has been depleted by tillage, contributing about 23% of the total greenhouse gas concentration in the atmosphere (Intergovernmental Panel on Climate Change, 1996; Lal, 2004).

Sequestering C in soil in natural and agricultural ecosystems has the potential to offset the future atmospheric increases in CO₂ (Caldeira *et al.*, 2004).

C sequestration was defined as the process of transforming C in the air (CO₂) into stored soil organic C (SOC), primarily through plant photosynthesis and residue deposition.

On a global average, C stored in cultivated shallow, saline, sodic and arid soils was considerably lower than that of the native soils. It had been observed that, soil C increases linearly with additions of crop residues and root organic matter (Paustian *et al.*, 1998).

Lal, 2000 estimated that agricultural ecosystems lose one-third to one-half of their native SOC pool on conversion from natural ecosystems. Loss of SOC by

cultivation can be mitigated by reducing cultivation and restoring the land to the original land cover.

No-till agriculture is considered as the management practices that preserves soil and water and increases SOC pools compared with conventional tillage practices. The SOC associated with agricultural soils has long been recognized for its positive contribution to plant nutrition, soil structure, resulting in improved soil fertility and agronomic production.

Carbon mapping is possible on the basis of reasonable amount of information on soil organic carbon status and carbon stock for different land use in spatial scale. Information on spatial scale to assess the status of soil organic carbon fractions at *Terai* region is limited. At the same time, spatial information at regional scale on land use or land cover pattern in the *Terai* region of West Bengal is also lacking.

With the advent of geospatial tools like geographic information system (GIS) and traditional point based observation, it is possible to create land use / land cover map from multi-temporal data and generate spatial databases on soil carbon inventories at regional scale.

The terrestrial carbon flux is an essential function of the earth's system linked to the physical climate system and its response and adaptations to global climate change have become important area of research (Sheikh *et al.*, 2011).

The dynamics of soil organic C across a landscape are strongly controlled by environmental determinants such as temperature and moisture, which are sensitive to climate change where the change has shown prudent influence on soil C loss across the wide region (Bellamy *et al.*, 2005).

Terai region of West Bengal, India depicts a distinct pattern in terms of land use as compared to rest of the country due to the abrupt land transformation and land cover change due to large scale deforestation by over exploitation of forests for fuel, timber and fodder surrounding human settlement, clearing of forest lands to agricultural land and tea garden.

The *Terai* region has enormous potential of biomass production, well supported by complimentary climatic factors, specially high rainfall for luxuriant vegetative growth and regeneration rate. Availability of abundant phyto-biomass (both above and below ground) in the form of forests and other allied sources has made the region a unique place in the world. Since vegetation is one of the most

important sources to enrich soil with carbon, a general belief is that the soils of *Terai* region will be rich in carbon content covering all major landuse practices.

Extensive information at spatial scale to assess the status of soil organic carbon and the estimation of carbon stocks at regional level is limited. Similarly, spatial information at regional scale on landuse-land cover pattern/change of the region is also lacking.

With the use of carbon fractions determined depthwise under different land uses and its integration with geographic information system (GIS), it was possible to delineate carbon mapping under different landuse pattern of the region. The outcome of mapping would give new dimension for landuse planning and management of soil. It will also help in identification on location specific adaptation and mitigation strategies related to carbon sequestration and sustainable agriculture.

1.2 Objectives

Based on the background as mentioned, the experiments were undertaken with the following objectives-

1. To determine the forms of carbon pools of the soils of different landuse system under *Terai* region of West Bengal.
2. To delineate the distribution of the forms of carbon under different land use pattern by the GIS tools.
3. To determine soil nutrients, carbon pools and yields under different treatment and practices in experimental field.
4. To assess the important environmental factors governing the forms of carbon in soils.

Conversion of land can change Soil Organic Carbon (SOC) due to the perturbation of soil. Increasing SOC storage in the subsoil layers constitutes a major portion of C-sequestration in the soil profile. Soil can act as source and sink of the atmospheric C depending on landuse, cropping system and management practices. Loss of SOC often occurs under tillage practices for mixing in surface residues and by raising the turnover rates.

Terai region of West Bengal have different types of landuses and land covers. Conversion of lands in this region occurs frequently by large scale deforestation and clearing of forest lands to agricultural land and tea garden. The agricultural practices are also conducted without adopting proper management systems. Loss of SOC often occurs under tillage practices for mixing in surface residues and by raising the turnover rates. To maintain soil health it is necessary to adopt zero tillage management practices which can retain soil nutrients, increase crop productivity for sustainable agriculture and for controlling global climate change.

This study has shown the changes in physico-chemical properties, spatial distribution of soil carbon in soils under different landuse determining the fractions of soil carbon (Labile Carbon, Particulate Organic Carbon, Oxidisable Organic Carbon etc.) with the increasing soil depth. It was also found that Oxidisable Organic Carbon was relatively higher in forest soils compare to that of agricultural lands indicating that emission of green house gasses (GHG) increases due to conversion of forest lands to agricultural land. Work suggests that further deforestation should be prevented to build up soil carbon reducing GHG.

Mapping of forms of carbon under different landuse pattern in *Terai* region of West Bengal will help for Assessment of the important environmental factors like temperature, humidity, rainfall governing the forms of carbon in soils

The study undertaken at the Instructional farm of Uttar Banga Krishi Viswavidyalaya, Pundibari, Coochbehar with wheat to determine the different pools of carbon, N-P-K, yield attributes and yield with respect to two different (Zero-tillage and Conventional tillage) management practices under different inputs (paddy straw, farm yard manure, control) showed that carbon sequestration and yields were higher in zero-tillage practices than that of conventional tillage practices indicating the management practices to be adopted for better carbon sequestration in soils. The results also indicates that of all treatments tested, balanced N-P-K fertilisation along with an adequate amount of FYM following zero tillage management was most suitable for the continuous rice-wheat cropping system for improving the SOC stock and sustaining crop productivity. It was observed that zero tillage operation had better balance in CO₂-in and CO₂-out from leaf during photosynthesis compare to conventional tillage.

This research work will help farmers to motivate and to adopt zero tillage or reduced tillage practices with organic inputs in the agricultural field to achieve sustainable agriculture.

Chapter 2

REVIEW OF LITERATURE

2.1 Carbon Pools

The climate, plant and microorganism, topography and time have considerable influence on soil carbon level. Equilibrium conditions of soil carbon can be changed with climate and management practices. Climate has profound influence on soil organic carbon pool.

Soil had been considered one of the important source for global carbon stock (3.5%). Increase in global temperature during last century through climate change caused high intensity precipitation, heat waves, droughts etc. Green house gasses (GHG) like CH₄ and CO₂ are the main factors for global climate change (Purakayastha *et al.*, 2007, Murty, *et al.*2002) .

Soils have potential to act as sink for atmospheric CO₂ as it can store large amount of carbon. Previous studies have shown that soil organic matter contains three times more carbon found in land vegetation (Raymond and Bauer, 2001). In addition, soil C has more larger residence mean times than the

C in the vegetation. This carbon sequestration in soil may be termed as storage of organic carbon in soil for longer residence time (Wang and Hsieh, 2002).

About 1000 Mg ha⁻¹ of organic carbon was stored in swamps and marshes in the top 1 m soil surface (Trumbore and Harden, 1997; U.S. Department of Energy, 1999). This stored carbon tend to have very long turnover times (Choi and Wang, 2004). Anaerobic conditions of these soils due to limited rate of organic decomposition accumulates more carbon in soils (Brady and Weil, 1996).

It was evaluated to quantify soil C content and residence times in specific locations to understand about increasing atmospheric CO₂ and its role in future global climate change (Fung *et al.*, 2005; Matthews *et al.*, 2005).

2.2 Soil Carbon Pools

Soils play an important role in the global C cycle. They are the third largest active C pool (1550 Pg of organic C and 750 Pg inorganic C to a 1-m depth) after the hydrosphere (38 000 Pg) and the lithosphere (5000 Pg) (Lal, 2001).

The slowest C turnover rates in terrestrial ecosystems are found in soils (Trumbore, 1997). Soil C sequestration is very much cost-effective than other techniques used for C sequestration (Lal, 2008). In addition, soil organic matter (SOM) has the potential to increase the soil fertility and put more energy for soil biota (Robertson and Swinton, 2005; Janzen, 2006).

From the different experiments it was shown that, soils under management practices such as reduced tillage, residue incorporation have greater SOM, which in turn can function as a C sink and a nutrient reservoir for soil biota (Sleutel *et al.*, 2006).

High level carbon inputs sometime has little impact on SOC sequestration in a broad range of soil carbon inputs. This result indicates that soil C sequestration is governed by soil C dynamics ((Kool *et al.*, 2007; Gulde *et al.*, 2008).

The sensitive indication of change in SOC depends on the density of microbial biomass, light fraction organic matter, organic matter present in soil and soil aggregates (Six *et al.*, 2002; Jastrow *et al.*, 2007).

Soil organic matter is probably the most known and studied indicator of soil quality due to its direct effect on soil properties. Soil quality is normally stated as the capacity of the soil to perform ecological functions, resist erosion, and reduce negative impacts on associated air and water resources (Karlen *et al.*, 1997). Major soil quality indicators influenced by SOM are, structure, aggregate stability, water infiltration, water availability, biological activity, cation exchange capacity, nutrient storage and release, sorption of agrochemicals, metal mobility (chelation) and pH buffering.

A soil's C sequestration capacity is controlled by its physiochemical characteristics. It was observed that various soil physical and chemical properties are known to be involved in protecting and reducing organic residue decomposition (Six *et al.*, 2002).

A soil having saturated C storage with surfaces of silt and clay fraction and aggregates with maximum humic substances have more carbon storage capacity (Six *et al.*, 2002). Carbon saturation is defined as a soil reaching its maximum C sequestration capacity (Watson *et al.*, 2000; Six *et al.*, 2002; Goh, 2004).

Management and sustainability of soil functions are linked with quantity and quality of soil organic matter. Experimental study confirmed that conversion to crop production practices has caused a decrease in SOM compared with the original grassland levels (Allmaras *et al.*, 2000). Depending on the geographic location, soil carbon loses from 28 to 77% due to different tillage effect (Paustian *et al.*, 1997).

Soil quality and fertility can be improved by SOM accumulation which contributes C sequestration (Six *et al.*, 2000; Mikha and Rice, 2004; Wright and Hons, 2005a). The impact of tillage practices depends on soil type, residue

management practices and climate (Paustian *et al.*, 1997). Soil aggregate formation and stabilization are linked to SOM dynamics. Aggregation of soil is controlled by microbiota, soil organic C, clay, and carbonate content of the soil (Bronick and Lal, 2005).

2.3 Soil Carbon and landuses

A study on the effect of combination of two irrigation practices (irrigated and non irrigated) and six cropping system in north Dakota conducted in surface soil (0-15 cm) reported that plant biomass carbon was greater in no-tilled nitrogen fertilisation field than no-tilled, no fertilisation field (Sainju *et al.*, 2010). Grass lands emit more CO₂ than croplands due to extensive root systems and greater soil organic carbon levels (Frank *et al.*, 2006). Conversion of grass lands to croplands can reduce the SOC level due to emission of CO₂ (Davidson and Ackerman, 1993).

Cultivated soils lost between 28 and 38% of the original organic C, compared with virgin grassland, after 25 yr of cultivation, depending on the tillage system (Bauer and Black, 1981). Similar findings were estimated by Bowman *et al.*, 1990 that, after 60 yr of tillage, approximately 60% of the original organic C was lost in the surface soil of a sandy soil in eastern Colorado. Most of the C loss occurred in the first 3 year after the onset of cultivation.

In no-till system organic carbon was increased with C addition to the system due to increasing cropping intensity. This occurred due to decrease of oxidation caused by no-tillage (Mikha *et al.*, 2006; McVay *et al.*, 2006). The strategy to mitigate the flux of atmospheric CO₂ could be adopted by soil aggregation process.

Soil had been considered as source or sink of atmospheric C depending on land use, cropping system, and management practices (West and Marland, 2002; Lal, 2003; Singh and Lal, 2005). Soil management through enhanced

aggregation may be an important strategy for soil C sequestration as well as to mitigate the release of atmospheric CO₂ (Shrestha *et al.*, 2004; Bronick and Lal, 2005).

Change in landuse from forest to another land cover led to higher bulk density, lower water conductivity and higher erosion of soil which causes soil degradation and reduction in SOC density (Spaans *et al.*, 1989; Lal, 2003b; Lal *et al.*, 1997). Farming practices also affected SOC concentration and physical properties (Gami *et al.*, 2001; Hao *et al.*, 2001).

Land cover with perennial grasses increased soil carbon stock (Post and Kwon, 2000). On the other hand cropping system intensity influenced soil C stock and its productivity (Akala and Lal, 2001; Lal, 2004).

Decomposition of roots and grasses were partly attributed to improve soil C storage and its residence time in soil (Puget and Drinkwater, 2001). SOC was protected through soil micro and macro aggregates formation by roots of grass (Chevallier *et al.*, 2004).

Reduced tillage, row-crop field, nutrient management could enhance soil carbon stock (Lal, 2004). Crops with higher residue produced SOC better than the crops with less residue (Paul *et al.*, 1999).

Once soil C is lost due to change of landuse required a long time to regain it to initial level. SOC stock was greatly affected by change in landuse (Guo and Gifford, 2002; Paul *et al.*, 2002). Loss of carbon due to deforestation required 40 years for recovery for its slow accumulation. This was suggested that, at least 80 yr were required for initial stock levels to recover after afforestation (Thuille and Schulze, 2006).

Change in land cover from prairie to agriculture in north America resulted 24-89% loss of soil carbon (Knops and Tilman, 2000; Kucharik *et al.*, 2001; VandenBygaart *et al.*, 2003). However, loss of SOC in the top level (25 cm) was 12 to 32% for conversion of wet prairie to agricultural land (Matamala *et al.*, 2006).

No-tillage agriculture practice was a useful measure for C sequestration (Post *et al.*, 2004; Bernacchi *et al.*, 2005). SOC stock is a fraction of soil nitrogen (N) dynamics. Hence, data of total N was required for study of SOC (Christopher and Lal, 2007; Kucharik, 2007; McLauchlan, 2006b).

Increasing green house gas (GHG) emission in the atmosphere mainly emission of CO₂ was due to change in vegetation to agricultural land (Ruddiman, 2005). GHG emission can significantly reduced through cropping system, soil management practices and selection of landuse system. Atmospheric CO₂ can be stored in soil by introduction of conservation agriculture system (Bernoux *et al.*, 2006). This phenomenon had been called carbon sequestration. A degraded soil had higher potential for C sequestration as it has lost soil organic matter due to inappropriate management (Lal, 2004).

2.3.1 Soil Carbon in forest soils

It was assessed that soils having close C saturation capacity have the less potential to store additional C compare to soils having less saturation capacity in temperate ecosystem (Chung *et al.*, 2010)

Release of summer CO₂ from montane forest in Utah and range lands were effected by vegetation cover resulting its effect on SOC quality and soil micro climate. Surface soils of forest contain more decomposable SOC which favour more carbon turn over by emission of enhanced CO₂ emission compare to adjacent range lands (Olsen *et al.*, 2010). The source of C inputs (root- or shoot-associated) may influence the potential to form aggregates. Root-associated C may promote aggregate formation more than shoot C (Gale and Cambardella, 2000; Wander and Yang, 2000; Puget and Drinkwater, 2001; Schwenke *et al.*, 2002).

Soil organic C dynamics were controlled in large part by climate, soil physical properties and the amount of plant litter input. Climate change would affect important controls of C mineralization such as soil temperature, moisture and litter quality.

A good number of field and laboratory studies had demonstrated that addition of litter to soil increases the rate of soil C mineralization and the total amount of soil C mineralized (Hamer and Marschner, 2002; Bol *et al.*, 2003; Sulzman *et al.*, 2005). This interaction was called the priming effect.

It had been identified that temperature influences the rate of soil C mineralization, as well as control microbial community size and structure (Andrews *et al.*, 2000; Waldrop and Firestone, 2004).

The decreases in soil C following the conversion of forests or grasslands to agriculture were well documented (Post and Kwon, 2000),

Some studies had shown that conversion of agricultural land to forest land results large amount reaccumulation of C stock in soils (Jenkinson, 1991). But in other cases little or no reaccumulation had been found (Compton and Boone, 2000; Richter *et al.*, 1999). Schlesinger 1990 indicated that the potential of soils to sequester C is too low to be an important factor mitigating atmospheric CO₂ increases.

Soil C change and soil N change has strong link in soil C-N dynamics. C/N ratio of soil indicates the amount of N change to soil C change.

Most studies had indicated a relatively rapid increase in soil C during forest regeneration (Johnston *et al.*, 1996; Templer *et al.*, 2005).

Time, soil texture and land history had shown significant impact on accumulation of soil C (Brye and Kucharik, 2003; Lettens *et al.*, 2005; Templer *et al.*, 2005) The rates of change in soil C as communities develop may also be dependent on the rates of change of soil N (Knops and Tilman, 2000; Poulton *et al.*, 2003).

Study had indicated that rapid gain in soil N and C can be obtained by dinitrogen-fixing trees (Bormann *et al.*, 1994).

High natural variability in forest floor caused challenge for precise and accurate estimation of C and N in forest soil. The major variables in determining the soil fertility were soil C and N (Johnson and Curtis, 2001). The

status of soil C and N dynamics were dependent on forest management practice (Boyle and Powers, 2001).

Soil C and N were important in the context of sustainable forest management. Soil organic C was considered as a surrogate for SOM (Pag *et al.*, 2000; Ogle and Paustian, 2005). Soil organic matter influenced on nutrient cycle, microclimate and water dynamics resulting in soil process and acted as C source for soil biota (Raison and Rab, 2001). Hence, SOM protection was important for sustainable management of forest (Page *et al.*, 2000).

It was recorded that soil C and N pools may be increased following fertilisation through silvicultural practices (Johnson and Curtis, 2001; Johnson *et al.*, 2002).

The primary source of C to mineral soils were biomass and litter inputs which was influenced by fertilisation (Giardina *et al.*, 2004; King *et al.*, 2002; Matamala *et al.*, 2003; Yano *et al.*, 2005). It was noted that fertilization decreased the amount of C entering mineral soil through roots and mycorrhizae in a tropical forest in Hawaii (Giardina *et al.*, 2003, 2004) and decreased root production (Gower *et al.*, 1992; Haynes and Gower, 1995). On the other hand, increasing root C inputs to soil indicated greater biomass turnover and mortality rates of tree (Haile-Mariam *et al.*, 2000; King *et al.*, 2002).

2.3.2 Soil carbon in agricultural soils

Agricultural lands may have potential to help mitigating the increasing atmospheric CO₂ concentration through photosynthetic C-fixation into crop biomass. Increasing amount of crop biomass and return of crop residue to the soil has increased crop productivity (Burney *et al.*, 2010; Johnson *et al.*, 2006). Increase in crop production has the potential for increasing SOM.

SOM is improved through adoption of conservation management practices which can lead soil to act as C sink (Lal, 2003; West and Post, 2002). In contrast, little effect on SOM accumulation due to tillage was found in the soil depth greater than 30 cm (Baker *et al.*, 2007)

Agricultural sustainability can be obtained through by adopting reduced tillage in agricultural soil which results in reducing fossil fuel consumption, low labour cost, lower equipment maintenance and increasing soil water conservation (Lal, 2001). Many field trials suggested that, CT increases particulate organic matter or light fraction organic matter which is an unstable, transitory C pool (Schwenke *et al.*, 2002; Fabrizzi *et al.*, 2003; Liebig *et al.*, 2004).

Light fraction organic matter which is physically or chemically protected had a lower decomposition rate than unprotected light fraction, suggesting that it can be protected from microbial attack (Gale and Cambardella, 2000; von Lutzow *et al.*, 2002).

Changes in agricultural management from conventional tillage to NT and increased crop-rotation diversity could increase accumulation of soil carbon (SC) (West and Post, 2002).

Research had shown that the process of decomposition under different agricultural systems results in unique chemical constituents of humic materials that results in resulting soil stability.

It was found that SOM associated with clay minerals gave increased hydrophobicity and water stable aggregation which could be ascribed to resistance of aggregates to slaking (Chenu *et al.*, 2000).

The extent to which agricultural practices result in changes in SOC storage may depend on multiple factors, including the initial levels of SOC (Ismail *et al.*, 1994) and the degree of system SOC saturation (Hassink and Whitmore, 1997); soil properties such as texture and aggregation (Balesdent *et al.*, 2000; Six *et al.*, 2004); artificial drainage (Sullivan *et al.*, 1997) and productivity (AlKaisi *et al.*, 2005), environmental conditions (Campbell *et al.*, 1995); and time.

It was reported that on an average, a shift from CT to NT can sequester nearly $60 \text{ g C m}^{-2} \text{ yr}^{-1}$ (West and Post 2002).

Accumulation of SOC below the soil surface was significant in terms of soil processes such as nutrient leaching or microbial activity in the context of using agricultural soils as sinks for mitigating rising levels of atmospheric CO₂.

2.3.3 Soil carbon in fallow land

The effect of plow, sub till and no-till fallow management was conducted near Sydney, Australia on soil properties and carbon -nitrogen cycle. It was found that biological activity and organic C and N were abundant near surface soil with no-till fallow system. Results also indicated that no-till management had a protective surface cover near the soil surface due to presence of layer of residue and decomposed materials (Doran *et al.*, 1999).

Despite the lack of information on GHG flux in fallow, management strategies were needed to limit emissions during non-cropping phase (Barton *et al.*, 2008).

The study envisaged on the impact of fallow periods on soil organic carbon in semiarid subsistence cultivated lands on sandy and poor soils in Kordofan, Sudan. Soil organic carbon showed a significant negative relationship with cultivation intensity. Measurements indicated a mean increase of approximately 4 g SOC per square meter per year during fallow periods (Ardo *et al.*, 2004).

While conducting a study conducted in Bulgaria to determine the effect of different land use including fallow on humus content and organic carbon content in soil solution (Stoicheva *et al.*, 2003), an increasing trend in dissolved organic carbon content in the soil solution from fallow was observed. Results indicated the influence of the fallow land on the content of humus and dissolved organic carbon in soil.

Study in sub-Saharan Africa (SSA) showed that soil organic carbon (SOC) contents decrease in following deforestation. There existed a high potential for increasing SOC through establishment of natural or improved fallow systems (Vagen *et al.*, 2005)

The dynamics of organic carbon upon natural overgrowing of abandoned croplands transferred into the category of fallow lands was analyzed for a period from 1990 to 2002. The results of calculations showed that the fallow lands have lost 9.9 million tons of organic C (Romanovskaya *et al.*, 2006).

Experimental studies were conducted at contemporary fallow practices in the Western Highlands of Guatemala. Soil in cropped plots, showed 25 per cent higher soil organic matter and five times higher nitrate concentrations than soil in fallow plots, which resulted from additions of compost and inorganic fertilizer to cropped plots (Wittman *et al.*, 2008).

Six land-use types were taken in the steppe grasslands of Inner Mongolia to find out correlations with soil carbon and nitrogen and soil particle size distribution. Results showed that organic carbon of the fallow land (FL) were consistently higher than the other land-use types (Qian *et al.*, 2008).

The carbon balance of cultivated soil under fallow was compared with that of soils abandoned to permanent grassland in Russia. The carbon balance in the abandoned ecosystems were depended on the period of abandonment (Kurganova *et al.*, 2008).

Study conducted on the impact of the conversion of a succession fallow (F) to organic (O) and intensive (I) agriculture on TOC, total N (TN) reflected that the conversion of succession fallow to cultivated land resulted in a significant decrease of TOC, TN at 0-10 cm soil depth (Bohm *et al.*, 2010).

Study on three landuse types including natural grassland, crop-field and abandoned old-field (10 y) in the north-eastern Tibetan plateau were conducted by Chen *et al.*, 2010 to assess the influence of land-use on soil and microbial characteristics. It was found that the losses of soil organic carbon (SOC) and total nitrogen (TN) were about 45 and 43 per cent, respectively, due to cultivation comparing with natural grassland. SOC and TN were increased by 27- 23% depending on the period of fallow. It was also observed that cultivation decreased the organic matter and microbial biomass in soils

A study conducted in the Andean highland region (Altiplano) of Bolivia to determine the effects of the length of cropping and fallowing periods on soil degradation or soil restoration and to compare the potential soil carbon and nitrogen mineralization from a range of cropped and fallow lands. Fallowing was observed to restore total and active soil organic carbon and total and active soil nitrogen more rapidly (Aguilera *et al.*, 2013).

Soil microbial biomass C were examined along different age series of abandoned cultivated lands for different fallow period to assess the impact of land abandonment on soil fertility restoration of tropical cultivated lands. The results showed that the microbial biomass properties (C, N & P) were significantly different ($p < 0.05$) along all the sites, depths and months depending on the fallow periods (Haripal *et al.*, 2014).

2.3.4 Soil carbon in tea garden

Tea (*Camellia sinensis*) is a globally important crop and is unusual because it requires an acid soil and acidifies soil. Tea stands tend to be extremely heavily fertilized in order to improve yield and quality which results in a great potential for diffuse pollution. Tea (*Camellia sinensis*) is a kind of evergreen shrub or tree, which has been widely planted as an important economic crop in mountainous tropical and subtropical regions of China. Tea gardens are considered both ecologically friendly and economically profitable due to their high plant standing biomass and important role in soil and water conservations.

Conversion of forest land to the tea gardens was one of the important human interferences in natural ecosystems, which was effective on ecosystem processes particularly soil. Strongly acidic tea soils can potentially sequester large quantities of applied C, mainly from trimmed branches. Thus, tea soils were important for alleviating greenhouse gas emissions from tea gardens (Leon *et al.*, 2015).

Carbon to nitrogen ratio and the ratio of carbon to soil phosphorus in forested area have been replaced to be more than tea gardens area and on the

contrary, the percentage of organic carbon, nitrogen and phosphorus content in tea garden soil is more than forested areas.(Mahrer *et al.*,2014)

A study in subtropical and tropical region of China showed that tea biomass increased rapidly during the first 10 years and then slowly after the first 15 years. Carbon (C) mass of 10 and 15 year-old tea plants was 92% and 98% of 25 year-old tea plants respectively .(Min *et al.*, 2013)

Studies on varying paddy field, vegetable field, tea garden, upland, fallow grassland, citrus grove, bamboo land, woodland, and eroded fallow were used to examine the effect of land use on microbial biomass C (C_{mic}), by Chao *et al.*,2003. Land use had considerable effects on the amounts of soil C_{mic} . The C_{mic} was lowest in eroded fallow land, followed by woodland, tea garden, citrus grove and fallow grassland, and highest in vegetable and paddy fields. There was a significant correlation between C_{mic} and organic matter content, suggesting that the influence of land use on C_{mic} is mainly related to the input and accumulation of organic matter.

A study conducted in 4, 6 and 16 years old tea garden managed by organic treatment showed that biomass carbon , organic matter , total N and available N, P and K were higher in 16 year old tea garden in comparison to other tea gardens indicating advantage in forming activated soil with increasing year (Xin *et al.* 2006).

Research conducted at the Tea Research Institute, Hangzhou, China resulted that microbial biomass carbon is lower in tea gardens compare to that of adjacent forest soils (Yan *et al.*, 2007). Results demonstrated that tea cultivation intensity and duration had a strong impact on the microbial community structure, biomass and its functioning, likely through soil acidification and fertilizer addition.

An experiment conducted on vertical distribution and storage of soil organic carbon in north subtropical areas of China at various soil depth under different eight landuses, it was found that the contents of SOC on the top soil profile (0-10 cm) were the greatest, compared with the other soil profiles(10-

100 cm) in the eight land-use types, whereas in the tea garden an increase from 0 to 30 cm and a decrease from 30 to 100 cm in depth (Cai *et al.* 2007) of the SOC was observed.

In an experiment using different treatments by using straw mulch, organic manure and fertilisers in red soil in tea garden reflected significant correlation of soil microbial biomass carbon with the active organic matter, the total nitrogen, the microbial biomass N, the microbial biomass P, but no significant correlation was found with available nitrogen, total phosphorus, total potassium and moisture (Qin *et al.*, 2008).

Similar experiment was conducted by Song *et al.* 2010 in tea gardens using straw and white clover which showed that the content of soil microbial biomass of C, P, and K after two years' mulching was higher than that of the control. A dynamic changes were correlated to the seasons temperature had also been found.

Microbial and biochemical parameters of soil under different land use (forest, tea garden and arable land) in Tista valley, India, were studied under different landuse system. The soils varied with respect to their organic carbon (OC) and total nitrogen (TN) contents and was the highest in forest soil, followed by the decreasing order by tea and agricultural soils (Tripathi *et al.*, 2011).

The performance of crop residues in an acidic tea garden soil showed that the soil pH was positively correlated with carbon C/N ratios of crop residues both in low-level treatment ($R^2=0.955$) and in high-level treatment ($R^2=0.981$). Results also suggested that crop residues with relatively high C/N ratios were considered to be more suitable for long-term pH adjustment of tea garden soils (Fei *et al.*, 2013).

In a study for seasonal variation in fertility parameters and the comprehensive fertility of three types of tea garden soils in Western Sichuan, China, showed that ; TOC was lower in summer due to higher decomposition

rates and extensive soil erosion and higher TOC and total nitrogen (TN) in autumn occurred as litter returned to the soil (Gang *et al.*, 2013).

It was observed that relatively higher and positive correlation was found between MBC and soil organic carbon (0.957) in the surface soils (0-20 cm) (Chattopadhyay *et al.*, 2012) while conducting experiment at three different land use systems viz., cultivated (paddy) land, tea garden and forest in the Jorhat district, Assam, India.

It was found that organic carbon could significantly stimulate soil CO₂ emission from the four fields, showing an order of tea garden and paddy field > vegetable garden and forest land. The experiment was conducted in four landuses in Jinjing river region, Changsha, to study the effects of application of carbon, nitrogen and nitrification inhibitor on N₂O, CO₂ (Fei *et al.*, 2013).

Regression models on the relationship between tea stand biomass and tea plant age or tea yield were established to find out how its carbon storage capacity changes and how much its carbon storage capacity can achieve during a production cycle of a common double-row tea garden.

Changes in total carbon (C) concentrations in topsoil were examined in response to organic amendments (OAs) in Japanese orchards and tea gardens at the farm level using 20 years of survey data. Soil C increased by 1.9 and 2.2 g kg⁻¹ yr⁻¹ at Andosol sites with 'decreasing pH. However, the soil C concentrations did not change at the Andosol sites where the initial soil C concentrations were high. It was found that strongly acidic tea soils can potentially sequester large quantities of applied C (Leon *et al.*, 2015).

An experiment conducted at the north Iran on the effect of the conversion of forest land to the tea garden, on some physical and chemical properties of the soil (nitrogen, organic carbon, phosphorus, carbon to nitrogen ratio carbon to phosphorus ratio) resulted that Carbon to nitrogen ratio and the ratio of carbon to soil phosphorus in forested area is more than tea gardens area, and on the contrary, the percentage of organic carbon, nitrogen and phosphorus content in tea garden soil is more than forested areas, which shows

improvement on soil quality due to conversion of forest land to the tea gardens in the forested areas destroyed (Mahrer *et al.*, 2014).

2.4 Factors affecting soil carbon pools

The maintenance of soil carbon in soil is governed by annual temperature, precipitation and many interacting factors such as soil types, tillage, application of fertilizers, quality and quantity of organics returned to soil and the method of residue management.

2.4.1 Tillage practices and change in soil carbon

Tillage intensity (Sainju *et al.*, 2008), fertiliser applications, total residue C inputs and the duration of residue management (Ramussen and Parton, 1994), were considered as crop management factors which have influence on the retention of above ground residue C inputs in soil. Below ground crop C inputs, e.g. root biomass, sloughed cells, mucilages and exudates were influenced by crop management.

No-tillage along with rotations in agricultural systems provide continuous C inputs via litter and root activity which might store soil C (Kay and VandenBygaart, 2002; Deen and Kataki, 2003; Carter, 2005; Puget and Lal, 2005).

Carbon storage occurred more rapidly in no-tillage system due to presence of specific group of soil biota (Six *et al.*, 2004).

Global climate change had encouraged the development of agricultural systems that sequester soil C (Ogle *et al.*, 2003). Sequestration of C was a function of the difference between C inputs, primarily from plant biomass, and C losses due to the activity of soil organisms. It was affected by agricultural management. Loss of soil C in agricultural systems had been occurred primarily due to oxidation following soil cultivation (Schlesinger, 1984).

2.4.2 Soil aggregate and soil carbon

It was also found that soil aggregate dynamics could strongly influence soil C sequestration and SOM cycling (Jastrow, 1996; Six *et al.*, 1998). The

incorporation of C in aggregates was an important mechanism for C sequestration in the long term(Six *et al.*,2000).

It was observed that micro aggregates within macro aggregates could explain almost the entire difference in SOC between non-till and conventional tillage systems (Denef *et al.*, 2004). Similar findings were identified by Kong *et al.*, (2005) on micro aggregates within macro aggregates as an ideal diagnostic factor for long term SOC sequestration.

The form of soil aggregate were determined by the source of C inputs via root or shoot associated with it (Gale and Cambardella, 2000; Wander and Yang, 2000; Puget and Drinkwater, 2001; Schwenke *et al.*, 2002).

2.4.3 Influence of cropping system

Soil C storage can be increased within an ecosystem. Cropping systems with higher soil N contents influence greater C processing and storage capacity than systems with lower soil N levels. Recalcitrant C derived from root biomass are stabilised in presence of sufficient available N.

Adoption of conservation tillage , diversification of crop rotations, inclusion of cover crops in the system and application of manure generally increased SOC and SON contents in the topsoil compared with conventional tillage (Doyle *et al.*, 2004; Franchini *et al.*, 2007; Gulde *et al.*, 2008; Huggins *et al.*, 2007; Lal, 2004; Marriott and Wander, 2006a; Purakayastha *et al.*, 2008; Steenwerth and Belina, 2008).

Crop rotation and tillage practices can affect cropland soil quality between the interaction of the fractions like soil type, management practice and climate.

Crop rotation had the impact on C substrate availability and decomposition rates by controlling the C quality, quantity and periodicity of C inputs, modifying soil and crop canopy environmental conditions, crop biomass accumulates and residues. Due to the crop rotation, there could be differences in C additions, while major tillage effects are on SOC decomposition rates and

losses via soil erosion due to the combined influence of crop and tillage management on SOC (Potter *et al.*, 1997).

Soil were interdependent for sources of C and energy (Phillips *et al.*, 2003). The ecological functions performed by the soil food web were determined by the identity, abundance and interactions of its components (Ferris, 2005). Carbon entered soil food webs in the form of plant litter and root exudates (Coleman *et al.*, 1976).

Consumption and incorporation of plant-derived C by food web organisms and biological transformation lead to formation of molecules that were more resistant to degradation (Wardle *et al.*, 2004) and decomposition of crop residues promoted to soil aggregate formation (Tisdall and Oades, 1982).

2.5. Physicochemical properties

A significant portion of cation exchange capacity (CEC) in a soil was often attributed to organic matter (OM). For the organic fraction, the charge arose largely from ionization of COOH groups in addition to contribution of phenolic OH and NH groups (Stevenson, 1982).

The results showed that for each unit change in pH, the change in CEC contributed from OM was several times greater compared to the contributions by the CEC from clay for several soils (Helling *et al.*, 1964).

At the level of pH 8.0, 45% of the CEC in several grassland soils was contributed by OM. Only 19% of the CEC was attributed to OM at pH 2.5. Kamprath and Welch 1962 also estimated that total CEC of OM in Coastal Plain soils at pH 7 ranged from 62 to 279 cmol kg⁻¹. Organic matter of these soils ranged from 5 to 184 g kg⁻¹.

Trivalent cations were more competitive in binding with OM than divalent cations. These were more effective in binding with OM than monovalent cations (Stevenson, 1982). Evidence existed for the complexing of divalent and trivalent cations by humic and fulvic acids, a fraction of soil OM, including the inability of K⁺ and other monovalent cations to replace sorbed

micronutrients from mineral and organic soils (Stevenson, 1982; Hue *et al.*, 1986).

Soil physical conditions had a direct effect on soil productivity for crop production. It determines water holding capacity, aeration, and soil strength limitations for root activity of the soil (Benjamin *et al.*, 2003).

Soil physical properties may change with the loss of organic matter. It was measured that lower water content at field capacity and lower cation exchange capacity is associated with the loss of organic matter (Bowman *et al.*, 1990).

Selected soil properties were improved by addition of manure which increases organic matter in soils.

Soil texture was another key determinant of soil quality. Textural composition moderates the behavior of several soil processes, including SOM dynamics and C sequestration (Kettler *et al.*, 2001).

2.6. Soil carbon in relation to soil depth

Fine roots were concentrated in surface soils and their vertical distribution in soil showed an exponential decrease with depth (Jackson *et al.*, 1996). They were present in lower density at greater depths in soil. Measuring as a percentage of the roots distributed from 0-80 cm, the depthwise distribution of fine root biomass in the 77-yr-old ecosystem was 3% (forest floor), 37% (0–10 cm), 33% (10–20 cm), 8% (20–30 cm), 14% (30–40 cm), 2% (40–50 cm), 1% (50–60 cm), 1% (60–70 cm) and <1% (70–80 cm) (Uselman *et al.*, 2007).

It was identified that larger aggregate size fractions were present at 0-5 cm soil for NT practice. This aggregate size was mostly affected by CT and RT reducing its size from 4750-2000 μm . At the 10- to 15-cm depth, more soil was found in the largest aggregates (>4750–2000 μm) from the NT and RT treatments compared with that from the CT treatment; (Zibileske *et al.*, 2007). Increases in organic carbon (OC) in the surface (5 to 7.5 cm) from NT soils had

been well documented. Dick (1983) observed an increase of OC in the surface of 7.5 cm depth of soil with NT corn when compared with intensive tillage (moldboard plow). It was reported that OC was significantly higher in the surface soil of 5 cm of depth in NT soils when compared with plowed soils after 20 yr of continuous agriculture (Ismail *et al.*, 1994).

Study conducted in an Alfisol in Nigeria showed that NT soils had higher SOC than CT in the 0- 15-cm depth, but CT soils had greater SOC in the 15-30-cm depth, and the total SOC in the profile was much greater under CT (Lal, 1997).

The amount of SOC stored in deeper layers was the most important fraction for long-term SOC sequestration. The SOC in subsoil was protected inside the soil aggregates and has lower turnover rates compare to SOC in the top soils which was prone to rapid changes and decomposition by the increase in the near surface microbial activity, change in soil temperature and moisture (Lorenz and Lal, 2005).

Conservation tillage management resulted in SOC stratification with depth. Reducing residue inputs would promote lower SOC contents at deeper soil depths (Deen and Kataki, 2003; Dolan *et al.*, 2006; Blanco-Canqui and Lal, 2008).

Dolan *et al.*,(2006) reported that surface soils (0–20 cm deep) under no-till management in Minnesota had >30% more SOC than soils under moldboard or chisel plow tillage. Below a 20-cm depth, however, the trend was reversed. The results from these recent studies have caused researchers to suggest that CT practices may not always lead to net SOC accumulation in the whole soil profile (Dolan *et al.*, 2006; Blanco-Canqui and Lal, 2008).

Storage of C in soils was considered to depend on four main factors: organic matter inputs, organic matter decomposability, the level of physical protection of organic matter in aggregates and the depth at which the organic matter is deposited (Jones and Donnelly, 2004; Breuer *et al.*, 2006).

It was observed that, 50% of the C and N stocks in the first 1m of soil in temperate grasslands was stored between 30 and 100 cm well below the average sampling depth of most studies examining C storage (Jobbagy and Jackson, 2000).

On analysis the data with sampling depths deeper than 30 cm, it was assessed that NT led to significant C increase in surface soil, while CT accumulated C near or below the 20-cm depth of the soils studied (West and Post, 2002; Halpern *et al.*, 2010; Jacobs *et al.*, 2009, 2010; Luo *et al.*, 2010). These results suggested that the greater C content at deeper depths under CT did not offset the C gain under NT surface depth, leading to a higher total C stock in NT. The nonsignificant differences in C sequestration between NT and CT, when C concentration with variations in soil depth and bulk density was accounted for (Baker *et al.*, 2007; Powlson *et al.*, 2011).

It was reported that, (Baker *et al.*, 2007) by limiting soil C measurements to 30-cm depths, tillage effects on C storage were likely to be overestimated even in long-term experiments.

2.7. Carbon fractions of soil

Soil organic matter (SOM) pool of particulate organic matter (POM) was more sensitive to soil management than total SOM. This fraction was mainly composed of fine root fragments and other organic debris and serves as a readily decomposable substrate for soil microorganisms (Mrabet *et al.*, 2001). It was observed that 25% greater SOC was under NT than under CT (Wander *et al.*, 1998). In case of analysing POM-C, this difference between tillage systems was increased to 70%. Another measurable C fraction was mineral associated carbon (C_{mic}), which was the SOM chemically stabilized on silt and clay surfaces (Hassink, 1997). This was more stabilized SOM than the POM and therefore, less sensitive to soil management.

Soil food webs dominated by organisms at the entry level tend to have greater C loss due to their rapid turnover and decomposition rates (Blagodatskaya and Anderson, 1998). Greater retention of C has been

hypothesized to occur when soil organisms at higher trophic levels were more abundant due to greater C conserved in biomass, gradual transformation to more recalcitrant forms of C and protection in smaller aggregate size fractions (Fu *et al.*, 2000).

Different biota may contribute to different ways to soil C sequestration. Fungi had a higher C/N ratio than bacteria (Kogel Knabner, 2002) which can increase aggregate formation, that physically protects and retains plant-derived C in the soil (Six *et al.*, 2004).

Intensive tillage increases the oxidation of SOC (Bowman *et al.*, 1999) and fallowing increases its loss by reducing the amount of plant residue returned to the soil (Campbell *et al.*, 1997).

Extending fallow increase soil water storage and crop yields (Jones and Popham, 1997; Pikul *et al.*, 1997) and also increase soil water and temperature during fallow enhance mineralization of SOC .

The use of no-till has allowed producers to increase cropping intensity in the northern Great Plains (Peterson *et al.*, 2001). No-till conserves surface residues and retains water in the soil profile more than conventional tillage (Farhani *et al.*, 1998).

Carbon conservation in soil and crop residues was needed not only to increase C sequestration for C trading and mitigate greenhouse gases but also to improve soil quality for economic crop production.

Since SOC had a large pool size and inherent spatial variability, it changes slowly with management practices (Franzluebbers *et al.*, 1995).

MBC (microbial biomass carbon) and PCM (potential carbon mineralization) fractions can provide an assessment of soil organic matter changes induced by management practices, such as tillage and cropping system (Sainju *et al.*, 2006).

POC had been considered as an intermediate fraction of SOC between the active and slow fractions that changes rapidly with time due to changes in

management practices (Bayer *et al.*, 2001). The POC also provided substrates for microorganisms and influences soil aggregation (Franzluebbers *et al.*, 1999; Six *et al.*, 1999).

Twenty-one years of tillage and dryland cropping sequences in the northern Great Plains significantly influenced the amount of crop biomass returned to the soil, the surface residue amount and C content, and soil C fractions.

Soil organic C sequestration had received much attention recently as the concentration of GHG rises in the atmosphere, intensifying climate change (Carbon Dioxide Information Analysis Center, 2008; Grunwald, 2008). Long-term sequestration of C in soils are involved in the decomposition of biologically labile organic matter into more recalcitrant macromolecules through the process of humification (Quideau, 2006). Several discrete organic C pools can be identified on the basis of size, turnover rate, and ecosystem function. The smallest pool with the most rapid turnover rate was typically designated as labile (e.g., residence time of days to years), and the larger pool, with the longest residence time (e.g., decades to thousands of years), was described as recalcitrant (McLauchlan and Hobbie, 2004; Rice, 2006). Thus, quantifying the different compartments of soil organic C improved our understanding of how and at what rate stable forms of C were being formed or lost in soils.

2.7.1 Soil Organic Carbon

Carbon occurs in soils in both organic and inorganic forms. The greater part of the soil C was usually found in organic matter. In humid regions, the entire soil profile was subject to leaching, C occurs predominantly or entirely as organic C. The organic fractions of soil C included the remains of plants, animals, and microorganisms in all stages of decomposition, but consists mainly of strongly altered material of unrecognizable origin.

Microbial activity was increased by SOM oxidation through aeration due to tillage operation (Vance, 2000). Soil structure is less disturbed by

conservation tillage (CT) or no-tillage resulting increase in SOC concentration (Lal and Kimble, 1997). Landuse and management practices significantly influenced soil structure and SOM concentration (Blanco-Canqui and Lal, 2004).

About 58% of the mass of the organic matter of soil existed as organic carbon. SOC was considered as part of SOM which contains dissolve organic matter, particulate organic matter, humus and resistant organic matter. It is responsible for plant growth as a source of energy and trigger nutrient availability through mineralisation.

Another form of soil organic carbon is "humus", which represents the vast of bulk resistant organic matter , having high adsorptive capacity for cations and capable of improving soil structure. The third form of soil organic matter included inert forms of nearly elemental C, such as charcoal, coal or graphite, which were occasionally present in appreciable quantities.

The concentration and content of soil organic C were influenced by climatic factors, soil physical and chemical properties, forest cover type or tree species(Jandle *et al.*2007) and also in the net primary productivity (Ingram and Fernandes,2001). The residence time of soil C was controlled by biochemical alteration and physicochemical protection which were the mechanism responsible for C stabilization (Jastraw *et al.*, 2007).

The C concentration and content did not reflect C stability. Three conceptual pools-labile, slow and resistant were usually defined to characterize soil organic C with a decreasing decomposability and an increasing residence time (Schwendenmann and Pendall, 2007).

Tillage and crop rotation were major regulators of SOC cycling, flow, and storage in cultivated lands. Tillage controled both SOC substrate availability and decomposition rates affecting the quantity and distribution of C derived from plant residues and roots in the soil profile (Wander *et al.*, 1998) and secondly by influencing edaphic factors such as aeration and water content

(Rasmussen, 1999), temperature (Phillips *et al.*, 1980), soil reaction (Dick, 1983), and soil aggregate properties (Six *et al.*, 2002).

A Shift from high to lower soil disturbance often accelerated the accumulation of labile SOC that was less available to microbial attack and subject to edaphic controls that slower down the rates of C decomposition (Paustian *et al.*, 1997). Accumulating greater SOC was dependent on the capacity of agro -ecosystem practices to increase the stability of highly labile C inputs (Huggins *et al.*, 1998). Many studies had revealed that SOC increases in reduced as compared with intensive tillage systems (Halvorson *et al.*, 2002).

The SOC in the clay fraction was more stable and was altered more by physical and chemical processes than by land use changes (Khanna *et al.*, 2001).

SOC retention could be affected by soil texture and mineralogy directly, through sorption by clays (Zinn *et al.*, 2007), and indirectly through soil structure.

In the last two centuries, SOC losses from agricultural soils had been estimated at about 54 Pg of C (Paustian *et al.*, 1998). These C losses had environmental and productivity effects on cultivated lands. As a result, mineralization of SOC had contributed to large CO₂ emissions from soils to the atmosphere and to global climate change (Paustian *et al.*, 2000). In addition, the depletion of SOC had been associated with a loss of fertility and thus with a loss of agroecosystem productivity (Bauer and Black, 1994).

Reducing tillage intensity may lead to a decrease in SOC losses either by enhancing C inputs returned to the field (Alvarez *et al.*, 1995) or, in contrast, by decreasing CO₂ emissions (Curtin *et al.*, 2000).

Soil tillage buried residues, disrupts macroaggregates, increases aeration, and stimulates microbial breakdown of SOC (Reeves, 1997).

High cropping intensity and biomass production was translate into a high potential for photosynthetic C fixation and SOC sequestration (Reeves and Delaney, 2002).

Soil organic matter contains 50 to 58% C and was a complex mixture of organic compounds with different turnover times (Christensen, 2001).

The turnover of SOM was a biological process which depends not only on the chemical composition of the substrate but also on the nature of its association with mineral particles (soil structure).Methods had been developed to isolate fractions according to the size and density of individual soil particles or aggregates (Christensen, 2001).

Accumulation of SOC was a function of eco-system processes, were influenced by current and historic land management practices (Collins *et al.*, 2000).

For soils to act as a C sink, organic C needed to be stabilized in stable C pools (Paustian *et al.*, 1997). SOC protected within aggregates was sensitive to land management practices such as manure application, tillage, or crop rotation (Angers and Carter, 1996).

2.7.2 Particulate Organic Carbon

Particulate organic matter (POM) was defined as this fraction associated with sandsized particles, and separated from the soil by sieving. It was defined that particulate organic matter (POM) as soil organic matter (SOM) particles less than 2 mm and greater than 0.053 mm in size (Cambardella and Elliot 1992). Generally, it consisted mainly of fine root fragments and other organic debris. The POM can account for well over 10% of the soil C (Gregorich *et al.*, 1994).

POM was biologically and chemically active and was part of the labile (easily decomposable) pool of soil organic matter (SOM). This pool was significant to SOM turnover because it served as a readily decomposable substrate for soil microorganisms and as short-term reservoir for plant nutrients. This fraction had been suggested as a sensitive indicator of changes of SOM because of its responsiveness to management practices (Gregorich and Carter, 1997). Vieira *et al.*, 2007 showed that particulate organic matter (>53 μm) could be used to determine the index that measures the lability of organic matter. The particulate fraction acted as a cementing agent, to stabilize macroaggregates and as intra-aggregate protection of the proper organic matter (Six *et al.*, 2002). Costa *et al.*, 2004 also found differential contributions of total organic and particulate organic carbon (more labile) in the formation of soil aggregates.

Particulate organic matter was considered an intermediately decomposable fraction of organic matter, representing in many ways the slow pool of the continuum active–slow–passive soil organic matter (Cambardella and Elliott, 1992). Particulate organic C and N were indicators of changes in soil organic matter brought about by changes in management. Particulate organic C often increased with a reduction in tillage intensity (Wander *et al.*, 1998) and could be the major fraction of total organic C near the soil surface under pastures (Franzluebbers 2002a).

POC was defined as pieces of plant debris of 0.53-2 mm in size. It is decomposed quickly (year to decade). It played important role in maintaining soil structure and providing soil nutrient. Having quick cycle, the POC was considered part of labile carbon.

The particulate organic matter (POM) fraction had been found to accumulate in surface depths, when tillage frequency was reduced. Its rate of accumulation appeared to be greater in finer textured soils (Amado *et al.*, 2006; Needleman *et al.*, 1999).

Particulate organic matter and free light fraction (FLF) consisted mainly of partially decomposed plant residues, microbial residues, seeds, and spores forming organo-mineral complexes with soil mineral particles (Baisden *et al.*, 2002). Particulate organic matter and the FLF have shown sensitivity to short-term changes in tillage management (Sharifi *et al.*, 2008; Yoo and Wander, 2008) but not to fertility treatments (Mirsky *et al.*, 2008).

Soil organic matter is mediated by chemical and physical soil properties (Carter, 2002) and was observed that SOM on soil aggregation and water infiltration had a disproportionate effect on soil physical properties (Boyle *et al.*, 1989). Soils high in SOM generally had greater available water-holding capacity than soils of similar texture with less SOM (Hudson, 1994).

Particulate organic matter was a labile intermediate in the SOM continuum from fresh organic materials to humified SOM (Paul *et al.*, 2001). It was more sensitive to changes in management than total SOM (Cambardella *et al.*, 2001). Under no-tillage practices, aggregate formation was directly related to root-residue decomposition and POM dynamics (Gale *et al.*, 2000a, 2000b).

The particulate organic matter (Cambardella and Elliott, 1992) was a fraction of SOM composed of particulate (>0.05 mm), partially decomposed plant and animal residues, fungal hyphae, spores, root fragments and seeds.

2.7.2.1 Management effects on particulate organic matter

A study on different cropping system recorded the effect of no-till cropping systems of wheat fallow (WF), wheat-cum-fallow (WCF), wheat-corn-millet-fallow (WCMF), opportunity cropping (OPP), and native grass species (G) on particulate organic matter (POM-C) and mineral associated C in the silt and clay fractions. Soil organic carbon (SOC) was increased with increasing cropping intensity after 12 years of no-till management (Sherrod *et al.*, 2005).

Reduced tillage and no-till helped to sequester more POM in the soil than cultivated systems (Angers *et al.*, 1993). It was shown that higher aggregation, carbon sequestration, pH decline and particulate organic matter (POM) build-up were major changes associated with shift from conventional to NT system (Mrabet *et al.* 2001).

POC was highly related with total organic C but became an increasingly larger portion of TOC near the soil surface, where both pools were greatest (Franzluebbers and Stuedemann 2002).

2.7.3 Soil Mineralisable Carbon

Mineralisable carbon was the conversion form to inorganic compounds and was a result of decomposition reactions carried out by decomposing organisms, i.e. bacteria and fungi.

Soil microbial biomass C (SMBC) and potentially mineralized C (CMIN) were considered active fractions of SOM. These active fractions were important for supplying plant nutrients, decomposing organic residues, and developing soil structure (Franzluebbers *et al.*, 2000a).

Soil respiration is defined as the production of carbon dioxide by the soil organisms. Microorganisms, edaphic fauna and plant parts in the soil, such as roots and rhizomes, were the main organisms which produce CO₂ in soil (Hansen *et al.*, 2000).

A small part of the soil respiration (up to 10%) was the result of the decomposition of the recalcitrant organic carbon (Hanson *et al.*, 2000; Schlesinger and Andrews, 2000).

Most of the studies concluded that the most part of the soil respiration (up to 95%) was due to the activity of heterotrophic microorganisms which use the organic matter recently introduced in the soil as an energetic source (Ryan and Law, 2005).

Soil respiration was influenced mainly by soil temperature and moisture (Orchard and Cook, 1983; Howard and Howard, 1993), by vegetation type (Raich and Tufekcioglu, 2000) and substrate availability (Vasconcelos *et al.*, 2004). The turnover or mineralization rate of soil organic matter depended on factors such as quantity and quality of plant residues, water table, salinity, cations and factors affecting microbial activity and soil properties (Baldock and Skjemstad, 2000; Blodau, 2002).

It was revealed that the seasonal variation of the soil respiration rate was consistent with the seasonal variation of temperature. The highest soil respiration rate was recorded in July/August, and the lowest in January. The annual cumulative respiration flux increased by 25.6% and 20.9% in the tea garden with high production (HP) and the vegetable field (VF), respectively, relative to woodland (WL). No significant differences were observed between tea gardens with medium production (MP), low production (Fan *et al.*, 2015).

Aerobic microorganisms were believed to be capable of decomposing organic matter completely whereas mutualistic consortia of microorganisms accomplish anaerobic decomposition because no single type of anaerobic bacteria seems capable of complete mineralization (Kristensen and Holmer, 2001). Presence of submerged conditions for prolonged period of time led to very slow organic matter mineralization in wetland soils as compared to upland soils.

Anaerobic conditions for prolonged periods prevented complete microbial decay of organic matter (Stevenson, 1994). Following the depletion of oxygen, some respiratory microbes can utilize alternative electron acceptors and continue to mineralize the soil organic carbon.

Air and soil temperature, water table level, and the quality of organic substrates could also be the main local controls of CO₂ emissions from peat lands (Mendelsohn, *et al.*, 1999).

2.7.3.1 Carbon fractions and soil respiration

Soil Carbon (SC) quantity had been correlated with the soil's low-density fraction, microbial biomass, and total enzyme activity (Landgraf *et al.*, 2005; Tirol-Padre *et al.*, 2005). SC had been used as a proxy for mineralizable C and had been correlated with basal soil respiration in some specific cases (Tirol-Padre *et al.*, 2005).

Identification of the “mineralizable” soil C pool accurately was essential since it is an important component soil C dynamics and environmental factors (Buchmann, 2000; IPCC, 1996; Stewart *et al.*, 2008).

Evidences do exist that extractable C pools represented chemically labile C, whereas other evidence suggested C biological availability. The water-soluble C (SC) component of soil originates, in part, was from microbial biomass and soluble carbohydrates (Ghani *et al.*, 2003).

It had been found to be sensitive to soil management (Haynes, 2005). It had also been identified as an indicator of soil quality (Ghani *et al.*, 2003).

Only a few studies had combined the measurement of extractable soil C pools such as SC and HC and laboratory incubations to better understand soil organic C dynamics (Paul *et al.*, 2006). The studies had been limited to one or only a few land use or soil types and to a relatively small sample size (Giardina *et al.*, 2001; McLauchlan and Hobbie, 2004).

Soil incubations were direct approach to quantifying mineralizable soil C. Measured $C_{\min}$ rates had ranged from less than 0.007 to 35.6% of total soil C using varying incubations times (12–800 days) and soil temperature and moisture conditions (Giardina *et al.*, 2001; McLauchlan and Hobbie, 2004). These were short-term measurements, and measure only a subset of the total potential mineralizable soil C (Paul *et al.*, 2001, 2006).

It was not well established the amount and distribution of potentially mineralisable carbon present in soils. The distribution of total organic C

(TOC), extractable C pools and in vitro mineralizable C in north Florida watershed was found to be quite heterogeneous (Ahn *et al.*, 2009).

2.7.3.2 Land use and C-mineralization

The impact of landuse changes on organic carbon pools in the mineral soil depended also on long-term site specific factors. Consequently, effects on SOC pools were evident only with the most intensive practices (Veldkamp, 1994). Pasture establishment in the tropics might maintain or even increase the soil organic carbon content with high percentages of below-ground biomass production grasses are used (Feigl *et al.*, 1995). A recent meta-analysis using data from temperate and tropical regions indicated that soil organic carbon stocks increased by 8% after converting native forests into pastures (Guo and Gifford, 2002).

The global carbon cycle was being changed response to human interference by land-use changes which contribute about 23% to human induce CO₂ emissions (Houghton, 2003). Carbon input, magnitude of soil organic carbon pools and finally carbon mineralization depended on many factors. Change in patterns of land-use and land-use management practices could have significant direct and indirect effects on soil organic pools, due to changes in plant species, primary productivity, litter quantity and quality and soil structure.

In contrast, no clear trend in soil C change following the conversion from forest to pasture was shown in a data compilation for the tropics by Lugo and Brown (1993). Murty *et al.*, 2002 also found no trend in soil C after conversion from forest to pasture in temperate and tropical regions.

It was proposed on the basis of recent studies that reforestation of degraded and abandoned tropical pastures has been taken as a measure to mitigate increasing atmospheric CO₂ levels (Silver *et al.* 2000). However, the effects of reforestation could result in losses or gains of soil C pools (de Koning *et al.* 2003, Silver *et al.* 2004).

Land-use change affected carbon stocks and also soil respiration rates (Trumbore *et al.* 1995). Since soil respiration was a major CO₂ flux in C cycle it is important to assess magnitude and dynamics of soil CO₂ emission to characterise the carbon exchange in ecosystem (Raich and Schlesinger 1992).

2.7.4 Labile Carbon

The labile C pool was the fraction of SOC with the most rapid turnover rates. Labile carbon referred to those fractions most subject to management changes and includes microbial biomass, particulate organic matter and POM density fractions. Labile carbon was closely associated with nutrient mineralization. This fraction was the first to be depleted by continuous cultivation and to first to reform during fallow or other management practices resulting soil C increase such as minimum tillage, crop residue retention or addition of manures (Lal *et al.*, 1998).

On oxidation, this pool of SOC added to the loading of CO₂ to the atmosphere to accelerate the process of global warming. This pool was also important from the point of view of crop production. It was the source of the soil food web and therefore greatly influences nutrient cycling for maintaining soil quality and its productivity (Chan *et al.*, 2001; Majumder, 2007).

The labile pool of SOM could be readily increased by the addition of plant and animal residues. It could be easily lost by reduced addition of SOM or tillage is intensified with associated mineralization (Doyle *et al.*, 2004; Liang *et al.*, 2004; Mirsky *et al.*, 2008).

Soil fractions belonging to the labile pool had turnover rates of days to a few years, while turnover rates for fractions in the intermediate and stable pools ranged from a few years to centuries (Wander, 2004).

Labile SOM pools were characterized by a rapid turnover, mainly consist of young SOM, and were affected by land management and environmental conditions.

Soil microbial biomass, particulate organic matter, dissolved organic matter, mineralizable organic matter and permanganate oxidizable organic matter had been recognized as labile SOM pools (Ladd *et al.*, 1994).

The most commonly isolated labile C pools were the light fraction (LF) and particulate organic matter (POM). The LF consisted mostly of mineral-free, partly decomposed plant debris and appears in soils as free POM (Six *et al.*, 1998).

Generally the labile pool had a greater turnover rate or shorter mean residence time, compared with recalcitrant pools (Paul *et al.*, 2001). Due to a greater turnover rate, the labile pool had a smaller pool size, ranging from 1 to 20% of total SOC (McLauchlan and Hobbie, 2004).

The lability of SOM was defined (McLauchlan and Hobbie, 2004) as the relative ease and rate with which it was decomposed by microbes. This depended on both chemical recalcitrance and physical protection from microorganisms.

Many investigation had reported responses of labile SOC pools to management practices (Franzluebbers *et al.*, 1995; Six *et al.*, 2000).

The highly recalcitrant or passive pool was altered only very slowly by microbial activities. It hardly served as a good indicator for assessing soil quality and productivity (Weil *et al.*, 2003; Sherrod *et al.*, 2005; Majumder, 2007).

It was noted that individual labile organic matter fractions are sensitive to changes in soil management and had specific effects on nutrient cycling. On the basis of resident time labile carbon was categorized as very labile, labile, less labile and non-labile carbon (Haynes 2005).

2.7.5 Soil Inorganic Carbon

A good portion of soil carbon occurs in inorganic form. In arid regions carbonate carbon dominates over organic carbon. Calcite and dolomite are the major components of the inorganic fraction of soil C. Soluble forms of carbonate-C occur in appreciable quantities in high sodic (alkali) soils of arid regions. The amount of carbon in this form is generally small as compared to the insoluble carbonate.

Soil inorganic carbon (SIC) consists mineral forms of carbon, either from weathering of parent material (bed rock) or from reaction of soil minerals with atmospheric CO₂.

Carbon sequestration in soil has been suggested as a means of reducing the rate of increase of atmospheric CO₂. Most soil science research has been on soil organic carbon (SOC) sequestration but in arid and semiarid climates, soil inorganic carbon (SIC) has potential for C sequestration.

The content of SOC in irrigated soils of semiarid and arid regions was low due to low formation rates and relatively high decomposition rates produced by high temperatures and sufficient water from irrigation. In these regions, net accumulation of SOC under irrigation was likely to be difficult (Lee *et al.*, 2006), and C sequestration as inorganic forms may prove to be acceptable alternative (Lal and Kimble, 2000a, 2000b; Lal, 2001a; Entry *et al.*, 2004).

Soils from semiarid and arid regions often contain Ca and Mg carbonates. Carbonate accumulation in soil profiles can result from all or part of the redistribution of detrital carbonate or redistribution of exogenous material and in situ secondary carbonate formation due to primary mineral weathering.

The redistribution of SIC can result from dissolution and reprecipitation of inherited carbonate minerals due to cycles of soil wetting and

drying or by translocation as colloidal suspensions with the soil solution (Neaman *et al.*, 2000).

2.7.6 Total Organic Carbon

Total organic carbon (TOC) is the carbon stored in Soil organic matter (SOM), Organic Carbon (OC) enters the soil through decomposition of plant, root, living and dead microorganism, soil biota.

It is the measure of the carbon contained within soil organic matter. It has been established that continuous pastures builds organic carbon quicker than other rotation.

Total organic carbon influences colour, nutrient, nutrient holding capacity and nutrient stability. It is the sum of three carbon forms (organic, elemental and inorganic carbon). This carbon is the combination of slow fraction and active or labile fraction.

2.8 Distribution of Soil Carbon

A number of data sources were needed to measure, model, and predict changes in soil C flux (Izaurrealde, 2005). To obtain soil C flux estimates with high spatial resolution and that cover a large geographic region, data were particularly needed that (i) represent local- to field-scale C dynamics, (ii) were consistently collected across the region of interest, and (iii) enable the attribution and distribution of C dynamics to appropriate land use classes across the region.

There were efforts currently underway to integrate data in a more robust manner and to use the final products to address a number of current issues, including land use change, C dynamics, and climate change (Melton *et al.*, 2005).

2.8.1 GIS mapping of Carbon pools

The demand for maps of soil properties across large regions has increased considerably in the last decades. This reflects a growing concern for the conservation of soil resources for the provision of commodities and ecosystem services, including food and fiber, water quality, and biodiversity. In this context, soil organic C (SOC) is a central property that relates to biological, chemical, and physical soil properties and processes.

Given ongoing anthropogenically induced climate change (Carbon Dioxide Information Analysis Center, 2008), it was essential to quantify the present SOC stocks and to understand how SOC behaved spatially across large regions. Spatial analyses were thus needed to assess the potential of soils to sequester C and mitigate climate change. Simply quantifying total SOC may not yield an adequate understanding of soil C dynamics because C exists in several different soil pools that can be defined on the basis of stability and residence time. The recalcitrance or lability of C forms in soils depended on several environmental determinants, such as climate, topography, hydrology, land use, and other properties (McBratney et al., 2003; Stevenson and Cole, 1999). To understand the dynamics of SOC across large landscapes, multiple C pools must be considered along with their interaction with environmental landscape properties.

Estimates of soil organic C (SOC) storage and their variability at various spatial scales were essential to better understand the global C cycle, estimate C sink capacity, identify effective C sequestration strategies, and quantify the amount of SOC sequestered during a specific period of time.

Soil organic C exchanges with atmospheric C pools in response to changes in crop inputs, residue decomposition, erosion, and soil aggregate breakdown (Bruce *et al.*, 1999; Stevenson and Cole, 1999). The numerous interactions between these factors created a complex gradient of SOC content across a landscape (Bird *et al.*, 2001).

Soil C had been shown to be spatially dependent, varying laterally both by and within soil type and landscape position (Davis *et al.*, 2004; Young and Hammer, 2000a, 2000b).

Precise measurement of the SOC stocks and verification of the amount of C sequestered in the soil were among the critical factors in implementing C trading programs. Similarly, estimates of the spatial distribution of SOC stocks were necessary to quantify the SOC sink capacity of soils.

Soil organic C maps showing the sink capacity at various scales were necessary to design an effective C sequestration program. Therefore, obtaining an accurate map was important, as both the rate of change in SOC and its fractions. The sink capacity depended on the initial SOC stock. Estimates of SOC stocks at larger spatial scales across different soil depth intervals are limited by time and cost constraints. Therefore, digital SOC mapping representing SOC stocks at different spatial scales such as plot, watershed, regional, and national levels are important.

Since the 2000s significant advances have been made in software for GIS (Schulp and Veldkamp, 2008; Hartemink, 2008; Lilburne *et al.*, 2012).

2.8.2 Spatial distribution of soil carbon

The estimation of soil carbon sequestration and its spatial distribution maps for Brazilian soils (Bernoux *et al.*, 2002; Wang *et al.*, 2003; Bernoux *et al.*, 2005; Bayer *et al.*, 2006; Cerri *et al.*, 2007; Fidalgo *et al.*, 2007; Tornquist *et al.*, 2009) have estimated to the preparation of national GHG inventories.

The magnitude of SOC stocks at a location depended on a range of factors such as the soil type, land use, annual input of biomass C, and the severity of degradation. Several approaches and techniques were needed to develop a reliable estimate of SOC stocks at different spatial scales (Lal, 2004). It was also reported the need for further research in using secondary information to map SOC stocks at different scales. Quantifying SOC stocks at

different spatial scales in a cost effective manner was a priority research topic for recent time research.

Studies showing the spatial variability of SOC stocks had been conducted at plot (Simbahan *et al.*, 2006), watershed (Minsany *et al.*, 2006) and regional (Meersmans *et al.*, 2009) scales. These studies used a variety of techniques such as geo statistics, artificial neural networks, and multiple regression in SOC stock mapping. These techniques were useful, as they showed the spatial variability of SOC stocks and their associated uncertainty. However, very few studies have been conducted to quantify SOC stock variability at different depth intervals using profile depth distribution functions and geo statistics at regional scales. The environmental variables of elevation, climatic factors (temperature and precipitation), and land use were included in this study predict and map SOC stocks at different depth intervals within the upper 1-m depth. (Mishra *et al.*, 2007).

Attempts to quantify global soil carbon stocks (SCS) since 1970s and develop maps of regional carbon distribution had greatly advanced efforts to predict temporal changes in SCS for different land use and soil management systems (Lettens *et al.*, 2004, Bradly *et al.*, 2005). These studies had strengthened the understanding of C distribution in diverse ecosystems and also advanced the management and monitoring techniques along with the use of GIS.

Inventories of C footprints on a landscape scale were essential tools for estimating C offsets from agricultural emissions. The study conducted in the subtropical humid ecosystem in southern Brazil (Morase Sa *et al.*, 2013) on landscape soil C stocks for each landuse system.

Reasonable amount of information on soil organic carbon status and carbon stock for different agro-ecological zones in spatial scale and their interaction with climate change implications based on past and present scenarios, projections of possible changes in future climate scenario etc. has

been generated for main land India (Ajtay et al., 1979; Dadhwal and Nayak, 1993; Chhabra et al., 2003; Bhattacharyya et al., 2009 and Singh et al., 2011).

2.9 Management Influence on Carbon Storage

Long term field experiments in north China plan suggested that returning of crop residue to the soil through rotary tillage and no tillage increased SOC and total N in the 0-30 cm soil layer. But no distinct change in SOC and total N concentration were observed at soil depth >30 cm. Conservation tillage (RT&NT) increased SOC and total N contents in the upper soil layers, but did not increase SOC & total N storage over conventional tillage in deeper soil. Experiment suggested that tillage practices strongly affected the soil bulk density and distribution of SOC and total N in soil profile in the north China plan (Du *et al.*, 2010).

Conservation management of degraded lands had the potential to build soil fertility, restore soil functions and mitigate green house gas emissions as a consequence of surface soil organic matter accumulation. Evidences suggested that conservation agriculture system in the south eastern United States would sequester a significant amount of organic C in the surface 20 cm of soil. Both conservation tillage croplands and perennial pastures exhibited high SOC sequestration.(Alan J. Franzlubbers, 2010).

Field study conducted in west-central north Dakota under no tillage management showed that the inclusion of cover crops during fallow (i.e. green fallow) may mitigate GHG emissions from dryland cropping systems (Liebig *et al.*, 2010). Some of the management practices that influenceed soil CO₂ emission were irrigation, tillage, cropping system and N fertilization (Curtin *et al.*, 2000; Sainju *et al.*, 2008). Irrigation could enhance CO₂ emission compared with no irrigation by increasing soil water availability (Sainju *et al.*, 2008), microbial activity, C mineralization, and respiration (Calderon and Jackson, 2002).

Decreased tillage intensity reduceed soil disturbance and microbial activity, resulting lower CO₂ emission (Curtin *et al.*, 2000). Increased tillage

intensity increased CO₂ emission by increasing soil aeration and disrupting soil aggregate and by physical degassing of dissolved CO₂ from the soil solution (Jackson *et al.*, 2003).

As the atmospheric CO₂ concentration continued to rise at a rate of 1.7 $\mu\text{mole mol}^{-1} \text{ year}^{-1}$, there was strong scientific interest in finding ways to slow or reverse this trend. Mitigation strategy for emission of CO₂ from soil may be adopted by agricultural practices that lower the release of C from soil (Lal, 2008). Conservation tillage practices such as RT and NT produced less soil disturbance and physical fragmentation of crop residue than CT which is expected to increase the SOC pool (Madgoff and Weil, 2004).

Adoption of practices like organic farming, minimum tillage, no-tillage in irrigated agriculture had produced a diversity of results with respect to net C sequestration (Schlesinger, 2000; Entry *et al.*, 2002, 2004; Lee *et al.*, 2006).

Management operations such as tillage, planting, field cultivation, and wheel traffic all had impact on these soil factors (Shipitalo *et al.*, 2000; Petersen *et al.*, 2001; Vogeler *et al.*, 2005). A successful management strategy should be able to manipulate soil factors to reduce chemical losses from agricultural systems.

The SOC pool in surface soil was sensitive to changes in land use and crop and soil management practices. Loss of SOC often occurred under tillage practices that mix in surface residue, thereby raising turnover rates (Prior *et al.*, 2000; Balesdent *et al.*, 2000; Bauer *et al.*, 2006).

Increases in SOC contents in surface soils had been achieved through CT management practices (Freibauer *et al.*, 2004; Goh, 2004; King *et al.*, 2004; Wang *et al.*, 2004). Tilling soils using CT practices, where surface residue was minimally incorporated, can increase SOC concentrations by minimizing residue oxidation (Bauer *et al.*, 2006).

A soil under CT management would eventually reach a maximum C sequestration capacity due to C input and output steady-state relationship will

occur (Sauerbeck, 2001; Swift, 2001). It was reported that soil C sequestration rates under CT management can be very rapid in the first 5 to 10 yr, but after 15 to 20 yr can be followed by little change (Freibauer *et al.*, 2004). Some soils under CT may take 50 yr to approach a steady-state C phase, depending on soil pedogenic properties, climatic conditions, and crop management (Lal, 1998).

No-till management could increase soil organic C (SOC) levels (Paustian *et al.*, 2000). This was an important management decision because terrestrial C sequestration has been suggested as a potential strategy for greenhouse gas mitigation.

NT farming was highly beneficial to soil and water conservation and reduction of production costs and it is potential for sequestering SOC (Puget and Lal, 2005).

2.9.1 Tillage effect on Carbon sequestration

No-till (NT) agriculture had been promoted as one of the optimal management practices that preserves soil and water, and increases soil organic C (SOC) compared with conventional tillage (CT) practices.

Most studies had suggested that any increase in SOC concentration with conversion from CT to NT occurs in the surface 0 to 15 cm of soil (Wander *et al.*, 1998; Needelman *et al.*, 1999). This had led to the assumption that the use of conservation practices would lead to net SOC accumulation. Several studies had actually noted an increase in the SOC content in CT compared with NT fields in the layer where the residue was incorporated (15–30-cm depth), presumably due to a greater input of biomass C with depth in CT fields where decomposition also may be restricted (Haynes and Beare, 1995; Angers *et al.*, 1997).

The lower SOC in deeper NT layers may offset the greater SOC in the upper layers, and the total profile SOC between NT and CT soil management may not significantly differ. Thus, the amount of SOC stored in deeper layers (>30 cm) was probably the most important fraction for long-term SOC sequestration.

Many studies had highlighted some of the variable management strategies affecting the SOC pool in NT fields, including the duration of NT (Six *et al.*, 2002; West and Post, 2002) and the quantity and pattern of residue additions to the soil (Angers *et al.*, 1997).

No-tillage crop management had been identified as an important practice to increase soil aggregation and C and N sequestration (Wright and Hons, 2005). Tillage disrupted aggregation and mineralizes SOC and STN (soil total nitrogen) by disturbing soil, exposing new soil to wet-dry and freeze-thaw cycles, incorporating plant residues into the soil, increasing aeration, and affecting microbial communities (Beare *et al.*, 1994; Paustian *et al.*, 1997).

Tillage was more disruptive of larger than smaller aggregates, making SOC and STN from larger aggregates more susceptible to mineralization (Six *et al.*, 2000).

Both tillage and fertilizer management influenced soil organic C (SOC) storage, but their interactive effects remain to be determined for various soil and climatic conditions. Several studies had shown that tillage and fertilization practices influence SOC content (Vanden Bygaart *et al.*, 2003).

By increasing crop productivity and the amounts of residue (including roots) returned to the soil, N fertilization could increase SOC storage (Campbell and Zentner, 1993). Moran *et al.*, 2005 also reported that N additions can increase the mineralization of crop residue C without increasing the mineralization of the native SOC.

Result showed that N additions accelerated decomposition of the light fraction of SOC but tended to further stabilize the SOC present in heavier fractions (Neff *et al.*, 2002). It was concluded that N addition stimulated litter decomposition for high-quality residues but decomposition was inhibited for low-quality residues (Knorr *et al.*, 2005).

- It was well documented that tillage method was a major land management factor controlling C sequestration and cycling in croplands (Dick

et al., 1998; Aslam *et al.*, 1999). Several studies had documented a restoration in soil biological activity with implementation of NT farming (Alvarez and Alvarez, 2000; Jacinthe and Lal., 2005).

Biochemical indices such as microbial biomass and activity tended to respond quickly following cessation of tillage disturbance (Islam and Weil, 2000) and were thus sensitive bio indicators of soil quality.

Conservation tillage involved minimal surface tillage, leaving crop residues to accumulate at the soil surface. The unincorporated crop residues decomposed slowly. Soil organic C accumulation under CT management was slow and depth specific (Lal 2004). The SOC accumulation in CT usually was in the top few centimeters of soil (Hunt *et al.*, 1996; Dolan *et al.*, 2006; Novak *et al.*, 2007; Blanco-Canqui and Lal, 2008).

2.9.2 Carbon storage under different Treatment

Crop residue and mechanical disturbance from tillage interactively affected SOC and total N storage distribution and storage in the soil profile. Study indicated that a sampling depth of 30 cm was appropriate to assess the change in SOC and total N in soil profiles under different tillage system (Du *et al.*, 2010).

Carbon dioxide, a major green house gas responsible for global warming, was emitted from crop and grass lands due to oxidation of soil organic matters, root and microbial respiration, and return of unharvested plant residues to soil (Curtin *et al.*, 2000; Sainju *et al.*, 2008).

Investigation on the fate and rate of stabilization of root vs residue C and the role of soil aggregates in root vs residue derived C accumulation with long term conventional, low- input and organic cropping system suggested that root C contributes more to over all C stabilization than residue C (Maillard *et al.*, 2010).

One of the challenges to assessing the impacts of crop residue and tillage management on SOM stocks was the fact that SOM concentrations

change slowly (decades) and could be difficult to detect over the course of typical field studies. Accurate assessment of changes in SOM stocks was affected by soil variability and number of samples as well as the duration of management practices and depth of sampling (Vanden Bygaart *et al.*, 2011).

The content and composition of SOM depended on both the input from crop and root residues (Francioso *et al.*, 2000) and the processes of OM decomposition (Mathers and Xu, 2003), which were controlled by soil type, climatic conditions, and management practices including soil cultivation, fertilization, and crop rotation (Antil *et al.*, 2005; Kaiser *et al.*, 2007).

2.10 Soil Carbon Pools and environmental effect

It is known that NT and CT systems could increase soil C, and the size of these beneficial effects is affected by soil type and climate (Collins *et al.*, 2000; Lal, 2000). However, soils under NT were wetter and cooler than under CT, a condition that may be more favorable for denitrification, resulting in higher N₂O emissions (Scott *et al.*, 2000; van Bochove *et al.*, 2000).

Land management strategy could reduce the rise of atmospheric CO₂ through C sequestration in soil. Below ground process controlled terrestrial C cycling largely (Ryan and Law, 2005).

Mineral soil accumulation was largely dependent on the factors, soil moisture and N availability tested in central and southern Appalachian forest (Trettin *et al.*, 1999). These factors regulated mineral soil C through their effects on productivity, belowground C allocation, and rates of decomposition and respiration.

Soil organic C dynamics are regulated largely by climate, soil physical properties, and the amount of plant litter input. Climate change affects soil temperature, moisture and litter quality which are the important controls of C mineralisation.

2.10.1 Temperature effect

Temperature and rainfall exert significant influence on the decomposition of soil organic carbon and crop residues. Rise in the mean annual temperature reduces the level of SOC of cultivated soil in the humid region. Higher temperature activates the soil microbial population to a greater extent than plant growth. In temperate climates, the soils are several times richer in organic carbon than warmer climate (Singh *et al.*, 2012). It was reported in a study in the redwood forest and seasonal grassland ecosystem at California that CO₂ flux increased exponentially with temperature. Emission of CO₂ is largely dependent on soil diffusivity with water content. Major flux (67%) was observed in the top 20 cm soil. Soil temperature and water content in the grassland exerted strong positive controls on CO₂ emission with CO₂ efflux highest in early spring (8g Cm⁻² d⁻¹) and lowest in last summer (0.4g Cm⁻² d⁻¹).

These two climatically similar sites showed reverse patterns of soil respiration. In the redwood soil, CO₂ emission rates were highest in the last summer and early fall. In this season the soils are no longer saturated and soil temperatures are greatest. While the efflux rates were lowest during the cool, wet winter. CO₂ production increased exponentially with increasing temperature was due to changes on soil diffusivity with increasing water content. At the seasonal grassland site, reverse pattern found, where CO₂ efflux rates were highest in the late winter and early spring and were lowest in the late summer and early fall (Sanderman *et al.*, 2010).

The primary factor influenced the rates of organic matter decomposition was temperature which is also a major determinant of microbial process (Andrews *et al.*, 2000; Waldrop and Firestone, 2004).

Temperature, a major determinant of microbial processes, was often identified as the primary factor influencing the rates of organic matter decomposition (Schimel *et al.*, 1994).

Temperature and rainfall exerted significant influence on the decomposition of soil organic carbon and crop residues. Rise in the mean annual temperature reduced the level of SOC of cultivated soil in the humid region. Higher temperature activated the soil microbial population to a greater extent. In temperate climates, the soils were several times richer in organic carbon than warmer climate. High rainfall and low temperature were conducive to accumulation of organic carbon in soils while high temperature and low rainfall decrease it.

Increase in global average air and ocean temperatures, widespread melting of snow and ice and rising average global sea level were the indicator of warming of climate system. The warming trend in India over the past 100 years (1901 to 2007) was observed to be 0.51°C with accelerated warming of 0.21°C per every 10 years since 1970. Global green house gas (GHG) emissions due to human activities have grown since pre-industrial times, with an increase of 70% between 1970 and 2004. Whereas the emission of carbon dioxide (CO_2) has grown by about 80% between 1970 and 2004, from 21 to 38 gig tones (Gt), and represented 77% of total anthropogenic GHG emissions in 2004 (IPCC, 2007). In view of the widespread influence of climate change, there was a need to reduce the emissions of green house gases which are the main factors of climate change. The mean annual temperature increase was more rapid in recent years than last century (AICRPAM, 2010-11)

Being the largest carbon pool in terrestrial ecosystem it was assumed that if the small fraction of soil C pools may mobilized due to global warming. To understand soil carbon dynamics under climate change study of the effect of temperature on soil organic matter decomposition was required. A Study conducted to investigate the temperature sensitivity of freshly added organic matter and bulk soil carbon that the addition of fresh organic matter accelerated decomposition of soil organic matter and relation with temperature. Result indicated that there is no simple substrate-temperature sensitivity relationship,

but complex interactions governing the emergent temperature sensitivity (Thiessen, *et al.*, 2012).

Research finding had been cited that soil C emission is high in a warmer atmosphere. In soil warming experiments, the initially increased carbon dioxide efflux returns to prewarming rates within one to three years and apparent carbon pool turnover times were insensitive to temperature. It had already been reported that the apparent lack of temperature dependence could be an artefact due to neglecting the extreme heterogeneity of soil carbon.

A simple three-pool model explains that partitions SOC into components with different intrinsic turnover rates. It was shown that the results of all the soil-warming experiments were compatible with long-term temperature sensitivity of SOC turnover. They could be explained by rapid depletion of labile SOC combined with the negligible response of non-labile SOC on experimental timescales. There was also evidence that non-labile SOC is more sensitive to temperature than labile SOC which implied that the long-term positive feedback of soil decomposition in a warming world may be even stronger than predicted by global models (Knorr *et al.* 2005).

Effect of particle size SOC on temperature had been poorly studied. It was compared the effects of temperature (7, 14, and 21°C) on C mineralization rates in fractionated soils from four land use systems viz agriculture, plantation; grassland, and native aspen stand in the parkland region of Alberta, Canada, over a 370-d laboratory incubation. Carbon was largely held in the fine fraction followed by the medium and coarse fractions. Across land uses and incubation temperatures, the amount of C mineralized from bulk soil over 370 d ranged between 2 and 9% of initial total organic carbon. Result concluded that the mineralization potential and temperature sensitivity of soil organic C in the studied land use systems were controlled mainly by organic matter quality and physical protection provided through aggregation and adsorption (Arevalo *et al.*, 2012).

2.10.2 Humidity effect

The combined effects of water status, vapour pressure deficit (VPD), and elevated temperature were studied by Diaz, *et al.*, 2002. Plants growing at high VPD, either under well-watered or water deficit conditions, had higher grain yield and grain filling rate than plants growing at low VPD. By contrast, water stress decreased grain yield and individual grain dry matter at any VPD. The differences between treatments were maximal in mature grains, where high VPD increased C for both water regimes. The effects of combined moderately high temperature and drought on yield were attenuated at high VPD (Diaz,*et al.* 2002).

Many soils of the lowland humid tropics were taken to be too infertile to support sustainable agriculture. However, there was strong evidence that permanent or semi-permanent agriculture could itself create sustainably fertile soils. These soils contained higher concentrations of nutrients such as nitrogen, phosphorus, potassium and calcium, as well as large amounts of stable soil organic matter (Jenny, H. and Raychaudhury, S.P. 1960).

A more humid atmosphere helped to explain PETM temperatures, but the ultimate mechanisms underlying the shift remain unknown (Bowen *et al.*, 2004)

Although the response of carbon fluxes to environmental variables, such as air humidity and temperature had been reported in some studies (Wang, *et al.*, 2004; Li, *et al.*, 2005) were rare. Increases in atmospheric concentrations of CO₂ could have large but offsetting effects on ecosystem productivity (King *et al.* 2005). Litter fall amounts could be altered by both elevated CO₂ and O₃ (Liu *et al.*, 2005).

2.10.3 Rainfall effect

High rainfall and low temperature are conducive to accumulation of organic carbon in soils while high temperature and low rainfall decrease it. (Singh *et al.*, 2012)

Organic carbon stocks in surface layer of the soils increased with rainfall while inorganic carbon stocks in soils were found in the regions with less than 550 mm annual rainfall. CEC showed better correlation with organic carbon stocks than clay content in soils. Results suggested that Indian dry land soils are low in organic carbon but had potential to sequester. Further potential of tropical soils to sequester more C in soil could be harnessed by identifying appropriate production systems and management practices for sustainable development and improved livelihoods in the tropics (Srinivasarao *et al.*, 2009).

SOC stocks increased as the mean annual rainfall increased. Significant correlation was obtained between SOC stock and mean annual rainfall. On the other hand, soil inorganic carbon (SIC) stocks decreased from 156.4 Mg ha⁻¹ to 25.97 Mg ha⁻¹ with the increase in mean annual rainfall from < 550mm to > 1100 mm. As the SIC stocks were more dominant than SOC, total carbon stocks decreased from 183.79 Mg ha⁻¹ with increase in mean annual rainfall from <550 mm to >1100 mm in the arid environment 70.24 Mg ha⁻¹ in sub-humid regions. In the present scenario of differing climatic parameters such as temperature and annual rainfall in some areas of the country, it would continue to remain as a potential threat for carbon sequestration in tropical soils of the Indian sub-continent. Therefore, the arid climate would continue to remain as a bane for Indian agriculture because this will cause soil degradation in terms of depletion of organic carbon and formation of pedogenic CaCO₃ with the concomitant development of sodicity and / or salinity (Eswaran *et al.*, 1993).

Tropical regions had limitation of sequestering carbon in soil due to high temperature, adoption of appropriate management practices helps in sequestering reasonable quantities of carbon in some cropping systems

particularly in high rainfall regions (Srinivasarao *et al.*, 2009, 2011b, 2012 b). The potential of cropping systems could be divided in to that of soil carbon sequestration and sequestration in to vegetation. Tree based systems could sequester substantial quantities of carbon in to biomass in a short period. Total potential of soil C sequestration in India is 39 to 49 Tg yr⁻¹ (Lal, 2004).

It is evident from various studies undertaken on soil C sequestration, determination of soil physico-chemical properties, carbon fractions and management practices that soil carbon stocks are largely dependent on land use and land cover systems. Soil can act as sink for atmospheric carbon depending on the adoption of proper management practices, mapping of soil carbon and appropriate land use planning. No-till agriculture has considerable potential to mitigate CO₂ efflux to atmosphere and accumulation of SOC in the soil at greater extent. Moreover, carbon mapping of an area help in identification on location specific adaptation and mitigation strategies related to carbon sequestration and sustainable agriculture.

The mean annual precipitation varies from 249 - 389, 129- 1080 and 219 - 338 cm under Tista- Brahmaputra plains, Assam Hill and valleys, and lesser Himalayan ranges, respectively. The mean annual temperatures of Himalayan range are plotted against elevation has a nearly perfect straight line results with a negative gradient of 0.062°C per 30.5 m. The organic carbon values of these soils are two to three times higher than those of the cultivated soils of the Indo-Gangtic alluvium, presumably because of higher rainfall (254-356 cm) and finer textures of the soils (Singh *et al.*, 2012).

Chapter 3

MATERIALS AND METHODS

3.1 Materials

3.1.1 Soils under study and their collection

Total 48 soil samples were collected using GPS72 (GARMIN) covering three districts (Cooch Behar, Jalpaiguri and Darjeeling) of *Terai* region of West Bengal. The experiment was conducted in the laboratory of Soil Science and Agricultural Chemistry, in the Faculty of Agriculture, Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal. The soil used in this study belongs to four landuse of Terai region. Soil samples were collected randomly and composite surface soil samples from several locations of three districts (Cooch Behar, Jalpaiguri and Darjeeling) of the northern parts of West Bengal were prepared. After removing the surface litter, soil samples were taken from 0-20 cm, 20- 40 cm and 40-60 cm depth from sixteen (16) locations by using an auger and mixed thoroughly to make a composite sample. All soils were collected in the month of October,2013 to April,2014. Soils were air dried in shade and ground to pass through a 2 mm sieve and retained for analysis.

A portion of the fresh soils were quickly transferred to plastic containers and kept under refrigeration as soon as possible. A portion of the soils were oven dried at 105° C for eight hours for calculation of moisture percentage. All results are reported on oven dry basis. Physico-chemical characteristics of the soils were determined by standard methods.

Table 1. Geographical Locations of the collected soil samples

Type of Soil	Place	Item	Elevation	Latitude	Longitude
Agriculture	Balarampur	1	26m	N- 26° 14'15.1"	E- 89° 34'50.4"
		2	31.5m	N- 26° 14'15.2"	E- 89° 34'50.8"
		3	33.6m	N- 26° 14'14.6"	E-89° 34'50"
	Kumargram	1	46.6m	N- 26° 33'16.4"	E- 89° 49'25.6"
		2	63.3m	N- 26° 33'17.6"	E- 89° 49'23.2"
		3	70.8m	N-26° 33'18"	E-89° 49'22"
	Binnaguri	1	150.2m	N- 26° 52'30.4"	E-88° 55'01"
		2	149.7m	N- 26° 52'30.3"	E- 88° 55'01.4"
		3	151.6m	N- 26° 52'30.8"	E- 88° 55'02.3"
	Kharibari	1	71.6m	N- 26°33'41.6"	E- 88°12'33.2"
		2	72.4m	N-26°33'36"	E- 88°13'00.3"
		3	74.8m	N- 26°33'48.3"	E- 88°13'09.1"
Fallow	Balarampur	1	22.5m	N- 26° 14'38.5"	E-89° 35'03"
		2	33.7m	N-26° 14'38"	E- 89° 35'02.6"
		3	30.9m	N- 26° 14'39.1"	E- 89° 35'02.4"

Type of Soil	Place	Item	Elevation	Latitude	Longitude
	Kumargram	1	60.9m	N-26° 33' 33"	E-89° 49' 26.9"
		2	58.3m	N-26° 33' 32.7"	E-89° 49' 27.6"
		3	72m	N-26° 33' 33.7"	E-89° 49' 27"
	Binnaguri	1	135.7m	N-26° 46' 18.7"	E-89° 02' 3.1"
		2	146.6m	N-26° 46' 16.2"	E-89° 02' 3.3"
		3	148.6m	N-26° 46' 19.2"	E-89° 02' 3.2"
	Kharibari	1	80.4m	N-26° 34' 57.8"	E-88° 15' 40.3"
		2	81.2m	N-26° 34' 57.9"	E-88° 15' 40.6"
		3	80.6m	N-26° 34' 40.6"	E-88° 15' 40.5"
Tea Garden	Nimti Jhora Tea Garden	1	47.4m	N-26° 35' 25.7"	E-89° 26' 48.1"
		2	66.9m	N-26° 35' 25.9"	E-89° 26' 47.9"
		3	58.4m	N-26° 35' 25.6"	E-89° 26' 46.2"
	Moraghat (Binnaguri) Tea	1	139.1m	N-26° 46' 5.6"	E-89° 02' 3.9"
		2	139.5m	N-26° 46' 6.9"	E-89° 02' 4.1"
		3	137.9m	N-26° 46' 08.1"	E-89° 02' 3.8"
	Kumargram	1	74.4m	N-26° 38' 39.2"	E-89° 49' 44.1"
		2	85.8m	N-26° 38' 39.8"	E-89° 49' 44.5"
		3	88.4m	N-26° 38' 39.6"	E-89° 49' 45.2"
	Elena Bari (Odlabari)	1	188.8m	N-26° 52' 16.9"	E-88° 32' 6.2"
		2	196.1m	N-26° 52' 15.9"	E-88° 32' 6.6"

Type of Soil	Place	Item	Elevation	Latitude	Longitude
		3	185m	N- 26° 52'16.7"	E-88° 32'7.6"
Forest	Mahananda North Range	1	228.6m	N- 26° 51'32.5"	E-88° 27'43.2"
		2	232.4m	N- 26° 51'33.3"	E-88° 27'43.1"
		3	246.1m	N- 26° 51'35.0"	E-88° 27'41.4"
	Gorumara National Park	1	183.3m	N- 26° 47'27.5"	E-88° 48'56.6"
		2	185.7m	N- 26° 47'28.2"	E-88° 48'55.7"
		3	185.1m	N- 26° 47'20.1"	E-88° 48'08.3"
	Chilapatta	1	239.4m	N- 26° 33'29.8"	E-89° 22'49.7"
		2	282.2m	N- 26° 33'30.8"	E-89° 22'49.6"
		3	324.8m	N- 26° 33'30.4"	E-89° 22'47.7"
	Buxa (Rajabhatkhawa)	1	62.1m	N- 26° 36'50.6"	E-89° 32'03.2"
		2	83.7m	N- 26° 36'49.9"	E-89° 32'02.9"
		3	116.5m	N- 26° 36'50.2"	E-89° 32'03.3"

3.1.2 Soil sampling

The soils were collected at four to five uniform spots from each land use/land cover site at 0-20 cm, 20-40 cm and 40-60 cm depths during 2013-2014 using a soil auger (5 cm diameter). At each site, three sub-samples were drawn and pulled together to form one composite soil sample. After removing all stubbles, residues and unwanted substances, composite soil sample collected from each site and depth were homogenized and air dried at room temperature, ground in wooden mortar, sieved through 2 mm sieve and preserved with care in covered plastic containers for further analysis.

3.1.3 Laboratory Instruments/Equipments

- a. Electrical balance:** All solutions used for the investigation were prepared by using an electronic balance (METTLER TOLEDO-PL-202-S/03).
- b. Augur:** For collecting soil samples, a Dutch Augur was used (Make: AIC Agro-Industries PVT. Ltd. Kolkata).
- c. Spectrophotometer:** During the study, the spectroscopic estimation of different compounds of the experimental soils and organic matters were done by Systronics make digital Spectrophotometer (Model: Systronics, 104).
- d. Flame photometer:** Potassium of the soil and organic matters were measured by using a flame photometer (Model: Systronics, 128).
- e. pH meter:** pH of the soils and adjustments of solutions to defined pH was measured by using a digital glass electrode pH meter (Model: Systronics, 335).
- f. Centrifuge:** Supernatant solutions were separated from the soil by using a research centrifuge (Model: SiGmA-3k30).
- g. BOD Incubator:** The incubation study and kinetics experiments were conducted in a BOD Incubator (Make: Remi-CIS-24 BL).
- h. Hot Water Bath:** For the estimation of dehydrogenase activity, anaerobic mineralization index estimation and for heating of samples water bath was used (Make:YOMA).
- i. FOSS N-Autoanalyzer:** For inorganic nitrogen estimation (NH_4^+ and NO_3^-) N-autoanalyser (FIAstar 5000 Analyzer) was used.
- j. Kjeltex-2300:** For the estimation of kjeldahl nitrogen, Kjeltex-2300 was used.
- k. CHNS-Analyser:** Total organic carbon was analysed by CHNS-Analyser (Elementar, Vario EL III, Jarman g m b h).
- l. IRIGA-Hand-Held Portable Photosynthesis System:** Leaf temperature, CO_2 -input and CO_2 -output of leaf at various stage of wheat were measured by IRIGA (CL-340 CID, Inc).

3.1.4 Chemicals

All the chemicals used in the dissertation works were AR and GR quality and were purchased from Hi Media, Mumbai, India, Merck, Mumbai, India and Sigma-Aldrich, Germany.

3.2 Methods

3.2.1 Physico-chemical properties of soil:

Important Physico-Chemical properties of collected soils (pH, EC, Maximum water holding capacity, Organic carbon, Textural classes, Available-N, Available-P and Available-K, Cation Exchange Capacity, Exchangeable Ca^{+2} and Mg^{+2} , total N, total organic carbon) were determined following the standard methodology.

a. Soil texture: Sand, silt and clay content was estimated following hydrometer method as described by Bouycous (1962).

b. pH: pH of the soils was determined by using soil suspension in water in the ratio of 1:2.5 (Jackson, 1973).

c. Organic carbon: Oxidisable Organic carbon of soil samples was estimated by the method of Walkley and Black (Nelson and Sommers, 1982).

d. Electrical Conductivity: Electrical Conductivity of the suspension (soil: water; 1:2) was determined at room temperature by using a direct reading conductivity meter (Jackson, 1973).

e. Cation Exchange Capacity (CEC): This was determined by ammonium saturation method (Jackson, 1973).

f. Available-N: Available-N was determined by the method of Kenny and Bremner (1964) as described by Page *et al.*, 1982 using 2 M KCl and titrimetrically determining the ammonia liberated after steam distillation with magnesium oxide and Devardas alloy.

g. Available-P: Available-P content of the experimental soil was determined by extracting 2.5 gm of each soil with a mixture of 25ml of 0.03M NH_4F and

0.025 M HCl for 5 minutes (Bray and Kurtz, 1945), followed by colorimetric measurement of phosphorus (P) by Spectrophotometer.

h. Available-K: For determination of available potassium status in soil, potassium was extracted by shaking the soil with neutral normal ammonium acetate (1N NH_4OAc) in 1:5 ratio followed by filtration as described by Hanway and Heidel, 1952.

i. Total-N: Total N was determined by modified kjeldhal digestion method. Soil was digested with sulphuric acid, salicylic acid, sodium thiosulphate and the catalyst mixture. The digested material was then steam distilled with concentrated (40%) NaOH. The amount of liberated ammonia was absorbed in boric acid and titrated with standard HCl (Bremner and Mulvaney, 1982).

j. Total-P: Total-P was determined by digesting a suitable amount of soil in a mixture of nitric acid and perchloric acid (9:4). The digest was filtered and made to known volume. Phosphorus in the digest was estimated by the vanadomolybdate yellow color method (Jackson, 1973).

k. Total Organic Carbon: Total organic carbon of soils were directly analysed by CHNS analyser. For total organic carbon soil was treated with 6M sulphuric acid to remove the calcium carbonate.

3.2.2 CARBON FRACTIONS

3.2.2.1 Oxidisable Organic Carbon (SOC): Soil organic carbon was determined by Walkley & Black, 1934 followed by Nelson and Sommers, 1982 and Chan *et al.* 2001. A known weight of soil will be treated with excess volume of standard one normal potassium dichromet (1 N $\text{K}_2\text{Cr}_2\text{O}_7$) in presence of H_2SO_4 and H_3PO_4 . The H_2SO_4 is added to create heat and H_3PO_4 is added to have a sharp colour change at end point of titration. The excess amount of $\text{K}_2\text{Cr}_2\text{O}_7$ is titrated with the ferrous iron solution in presence of diphenylamine indicator.

3.2.2.2 Particulate Organic Carbon (POC): Particulate organic carbon was determined by the method Grigoric & Beare, 2007 followed by Walkley & Black, 1934. Air dried soil extracted with sodium hexametaphosphate by

shaking for 16 hours. Then the soil is passed through 50 micron sieve and washed with distilled water to obtain the particulate organic matter (Grigoric & Beare, 2007). POC is estimated by wet oxidation method of Walkley and Black method (Mrabet *et al.* 2001).

3.2.2.3 Soil Inorganic Carbon (SIC): Soil inorganic carbon was determined by the method based on utilization of the sample by a titrated acid (Handbook of Soil Analysis- Mineralogical, Organic and Inorganic Methods. by Marc Pansu and Jacques Gautheyrou, Springer International Edition, 2003).

3.2.2.4 Mineralizable Carbon (MC): Mineralizable carbon was estimated by the method as given by Anderson, 1982. A 25-g portion of field-moist soil sample was wetted to 50% water filled pore space. It was placed in 1.0L cunning jars along with vials containing 10mL of 1.0 mol L⁻¹ NaOH to trap the evolved CO₂ and was incubated for 24 days at 25±2°C. Alkali traps were replaced at 3 to 10 days and finally was removed at 24 days. Evolved CO₂ was estimated by titrating the excess alkali in the traps with 1.0 mol L⁻¹ HCl to a phenolphthaline end point.

3.2.2.5 Labile Carbon (LC): Labile carbon was measured by using Blair *et al.*, (1995) method. Two g of soil was taken in centrifuge tube and oxidized with 25 ml of 333mM KMnO₄ by shaking in a mechanical shaker for 1 hour. The aliquots were centrifuged for 5 minutes at 4000rpm and 1.0 mL of supernatant solution was taken in a conical flask, to which 250 ml of double distilled water (DDW) was added for dilution of the supernatant solution. The concentration of KMnO₄ was measured at 565nm wavelength using spectrophotometer. The change in concentration of KMnO₄ was used to estimate the amount of carbon oxidized assuming that 1.0mM of KMnO₄ was consumed (Mn VII-Mn IV) in the oxidation of 0.75mM(9.0mg) of carbon.

3.2.2.6 Total Organic Carbon (TOC): Total organic carbon was measured by Walkley & Black, 1934 and modified by Nelson and Sommers, 1982 using CHNS-Analyzer (Elementer, Vario EL, Germany). The soil samples are oven dried, powdered and passed through 2.0-mm sieve, while the organics

(Farmyard manure, paddy straw, green manure, stubble and roots) were oven dried and finally grounded in a mechanical grinder following the method described by Nelson and Sommers, 1982. The samples were all analysed for carbon by a CHNS analyzer. Soil samples were also analyzed for inorganic carbon titrimetrically by digestion them with dilute HCl following the method of Bundy and Bremner(1972). The C_{tot} was computed by multiplying the C_{tot} (obtained by $C_{tot} = CHNS\ C-HCl-C$) content ($g\ kg^{-1}$) by the bulk density($Mg\ m^{-3}$) and depth(m).

3.3 CARBON MAPING

Preparation of carbon stock map at different ecological systems:

Base maps of the two districts (Jalpaiguri and Darjeeling) of West Bengal comprising all the ecological sites were created and saved as shape file using ArcGisR 10.2. The files include location, shape and attributes of geographic features of both the districts. The spatial data include a 1:50000 digital map of the districts and all geo-referenced soil sampling profile sites derived by digitizing maps at 1:50000 scale. ArcMap 10.2 version was used for preparation of the maps. To prepare map for a particular ecology, different layers were first brought in the same workspace including different shape files and soil database. The soil data base contains the spatial information of soil carbon content at different depth of soil. The coordinate system of all layers were made uniform to that of the data frame. Symbology was prepared to draw the layers. The soil database was linked to the layers to display geo-referenced soil profiles with soil carbon content according to soil depths.

3.4 Field Experiment

The present study was carried out during the Rabi season of 2014 - 2015 and 2015-2016 to study the "**Soil carbon pools under different landuse and management systems in the Terai region of West Bengal (India)**". The details of the experimental materials used, methods followed and the statistical techniques adopted during the course of study have been discussed in this chapter.

3.4.1 MATERIALS

3.4.1.1 Experimental site

The field experiment was conducted with wheat (*Triticum aestivum* L.) on the agricultural farm of Uttar Banga Krishi Vishwavidyalaya, Pundibari, Cooch Behar, 736165, West Bengal. The agricultural farm is located within the *Terai* region and its geographical location is N 26°23'59.9'' latitude and E 89°23'24'' longitude. The farm's elevation is 185 mt above the msl. The farm's experiments were carried out during two winter season 2014-2015 and 2015-2016.

3.4.1.2 Experimental soil

The topography of the study area was upland with good drainage facilities. The texture of the soil was sandy loam. The composite soil samples from the experimental site was collected and analyzed before starting of the field trial.

3.4.1.3 Cropping History of Experimental Plot

A cropping sequence of rice –wheat was practiced in the study area.

3.4.1.4 Test crop and varieties

Crop: Wheat (*Triticum aestivum* L.) **Variety:** K-1006

3.5 Details of Experiment

3.5.1 Details about experiment

Particulars	Details		
Experimental design	RBD		
Total area (m ²)	1596.5 m ²		
Plot size	5 m × 4 m		
Total Plot size	20 m ²		
Number of replication	3		
Seed row to row spacing	Zero and conventional both were 23 cm (Row to Row) spacing		
Seed Rate	100 kg ha ⁻¹		
Uniform Depth	2.5-3.9cm (Zero and conventional both)		
Treatment details			
Conventional Tillage		Zero Tillage	
Treatments	Doses	Treatments	Doses
T ₁	100% (N:P:K) + P ₀ F ₀	T ₁	100% (N:P:K) + P ₀ F ₀
T ₂	100% (N:P:K) + P ₀ F ¹ / ₂	T ₂	100% (N:P:K) + P ₀ F ¹ / ₂
T ₃	100% (N:P:K) + P ₀ F ₁	T ₃	100% (N:P:K) + P ₀ F ₁
T ₄	100% (N:P:K) + P ¹ / ₂ F ₀	T ₄	100% (N:P:K) + P ¹ / ₂ F ₀
T ₅	100% (N:P:K) + P ¹ / ₂ F ₁ / ₂	T ₅	100% (N:P:K) + P ¹ / ₂ F ₁ / ₂
T ₆	100% (N:P:K) + P ¹ / ₂ F ₁	T ₆	100% (N:P:K) + P ¹ / ₂ F ₁
T ₇	100% (N:P:K) + P ₁ F ₀	T ₇	100% (N:P:K) + P ₁ F ₀
T ₈	100% (N:P:K) + P ₁ F ¹ / ₂	T ₈	100% (N:P:K) + P ₁ F ¹ / ₂
T ₉	100% (N:P:K) + P ₁ F ₁	T ₉	100% (N:P:K) + P ₁ F ₁
N: P: K =100:60:40 kg ha ⁻¹ (Recommended doses as 100%)			
Paddy Straw (10t ha ⁻¹) Full (Recommended doses)			
Farmyard Manure (10t ha ⁻¹) Full (Recommended doses)			

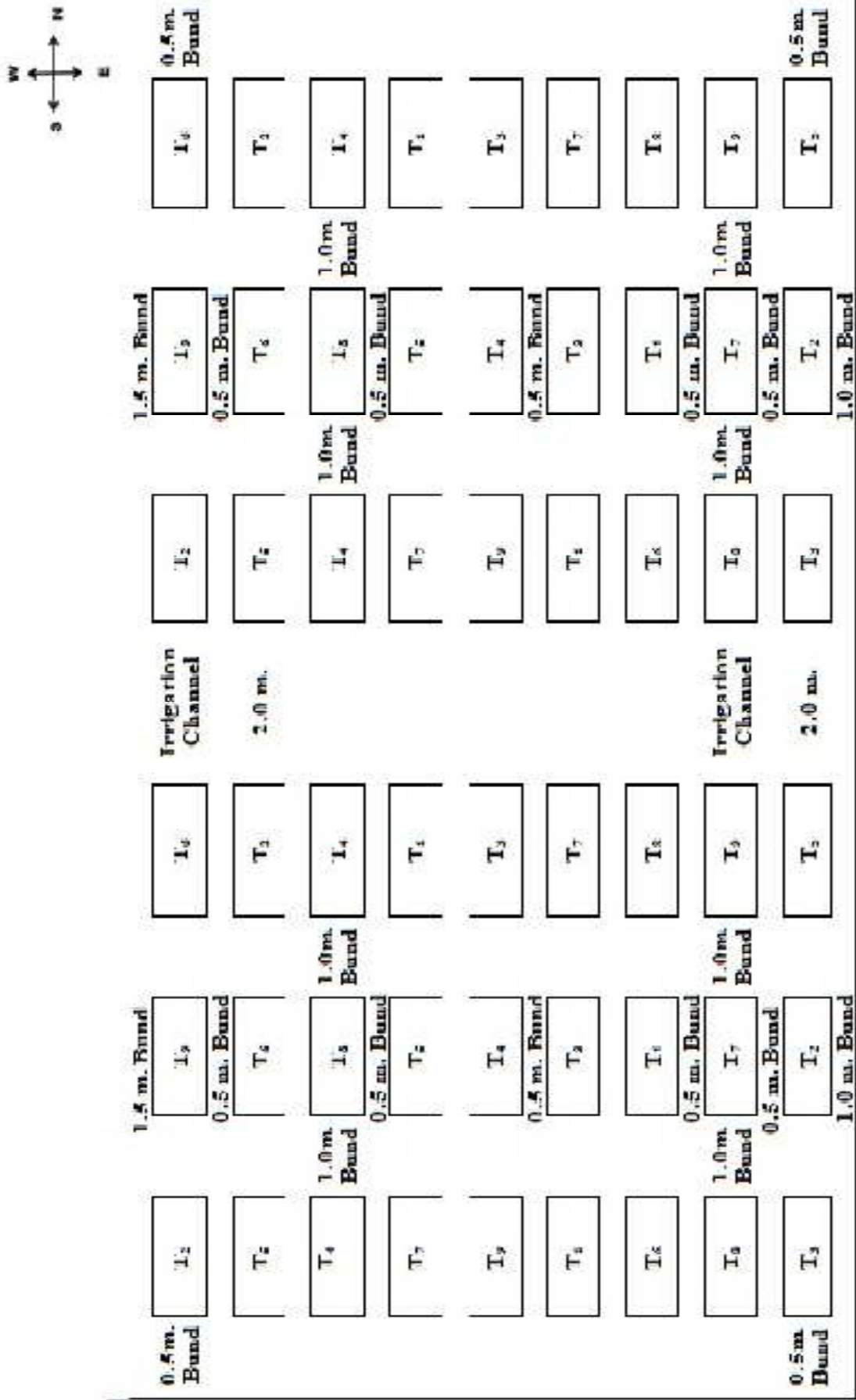


Fig.1 Layout of the experiment

3.5.2 Calendar of operations

Sl. No.	Operation	Date of 1st Year	Date of 2nd Year	Details of operation
1	Land preparation	15-11-2014 to 21-11-2014	10-11-2015 to 17-11-2015	Three passes by tractor fitted with cultivator, two passes of power tiller and two passes by rotavator for final land preparation. The weeds and stubbles were removed and cleaned. Seed sown by zero tillage seed cum fertiliser driller machines without fertilizer and basal dose of fertilizer was applied during the final land preparation.
2	Preparation of bunds, channels and beds	22-11-2014 to 23-11-2014	18-11-2015 to 19-11-2015	Bunds surrounding the plots and irrigation channels were prepared with the help of spade and the beds were prepared as per the requirements.
3	Application of fertilizers	24-11-2014	21-11-2015	Nitrogen (100 kg ha^{-1}), Phosphorus (60 kg ha^{-1}) and Potassium (40 kg ha^{-1}), in the form of Urea, SSP, MOP were well mixed and full dose of P, K and half dose of N was applied as a basal, thereafter, rest half dose of N was applied as topdressing at 21 DAS after completion of the first weeding. Paddy straw and

Sl. No.	Operation	Date of 1st Year	Date of 2nd Year	Details of operation
				FYM (10 q ha ⁻¹) are applied next day after sowing.
4	Sowing of seed	26-11-2014	23-11-2015	Seed rate @ 100kg ha ⁻¹ (10 g m ²) was used for wheat variety K-1006. Sowing was done in the lines with the help of duck-foot tyne by opening a shallow furrow of uniform depth (2.5-3.9cm) for conventional tillage. The zero tillage cultivation was done by the zero tillage machines. The tillage spacing followed was 23cm row to row in both the cases. The north-south direction of sowing was followed.
5	Intercultural operation	17-12-2015 to 18-12-2015 and 10-01-2015 to 11-01-2015	11-12-2015 to 13-12-2015 and 04-01-2016 to 06-01-2016	In conventional tillage first and final weeding was done at 21 and 45 DAS respectively and zero tillage Herbicide spray in application of Glyphosate @ 2.0kg a.i / ha seven days before sowing for weeds removed. Four hand weeding was done during conventional tillage both the years.
6	Irrigation and Fertilizer Application (Top Dressing)	17-12-2015	13-12-2015 11-01-2016	Three irrigations were given to wheat field at 21 DAS, 50 DAS and 75 DAS respectively. The depth of irrigation water was

Sl. No.	Operation	Date of 1st Year	Date of 2nd Year	Details of operation
		15-01-2015 and 09-02-2015	and 05-02-2016	maintained at 6 cm level. The excess water was drained out through the drainage channel. Application of boron after 35 and 45 days of sowing as borax (20% boron) @ 1g / litre. Top Dressings with urea after 20-21 days of sowing followed by irrigation.
7	Sample Collection (Soil and Plant)	17-12-2015, 15-01-2015 20-02-2015 and 17-03-2015	13-12-2015, 11-01-2016 15-02-2016 and 11-03-2016	Data were collected at 21, 50, 85, 110 days after sowing starting from 21 days after sowing and continued up to harvest.
8	Harvesting and processing	17-03-2015 And 22-03-2015	11-03-2016 And 16-03-2016	The wheat plants were harvested from net plot area (harvesting area) discarding the plants of border area and were subsequently threshed after sun drying.

3.5.3 Collection of soil samples: The soils samples (0-20) cm. were collected from the cultivated wheat of Conventional and Zero tillage field of wheat in instructional farm of U.B.K.V. Pundibari, district of Cooch Behar, West Bengal and composite soil samples from the experimental plots were collected and analyzed for conducting the experiment.

3.5.4 Details of operation:

Three passes by tractor fitted with cultivator, two passes of power tiller and two passes by rotavator for final land preparation. The weeds and stubbles were removed and cleaned. Seed sown by zero tillage machines without fertilizer and basal dose of fertilizer applied during the final land preparation.

Bunds surrounding the plots and irrigation channels were prepared with the help of spade and the beds were prepared as per the requirements.

Nitrogen (100 kg ha^{-1}), Phosphorus (60 kg ha^{-1}) and Potassium (40 kg ha^{-1}), in the form of Urea, SSP, MOP; were well mixed and full dose of P, K and half dose of N were applied as a basal dose, thereafter rest half of N was applied as topdressing at 21 DAS after completion of the first weeding. Paddy straw and FYM (10 q ha^{-1}) were applied next day after sowing.

Seed rate @ 100 kg ha^{-1} (10 g m^{-2}) was used for wheat variety K-1006. Sowing was done in the lines with the help of duck-foot tyne by opening a shallow furrow of uniform depth (2.5-3.9cm) for conventional tillage. The zero tillage cultivation were done by the zero tillage machines. The tillage spacing followed was 23cm row to row. The North-South direction of sowing was followed.

First and final weeding were done at 21 and 45 days respectively in conventional land zero tillage of operation. Glyphosate @ 2.0 kg a.i / ha as herbicide was applied seven days before sowing. Four hand weeding was done during conventional tillage in both the years.

Three irrigations were given to wheat field at 21 DAS, 50 DAS and 75 DAS respectively. The depth of irrigation water was maintained at 6 cm level. The excess water was drained out through the drainage channel. Application of boron after 35 and 45 days of sowing as borax (20% boron) @ 1 g / litre was sprayed. Top Dressings with urea after 20-21 days of sowing followed by irrigation was given.

Data were collected at 21, 50, 85, 110 days after sowing starting from 21 days after sowing and continued up to harvest.

The wheat was harvested from net plot area (harvesting area) discarding the plants of border area and were subsequently threshed after sun drying.

3.5.4 Soil samples

3.5.4.1 Collection of soil samples: The soils samples (0-20)cm. were collected from the experimental plots of wheat under Conventional and Zero tillage practices at the instructional farm of U.B.K.V. Pundibari, of Cooch Behar, District of West Bengal. The composite soil samples from the experimental plots were collected and analyzed for conducting the experiment.

3.5.4.2 Methods of recording biometric observations: Leaving the border rows half of the area in each plot was marked for recording biometrical observation including destructive sampling and other half for recording yield components and yield.

3.6 Growth parameters

a. Plant height: Five plants were selected randomly from individual plots and properly tagged. Their heights were measured in centimeter from the ground level. Observations were taken at around 30-35 day's interval starting from 21 days after sowing. The average plant height was recorded at 21, 50, 85 and 110 days after sowing.

b. Dry weight of plant: During each destructive sampling, five plants from each plot were taken and then oven dried weight was recorded using an electronic balance.

3.7 Yield attributing characteristics

a. Number of tillers hill⁻¹: Productive and unproductive tillers were counted randomly from each variety at 30 days intervals starting from 21 days after sowing using 1 m² quadrat.

b. Number of panicles/plant: Total number of panicle plant⁻¹ was recorded from ten randomly selected plants of each plot at harvest thereafter average number of panicles/ plant was worked out.

c. Length of Panicle (cm): Panicles from five hills were selected randomly from each plot prior to harvest and the panicle length was recorded (cm) and the average length was calculated.

d. Number of grain panicle⁻¹: Ten panicles were randomly selected from each plot. The grains were counted. The average number of grains per panicle was determined.

e. 1000 grain weight (Test weight): From the fresh product of the each plot, 1000 grains were collected and counted; dried and weights (g) were recorded from each plot separately.

f. Determination of total nitrogen in plant sample

Estimation of total nitrogen of plant sample was carried out by modified Kjeldhal method as described by Jackson, (1967).

g. Determination of total phosphorus in plant sample

Estimation of phosphorus was carried out by Vanadomolybdo-phosphoric yellow colour method in nitric acid system and intensity of colour (red) was measured in Spectrophotometer (Systronic type) at 420 nm as described by Jackson (1967).

h. Determination of total potassium in plant sample

Total potassium in plant sample was estimated by flame photometer as proposed by Jackson (1973).

i. Statistical analysis: The statistical analysis was done by employing the GEN STAT (Version -11.10.1504) and XL STAT (Version – 2014).

3.8 Yield

a. Grain Yield (t ha⁻¹)

After harvesting from the net plot (discarding the border rows), crop was dried in the sun and subsequently threshed. The produce from each plot was cleaned thoroughly and calculated to tons per hectare basis.

$$\text{Grain yield (t ha}^{-1}\text{)} = \frac{\text{Plot yield (kg)} \times 10000}{\text{Plot size (m}^2\text{)} \times 1000}$$

b. Straw yield (t ha⁻¹):

After threshing grains were separated from harvested material of each plot. Weight of the remaining portion of the harvested parts was recorded and converted into tons per hectare basis.

$$\text{Straw yield (t ha}^{-1}\text{)} = \frac{\text{Straw yield plot (kg)} \times 10000}{\text{Plot size (m}^2\text{)} \times 1000}$$

3.9 Meteorological observation

Temperature, rainfall and relative humidity data was collected from Gramin Krishi Mousam Seva Kendra and Indian Meteorological Department, Pundibari, Coochbehar during the crop growth period (2014-15 to 2015-16) to study the variation of climatic parameter in the region.

3.10 Observation of IRIGA -Hand-Held Portable Photosynthesis System

Leaf temperature, CO₂-input, CO₂-output of leaf were measured for five consecutive days at flowering stage under conventional and zero tillage system for nine treatments during the cropping season (2014-15 and 2015-16).

Chapter 4

RESULTS AND DISCUSSIONS

4.1 Characterization of soils under study

4.1.1 Forest ecosystems:

The soils were collected from four locations (Gorumara, Mahananda, Buxa and Chilapata) under the region. The important soil properties of the samples from forest ecosystems are given in Table 1. In all the sampling sites (Table 2), the soil was acidic in reaction (average pH 5.15). A general trend of increasing the pH with the depth of the soils was observed. The range of pH in soils varied from 4.77 to 5.62. The ECs of the collected soils showed the non-saline characteristics having an average of 0.05 dSm^{-1} . The $(\text{Ca}^{+2} + \text{Mg}^{+2})$ content in soils was low in this zone (average 3.48 meq/l) which indicated the acidic nature of the soil. The oxidisable organic carbon (average 1.59%) showed variation at different depths of soils. The available nitrogen (kg ha^{-1}) was high (238.34) in Gorumara forest and lowest in Chilapata forest (194.43) at the surface soils (0-20 cm). Besides, significant variations of CEC with soil depths was observed at different sites of the forest ecosystems. The available nitrogen (N) trend to decrease with the depth of the soil. The lowest value of N ($119.17 \text{ kg ha}^{-1}$) was at 40-60 cm depth of soils under the Chilapata forest. The

available phosphorus under the forest ecosystem varied at different locations under study. A general trend of decreasing the available P with the depth of soil (except at the Mahananda and Chilapata forest ecosystems) was observed. The average Bray-extractable P was 86.09 kg ha^{-1} . In the Chilapata forest ecosystem the exchangeable ($\text{Ca}^{+2} + \text{Mg}^{+2}$) should have a positive correlation with the available P in soil at different depths. A general trend of lowering of K content with the soil depths was observed under this ecosystem. The average K content was $108.70 \text{ kg ha}^{-1}$. The maximum K content was at soils of the Gorumara and minimum at the Mahananda forest. The total (%) C-N-S decreased with the increasing depths of the soil having the average content (%) 2.07, 0.18 and 0.52 respectively. The total H (%) in general decreased with the depth for the soils of Mahananda, Buxa and Chilapata, while increased at Gorumara soils. Comparatively a lower C/N was observed in soil of Buxa than the others (Gorumara, Mahananda and Chilapata) land situations.

4.1.2 Agricultural land:

The soils were collected from four locations (Binnaguri, Balarampur, Kumargram and Kharibari) under agricultural field, the properties of which are given in Table 3. The soil samples collected from Binnaguri, Kumargram and Kharibari were acidic, while the soils of Balarampur were towards neutral. The average pH was 6.24 for the soils of agricultural land and in general, there was a trend of increasing pH with the soil depth. The ECs of the soil samples showed the non-saline character with an average value of 0.13 dSm^{-1} . The exchangeable ($\text{Ca}^{+2} + \text{Mg}^{+2}$) of the soils of Balarampur and Kumargram were relatively higher than the soils of Binnaguri and Kharibari. The variation may be due to the acidic reaction of the soils and indiscriminate application of liming materials in the field. The oxidisable organic carbon generally decrease with the depth of the soils, being the average of 0.93%. The available nitrogen in soils (0-20 cm depth) was in the order Binnaguri > Kharibari > Balarampur > Kumargram and the content tends to decrease with the increasing depth of the soil. The significant variation of the available P with the depth of the soil was observed. The mean P content of 30.99 kg ha^{-1} of the soils might be due to the fixation of the phosphate under the acidic condition of the soils. The mean exchangeable K was $150.92 \text{ kg ha}^{-1}$ in the agricultural field. The exchangeable K in Kharibari soil was highest followed by Binnaguri, Kumargram and Balarampur soils. The exchangeable K decreased with the depth of the soils collected from Binnaguri

and Kumargram. In most of the soils, the total C-H-N-S decreased in the sub-surface layers with an average distribution (%) of C-H-N-S as 1.17 – 0.29 – 0.14 – 0.43, respectively. The C/N was found in the order as Kharibari > Binnaguri > Kumargram > Kumargram. The average C/N of the agricultural field was 8.26.

4.1.3 Tea garden:

The soils were collected from tea gardens of Moraghat, Ellenbari, Nimti and Kumargram areas and their important properties are shown in Table 5. The soils were acidic with an average pH of 4.78 and ECs of 0.12 dSm⁻¹. The exchangeable (Ca⁺² + Mg⁺²) in soils of Kumargram was relatively higher than Moraghat, Ellenbari and Nimti soils. The variation may be due to the lowering of the soil pH and improper application of liming materials in the field (Roy and Mukhopadhyay, 2012). A general trend of decrease of the organic carbon with the depth of soils was observed. The available nitrogen, phosphorus and K also varied with the depth of the soils with an average value of 178.23, 82.34 and 199.86 kg ha⁻¹ respectively. The total C-H-N-S also varied with the soil depth in this region. The average C/N of the tea garden soils was 9.33.

4.1.4 Fallow land:

The soils were collected from the uncultivated fallow land of Binnaguri, Balarampur, Kumargram and Kharibari sites and were characterised with important soil properties (Table-4). All the soils were acidic in reaction (average pH 5.74) and ECs as 0.19 dSm⁻¹. A general trend of increasing the (Ca⁺² + Mg⁺²) content was observed with the soil depth having an average of 5.61 meq/l. This may be due to the sub-surface deposition of (Ca⁺² + Mg⁺²) with leaching water. The average organic carbon content (0.99%) was observed in this region while the mean available N-P-K (kg ha⁻¹) were 154.19, 60.75 and 162.15 kg ha⁻¹ respectively in soils (Table-4). The total available C-H-N-S (%) in soils were 1.22, 0.24, 0.15 and 0.42 respectively. The variation of C/N with the soil depth was observed with an average of 7.44 in soils under the fallow land situation.

While comparing the CEC of the soils in all the ecosystems (Table-1 to Table-4), it was observed that the CEC of soils of Agriculture > Tea garden > Forest > Fallow. This may be due to the difference in the degree of input of nutrients under different ecosystems.

The available N and P content (Figure 1) in forest land, fallow land and tea garden soils were quite comparable than under agricultural land. The available K content in soils was found to be in the order as fallow land > tea garden > agriculture land > forest land.

A significant positive interaction among the different ecosystems and soil properties (Table- 6) was observed, although, the total S and C/H were statistically at par with the soil depths and locations under different ecosystems. This might be due to the insufficient use of sulphur aided nutrients into the soils of these ecosystems.

From the correlation study (Table-7), it was observed that soil pH had a significant negative correlation with available N , available P , total carbon , C : N , C : S and C : H . The EC of soil had a positive correlation with available N , available K and negative with C : H . The oxidisable organic C had a significant positive correlation with available N, available P , total C, total N , C : N , C : S and C : H . The $(Ca^{+2} + Mg^{+2})$ of the soil had a significant negative correlation with available N , available P, total C , total N , total S , C : N , C : S , C : H and positive with available K . The significant negative correlation between CEC and available P , total S , C : H and positive correlation between available N , and available K, total N and C : S was observed.

Table 2. Important properties of soils under the Forest ecosystem

Forest Soils (L _i)	Depth (cm)	pH (1:2.)	EC (dSm ⁻¹)	Ca ⁺² +Mg ⁺² (meq/l)	CEC (meq/100g)	OC (%)	Available N (kg ha ⁻¹)	Available P (kg ha ⁻¹)	Available K (kg ha ⁻¹)	Total C (%)	Total H (%)	Total N (%)	Total S (%)	C/N	C/S	C/H
Gorumara (S ₁)	0-20 (D ₁)	5.13	0.10	5.40	26.37	2.51	238.34	92.93	206.45	2.63	0.31	0.24	0.99	12.26	2.75	8.76
	20-40 (D ₂)	5.05	0.02	3.13	15.40	2.07	200.70	59.84	162.03	2.84	0.38	0.23	0.68	12.58	4.31	7.47
	40-60 (D ₃)	5.15	0.01	3.00	18.20	2.38	165.16	39.59	128.80	2.68	0.40	0.20	0.61	12.15	4.39	6.51
Mahananda (S ₁)	0-20 (D ₁)	5.02	0.01	0.80	17.87	2.42	200.70	87.32	76.53	2.98	0.27	0.25	0.44	12.05	7.80	11.08
	20-40 (D ₂)	5.23	0.04	1.00	17.87	1.51	163.07	55.68	34.72	2.47	0.27	0.21	0.39	12.31	8.04	9.79
	40-60 (D ₃)	5.62	0.05	1.53	7.43	0.72	148.44	131.25	39.95	1.71	0.15	0.15	0.42	11.54	5.41	12.32
Buxa (S ₁)	0-20 (D ₁)	4.79	0.03	4.93	31.80	1.55	213.25	25.31	180.69	2.03	0.52	0.22	0.42	9.29	5.66	3.90
	20-40 (D ₂)	4.77	0.01	3.60	30.27	1.21	200.70	20.43	138.88	1.62	0.50	0.17	0.30	9.69	8.34	3.27
	40-60 (D ₃)	4.88	0.10	3.20	29.90	1.14	192.34	14.28	124.69	1.48	0.50	0.15	0.27	9.79	9.66	2.95
Chilapata (S ₁)	0-20 (D ₁)	5.32	0.10	2.00	19.13	1.47	194.43	156.02	101.17	1.83	0.32	0.16	0.62	11.49	4.67	5.97
	20-40 (D ₂)	5.36	0.06	2.47	14.23	1.09	137.98	167.95	57.87	1.37	0.26	0.12	0.61	12.08	4.06	5.42
	40-60 (D ₃)	5.49	0.06	10.67	14.80	0.96	119.17	182.42	52.64	1.18	0.25	0.10	0.44	11.35	3.66	4.79
Mean		5.15	0.05	3.48	20.27	1.59	181.19	86.09	108.70	2.07	0.34	0.18	0.52	11.38	5.73	6.85

Table 3. Important properties of soils under the Agro- ecosystem

Forest Soils (L ₁)	Depth (cm)	pH (1:2.)	EC (dSm ⁻¹)	Ca ⁺² +M g ⁺² (meq/l)	CEC (meq/10 0g)	OC (%)	Available N (kg ha ⁻¹)	Available P (kg ha ⁻¹)	Available K (kg ha ⁻¹)	Total C (%)	Total H (%)	Total N (%)	Total S (%)	C/N	C/S	C/H
Binnaguri (S ₂)	0-20 (D ₁)	5.26	0.02	3.80	15.57	1.16	202.79	45.92	174.35	1.39	0.25	0.16	0.69	8.70	2.05	5.66
	20-40 (D ₂)	5.55	0.01	5.40	17.77	1.05	152.62	35.80	141.12	1.24	0.22	0.14	0.72	8.60	1.71	5.62
	40-60 (D ₃)	5.62	0.07	3.60	15.57	0.78	142.17	40.68	103.41	0.98	0.16	0.13	0.74	7.96	1.39	6.34
Balarampur (S ₂)	0-20 (D ₁)	7.35	0.02	5.13	33.47	0.91	140.07	26.76	86.99	0.81	0.25	0.15	0.56	6.76	1.98	3.96
	20-40 (D ₂)	7.92	0.38	3.47	30.30	0.48	106.62	27.66	107.15	0.81	0.22	0.10	0.56	8.01	1.68	3.87
	40-60 (D ₃)	8.06	0.03	5.60	22.27	0.40	62.72	24.95	85.87	0.82	0.21	0.08	0.56	9.80	1.68	3.91
Kumargram (S ₂)	0-20 (D ₁)	6.14	0.16	10.80	30.67	0.78	133.80	23.86	137.01	0.92	0.23	0.13	0.33	7.19	2.90	4.09
	20-40 (D ₂)	6.56	0.07	10.20	26.57	0.63	125.44	21.51	133.65	0.76	0.22	0.11	0.30	7.18	2.68	3.50
	40-60 (D ₃)	6.66	0.06	6.47	17.50	0.44	87.81	24.95	96.69	0.56	0.13	0.09	0.27	6.42	2.26	4.39
Kharibari (S ₁)	0-20 (D ₁)	5.18	0.19	3.53	35.87	1.63	188.16	42.31	254.61	1.87	0.52	0.21	0.13	9.01	14.97	3.59
	20-40 (D ₂)	5.18	0.37	2.87	33.73	1.53	186.07	32.54	240.05	1.93	0.55	0.20	0.15	9.62	15.02	3.55
	40-60 (D ₃)	5.36	0.13	9.07	43.50	1.33	146.35	24.95	250.13	1.70	0.55	0.17	0.13	9.92	15.00	3.11
Mean		6.24	0.13	5.83	26.90	0.93	139.55	30.99	150.92	1.15	0.29	0.14	0.43	8.26	5.28	4.30

Table 4. Important properties of soils under the Fallow land situation

Forest Soils (L ₁)	Depth (cm)	pH (1:2.)	EC (dSm ⁻¹)	Ca ⁺² +Mg ⁺² (meq/l)	CEC (meq/100g)	OC (%)	Available N (kg ha ⁻¹)	Available P (kg ha ⁻¹)	Available K (kg ha ⁻¹)	Total C (%)	Total H (%)	Total N (%)	Total S (%)	C/N	C/S	C/H
Binnaguri (S ₂)	0-20 (D ₁)	4.78	0.06	2.00	20.23	1.56	175.62	74.67	113.87	2.00	0.30	0.20	0.75	9.71	2.62	6.42
	20-40 (D ₂)	5.10	0.08	1.40	18.43	1.04	163.07	67.98	85.12	1.35	0.24	0.14	0.74	9.43	1.87	5.64
	40-60 (D ₃)	4.99	0.01	2.47	19.43	1.11	163.07	101.60	82.88	1.32	0.22	0.14	0.64	9.45	2.26	5.95
Balarampur (S ₂)	0-20 (D ₁)	6.76	0.52	10.20	24.17	0.72	119.17	37.60	275.52	0.77	0.20	0.11	0.51	6.75	1.63	3.89
	20-40 (D ₂)	6.77	0.02	5.80	21.33	0.40	75.26	72.14	258.72	0.46	0.12	0.08	0.55	5.60	0.90	3.62
	40-60 (D ₃)	6.99	0.02	7.60	22.60	0.28	56.45	101.97	219.52	0.33	0.12	0.08	0.52	4.19	0.76	2.82
Kumargram (S ₂)	0-20 (D ₁)	6.07	0.07	6.20	7.13	0.51	123.35	49.18	125.81	0.65	0.08	0.10	0.26	6.51	2.74	9.23
	20-40 (D ₂)	6.18	0.06	9.47	16.40	0.44	108.71	41.04	137.76	0.51	0.07	0.10	0.29	5.12	1.76	7.76
	40-60 (D ₃)	6.21	0.06	6.73	16.93	0.52	140.07	34.17	148.59	0.65	0.11	0.13	0.29	5.19	2.42	5.84
Kharibari (S ₁)	0-20 (D ₁)	5.17	0.93	3.53	23.30	2.05	313.60	56.23	149.33	2.68	0.54	0.30	0.32	8.90	8.97	4.98
	20-40 (D ₂)	4.84	0.21	2.87	19.47	1.72	213.25	47.37	122.08	2.11	0.46	0.23	0.12	9.43	9.35	4.63
	40-60 (D ₃)	4.97	0.18	9.07	31.30	1.56	198.61	45.02	226.61	1.80	0.44	0.20	0.14	9.01	10.26	4.14
Mean		5.74	0.19	5.61	20.06	0.99	154.19	60.75	162.15	1.22	0.24	0.15	0.43	7.44	3.80	5.41

Table 5. Important properties of soils under the Tea gardens

Forest Soils (L ₁)	Depth (cm)	pH (1:2.)	EC (dSm ⁻¹)	Ca ⁺⁺ +Mg ⁺⁺ (meq/l)	CEC (meq/100g)	OC (%)	Available N (kg ha ⁻¹)	Available P (kg ha ⁻¹)	Available K (kg ha ⁻¹)	Total C (%)	Total H (%)	Total N (%)	Total S (%)	C/N	C/S	C/H
Binnaguri (S ₂)	0-20 (D ₁)	4.26	0.48	2.73	28.13	1.90	225.79	241.90	214.29	2.40	0.35	0.24	0.70	9.98	3.57	6.84
	20-40 (D ₂)	4.57	0.01	3.13	27.40	1.35	177.71	46.46	137.39	1.66	0.32	0.16	0.63	10.37	2.97	5.18
	40-60 (D ₃)	4.59	0.01	3.07	24.67	1.22	175.62	42.31	135.89	1.48	0.28	0.14	0.57	10.38	2.88	5.19
Balarampur (S ₂)	0-20 (D ₁)	4.35	0.02	1.47	21.03	1.59	175.62	301.56	119.47	1.75	0.19	0.19	0.49	9.57	4.47	9.52
	20-40 (D ₂)	4.56	0.02	1.40	16.33	1.26	175.62	120.77	104.91	2.17	0.26	0.20	0.47	10.65	5.20	8.50
	40-60 (D ₃)	4.73	0.01	1.40	12.73	1.19	194.43	68.34	116.11	1.42	0.18	0.14	0.41	10.12	4.02	7.85
Kumargram (S ₂)	0-20 (D ₁)	4.32	0.44	3.87	37.90	1.78	236.25	30.55	501.01	2.27	0.44	0.22	0.27	10.28	6.23	5.16
	20-40 (D ₂)	5.35	0.09	2.13	37.50	1.27	175.62	18.26	329.65	1.53	0.42	0.15	0.30	10.10	5.50	3.65
	40-60 (D ₃)	5.39	0.01	3.40	32.93	1.27	173.53	18.62	255.73	1.57	0.41	0.14	0.33	11.35	5.69	3.86
Kharibari (S ₁)	0-20 (D ₁)	5.03	0.15	7.80	22.13	0.85	133.80	52.43	185.92	0.99	0.16	0.15	0.25	6.78	4.05	6.52
	20-40 (D ₂)	5.18	0.08	5.80	26.40	0.78	148.44	27.84	182.93	0.91	0.17	0.13	0.27	7.03	3.79	5.44
	40-60 (D ₃)	5.03	0.07	7.20	26.10	0.49	146.35	18.98	114.99	0.55	0.15	0.10	0.25	5.30	2.30	3.55
Mean		4.78	0.12	3.62	26.10	1.25	178.23	82.34	199.86	1.56	0.28	0.16	0.41	9.33	4.22	5.94

Table 6. Interactions among soil properties and different ecosystems

	pH (1:2.5)	EC (dSm ⁻¹)	Ca ⁺² +Mg ⁺² (meq/l)	CEC (meq/100g)	OC (%)	Available N (kg ha ⁻¹)	Available P (kg ha ⁻¹)	Available K (kg ha ⁻¹)	Total C (%)	Total H (%)	Total N (%)	Total S (%)	C/N	C/S	C/H
Land (L)															
L₁	5.15	0.0485	3.48	20.27	1.59	181.19	86.09	108.70	2.09	0.340	0.180	0.520	11.38	5.73	6.85
L₂	6.24	0.1254	5.70	26.90	0.93	139.55	30.99	150.92	1.17	0.290	0.140	0.430	8.26	5.28	4.30
L₃	5.74	0.1863	5.61	20.06	0.99	154.19	60.75	236.82	1.22	0.240	0.150	0.430	7.44	3.80	5.41
L₄	4.78	0.1167	3.62	26.11	1.25	178.23	82.34	199.86	1.56	0.280	0.160	0.410	9.33	4.22	5.94
LSD (P=0.05)	0.022	0.0006	0.129	0.067	0.003	2.718	0.390	0.814	0.022	0.009	0.004	0.078	0.194	1.188	0.357
Sites (S)															
S₁	5.00	0.0744	3.26	20.60	1.51	181.89	74.14	140.47	1.82	0.290	0.180	0.710	10.13	2.73	6.30
S₂	6.11	0.0960	3.78	20.62	0.99	134.85	88.00	164.45	1.41	0.200	0.150	0.490	8.95	3.63	6.76
S₃	5.61	0.0955	5.92	26.29	0.96	159.24	26.85	192.52	1.22	0.300	0.140	0.300	8.18	4.66	4.80
S₄	5.18	0.2110	5.44	25.83	1.29	177.18	71.17	198.86	1.59	0.360	0.170	0.290	9.16	8.01	4.64
LSD (P=0.05)	0.022	0.0006	0.129	0.067	0.003	2.718	0.390	0.814	0.022	0.009	0.004	0.078	0.194	1.188	0.357
Depths (D)															
D₁	5.31	0.2055	4.85	24.67	1.46	188.42	84.03	223.44	1.77	0.310	0.190	0.480	9.01	4.82	6.22
D₂	5.51	0.0966	4.11	23.09	1.11	156.93	53.96	155.38	1.50	0.290	0.150	0.440	9.22	4.83	5.43
D₃	5.61	0.0557	4.85	22.24	0.99	144.52	57.13	143.41	1.27	0.270	0.130	0.410	9.07	4.63	5.22
LSD (P=0.05)	0.020	0.0005	0.112	0.059	0.003	2.356	0.337	0.705	0.020	0.008	0.004	NS	0.168	1.031	NS
L × S															
LSD (P=0.05)	0.048	0.0010	0.258	0.135	0.006	5.439	0.781	1.629	0.045	0.018	0.008	0.157	0.387	2.378	0.716
L × D															
LSD (P=0.05)	0.042	0.0010	0.222	0.115	0.003	4.709	0.677	1.410	0.039	0.016	0.007	NS	0.334	NS	0.621
S × D															
LSD (P=0.05)	0.042	0.0010	0.222	0.115	0.003	4.709	0.677	1.410	0.039	0.016	0.007	NS	0.334	NS	NS
L × S × D															
LSD (P=0.05)	0.081	0.0019	0.444	0.230	0.008	9.418	1.353	2.819	0.079	0.031	0.015	NS	0.671	NS	1.238

There were significant change in available N-P-K (kg ha^{-1}) in four landuse systems (Fig. 2). Maximum mean value of available nitrogen ($181.19 \text{ kg ha}^{-1}$) was found in forest soil followed by tea soils ($178.23 \text{ kg ha}^{-1}$), fallow land ($154.19 \text{ kg ha}^{-1}$) and cultivated land ($139.55 \text{ kg ha}^{-1}$). Available phosphorous was maximum in forest soil (mean value 86.09 kg ha^{-1}) and was minimum in cultivated land (30.99 kg ha^{-1}) where as available potassium was maximum in fallow land ($162.15 \text{ kg ha}^{-1}$) and was minimum in forest soil ($108.70 \text{ kg ha}^{-1}$).

Hence, it was observed that land use and management practices had a significant role to play on changing the available N, P, K status and also the ($\text{Ca}^{+2} + \text{Mg}^{+2}$) and organic carbon content in soils. The properties of the soils under the fallow land varied significantly with the other ecosystems (tea garden, agriculture and forest). The comparison of the status of the physico-chemical properties at different ecosystems emphasizes the need for proper management of the soils to refrain from soil erosion, reduction in soil fertility and land degradation.

Table 7. Correlation coefficients among different soil properties and nutrient pools

Soil Properties	pH	EC	Organic C	(Ca ⁺² + Mg ⁺²)	CEC
Available N	-0.733**	0.419**	0.809**	-0.432**	0.201*
Available P	-0.292**	0.001	0.216**	-0.253**	-0.342**
Available K	-0.001	0.696**	0.144	0.199*	0.439**
Total C	-0.639**	0.217**	0.948**	-0.577**	0.085
Total N	-0.630**	0.400**	0.891**	-0.442**	0.191*
Total S	0.017	-0.149	0.136	-0.230**	-0.263**
C : N	-0.493**	-0.073	0.705**	-0.607**	-0.044
C : S	-0.334**	0.238**	0.399**	-0.166*	0.400**
C : H	-0.281**	-0.178*	0.285**	-0.388**	-0.617**

** significant at the 0.01 level; * significant at the 0.05 level

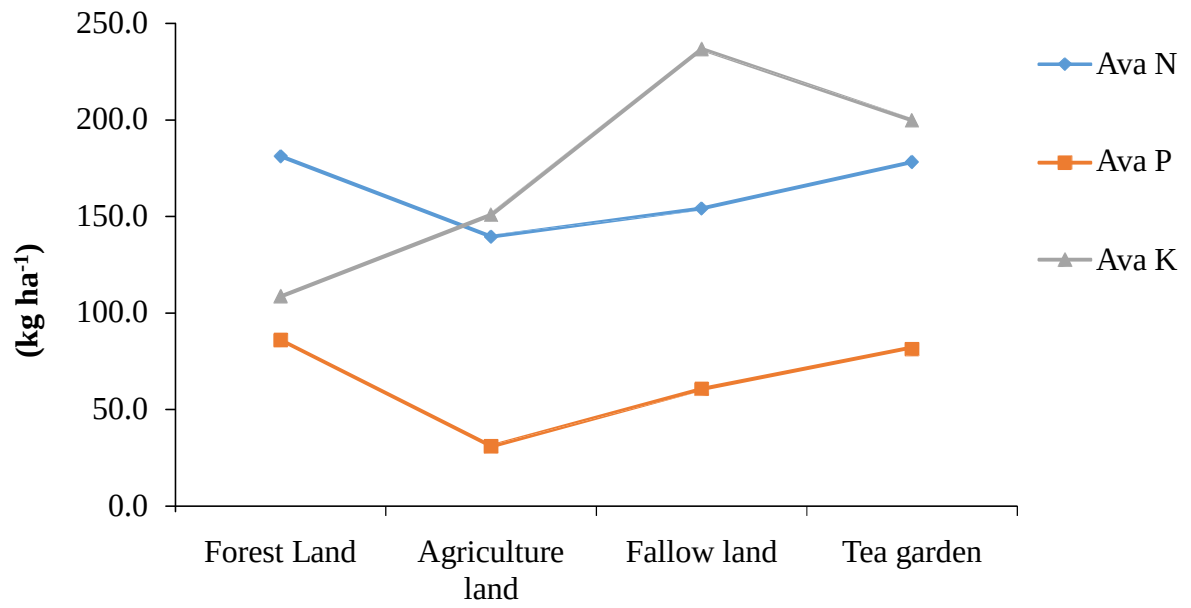


Figure 2. Change in available N-P-K (kg ha⁻¹) with different ecosystems

4.2 Carbon fractions under different landuse systems

4.2.1 Carbon fractions under the Forest ecosystems

Depthwise distribution of oxidisable organic carbon under four forest lands (Gorumara, Mahananda, Buxa and Chilapata) had been shown in Table 8. Very Labile Carbon was highest (13.32 g kg^{-1}) in Gorumara soil and lowest in Chilapata (8.57 g kg^{-1}) at 0-20 cm depth. Similar trend was found for Labile carbon at 0-20 cm depth, where as residual carbon was relatively higher (3.91 g kg^{-1}) in Buxa and lower at Gorumara (0.38 g kg^{-1}). Highest value of very Labile carbon (13.32 g kg^{-1}) was observed at Gorumara (0-20 cm depth) and lowest (5.69 g kg^{-1}) was found at Mahananda forest at 40-60 cm depth. Maximum value (11.63 g kg^{-1}) of Labile carbon was observed at Mahananda (0-20 cm) and minimum (0.97 g kg^{-1}) was found at Chilapata (20-40 cm). There is a trend in decrease in Labile carbon with increasing depth of all forest soil.

4.2.2 Carbon fractions at cultivated lands

It was observed in cultivated lands (Table 9) that, very Labile carbon was maximum (10.51 g kg^{-1}) in Kharibari soil (0-20 cm) and minimum (2.76 g kg^{-1}) in Balarampur soil. Less Labile carbon was lowest (0.30 g kg^{-1}) in Kharibari soil at 40-60 cm depth and was maximum (2.43 g kg^{-1}) at Binnaguri soil at 40-60 cm depth. Highest value of Labile carbon (5.61 g kg^{-1}) was found in Binnaguri soil at 40-60 cm depth and lowest (0.71 g kg^{-1}) at Kumargram soil in the depth 0-20 cm and 40-60 cm.

4.2.3 Carbon fractions at fallow lands

Among the oxidisable organic carbon fractions (Table 10) in fallow land it was observed that, Kharibari soil had highest (12.30 g kg^{-1}) Very Labile carbon at 0-20 cm depth and minimum value (1.48 g kg^{-1}) in Balarampur soil at 20-40 cm depth and 40-60 cm depth. Labile carbon was found maximum (7.76 g kg^{-1}) in Kharibari soil (0-20 cm) and lowest (1.43 g kg^{-1}) Kumargram soil at 20-40 cm depth where as Labile carbon was maximum (2.69 g kg^{-1}) in Binnaguri soil (0-20 cm) and minimum (0.02 g kg^{-1}) in Balarampur soil at 20-40 cm depth.

4.2.4 Carbon fractions at Tea gardens

In tea garden ecosystem it was found (Table 11) that, Very Labile and Labile carbon had highest value (10.71 g kg^{-1} and 7.86 g kg^{-1}) at Nimti Tea estate at 0-20 cm depth compare to other tea gardens. Less Labile carbon was maximum (3.16 g kg^{-1}) at Moraghat Tea garden (0-20 cm depth) and was minimum (0.02 g kg^{-1}) at Kumargram Tea Estate (0-20 cm depth).

Table 8. Oxidizable organic carbon of soils under the forest ecosystem

Ecosystem	Depth	Oxidizable Organic Carbon (g kg ⁻¹)				
		Location	Very labile	Labile	Less labile	Residual
Forest soil	0-20 cm	Gorumara	13.32b	11.58b	1.51	0.38a
		Mahananda	13.06b	11.63b	0.75	4.27c
		Buxa	8.67a	7.50a	0.24	3.91bc
		Chilapata	8.57a	6.68a	0.35	3.18b
		Mean	10.91	9.35	0.71	2.94
		SE(m)±	0.079	0.339	NS	0.219
		LSD (<i>P</i> =0.05)	0.274	1.172	0.950	0.757
	20-40 cm	Gorumara	13.01	7.81	1.03	6.52
		Mahananda	9.29	6.53a	0.28	9.76
		Buxa	10.71a	2.14	0.07	3.34a
		Chilapata	9.95	0.97	0.82	2.29a
		Mean	10.74	4.36	0.55	5.48
		SE(m)±	0.092	0.210	NS	0.705
		LSD (<i>P</i> =0.05)	0.092	0.726	0.725	2.438
	40-60 cm	Gorumara	9.03	10.92	5.14	1.16a
		Mahananda	5.69a	2.22	0.01a	9.75
		Buxa	6.17b	5.31a	0.71b	2.58a
		Chilapata	5.97ab	3.72	0.72b	1.38a
		Mean	6.72	5.54	1.65	3.72
		SE(m)±	0.086	0.153	0.112	0.523
		LSD (<i>P</i> =0.05)	0.298	0.529	0.387	1.811
	Grant mean		9.45	6.42	0.97	4.04
	Location	SE(m)±	0.060	0.141	0.120	0.285
		LSD (<i>P</i> =0.05)	0.177	0.413	0.353	0.836
	Depth	SE(m)±	0.052	0.122	0.104	0.247
		LSD (<i>P</i> =0.05)	0.153	0.358	0.306	0.724
	Location X Depth	SE(m)±	0.104	0.244	0.209	0.494
LSD (<i>P</i> =0.05)		0.306	0.716	0.612	1.447	

Means with common letters are not significantly different at $P \leq 0.05$, according to Fisher's Protected Least Significant Difference (LSD) test using the algorithm of Studentized range test (Hsu, 1996).

F₁ organic carbon oxidizable under 6 mol l⁻¹ H₂SO₄, F₂ the difference in oxidizable organic carbon extracted between 9 mol l⁻¹ and 6 mol l⁻¹ H₂SO₄, F₃ the difference in oxidizable organic carbon extracted between 12 mol l⁻¹ and 9 mol l⁻¹ H₂SO₄, F₄ residual organic carbon after reaction with 12 mol l⁻¹ H₂SO₄

Table 9. Oxidizable organic carbon of soils under the cultivated ecosystem

Ecosystem	Depth	Oxidizable Organic Carbon (g kg ⁻¹)				
		Location	Very labile	Labile	Less labile	Residual
Cultivated Soils	0-20 cm	Binnaguri	6.94	4.85	0.69	1.41a
		Balarampur	2.76	5.46a	1.60	0.13
		Kumargram	7.60a	0.71	0.21a	0.71
		Kharibari	10.51	6.68	0.14a	1.27a
		Mean	6.95	4.43	0.66	0.88
		SE(m)±	0.144	0.147	0.103	0.063
		LSD (<i>P</i> =0.05)	0.497	0.507	0.358	0.217
	20-40 cm	Binnaguri	5.10	5.61a	0.59	0.90
		Balarampur	2.09	3.06	0.26a	2.93a
		Kumargram	6.07a	0.77	0.12a	0.56
		Kharibari	8.37	6.99	0.92	3.13a
		Mean	5.41	4.11	0.47	1.88
		SE(m)±	0.067	0.138	0.089	0.060
		LSD (<i>P</i> =0.05)	0.234	0.478	0.125	0.207
	40-60 cm	Binnaguri	3.88b	2.19ab	2.43	1.40
		Balarampur	0.56a	3.32bc	0.70	3.53
		Kumargram	3.83b	0.71a	0.42	0.70
		Kharibari	8.21	5.71c	0.30	2.78a
		Mean	4.12	2.98	NS	2.10
		SE(m)±	0.152	0.700	0.763	0.077
		LSD (<i>P</i> =0.05)	0.527	2.421	2.639	0.267
	Grant mean		5.49	3.84	0.70	1.62
		SE(m)±	0.070	0.234	NS	0.039
		LSD (<i>P</i> =0.05)	0.205	0.686	0.739	0.115
	Depth	SE(m)±	0.061	0.203	NS	0.034
		LSD (<i>P</i> =0.05)	0.178	0.594	0.640	0.100
	Location X Depth	SE(m)±	0.121	0.405	0.437	0.068
		LSD (<i>P</i> =0.05)	0.355	1.188	1.280	0.200

Means with common letters are not significantly different at $P \leq 0.05$, according to Fisher's Protected Least Significant Difference (LSD) test using the algorithm of Studentized range test (Hsu, 1996).

F₁ organic carbon oxidizable under 6 mol l⁻¹ H₂SO₄, F₂ the difference in oxidizable organic carbon extracted between 9 mol l⁻¹ and 6 mol l⁻¹ H₂SO₄, F₃ the difference in oxidizable organic carbon extracted between 12 mol l⁻¹ and 9 mol l⁻¹ H₂SO₄, F₄ residual organic carbon after reaction with 12 mol l⁻¹ H₂SO₄

Table 10. Oxidizable organic carbon of soils under the fallow land ecosystem

Ecosystem	Depth	Oxidizable Organic Carbon (g kg ⁻¹)				
		Location	Very labile	Labile	Less labile	Residual
Fallow land	0-20 cm	Binnaguri	7.96a	5.92a	2.69	2.89a
		Balarampur	3.06	4.39	0.41	0.28
		Kumargram	3.93	1.63	0.18	1.06
		Kharibari	12.30	7.76	1.54a	5.29
		Mean	6.81	4.93	1.21	2.38
		SE(m)±	0.087	0.111	0.060	0.258
		LSD (<i>P</i> =0.05)	0.302	0.385	0.207	0.892
	20-40 cm	Binnaguri	5.51a	5.05a	0.59b	2.34
		Balarampur	1.48	3.05	0.02a	0.04a
		Kumargram	3.01	1.43	0.52b	0.13a
		Kharibari	10.26	6.07	1.87	3.08
		Mean	5.07	3.90	0.75	1.40
		SE(m)±	0.172	0.208	0.085	0.117
		LSD (<i>P</i> =0.05)	0.594	0.721	0.294	0.404
	40-60 cm	Binnaguri	5.56a	5.97a	0.35a	1.37a
		Balarampur	1.48	1.58	0.25a	0.03
		Kumargram	3.16	2.60	0.10a	0.55
		Kharibari	10.15	5.56a	0.86	1.56a
		Mean	5.09	3.93	0.39	0.88
		SE(m)±	0.053	0.158	0.129	0.146
		LSD (<i>P</i> =0.05)	0.184	0.547	0.448	0.507
		Grant mean	5.66	4.25	0.78	1.55
	Location	SE(m)±	0.067	0.099	0.053	0.108
		LSD (<i>P</i> =0.05)	0.198	0.289	0.156	0.316
	Depth	SE(m)±	0.058	0.085	0.046	0.093
		LSD (<i>P</i> =0.05)	0.171	0.251	0.135	0.273
	Location X Depth	SE(m)±	0.117	0.171	0.092	0.186
		LSD (<i>P</i> =0.05)	0.343	0.501	0.271	0.547

Means with common letters are not significantly different at $P \leq 0.05$, according to Fisher's Protected Least Significant Difference (LSD) test using the algorithm of Studentized range test (Hsu, 1996).

F₁ organic carbon oxidizable under 6 mol l⁻¹ H₂SO₄, F₂ the difference in oxidizable organic carbon extracted between 9 mol l⁻¹ and 6 mol l⁻¹ H₂SO₄, F₃ the difference in oxidizable organic carbon extracted between 12 mol l⁻¹ and 9 mol l⁻¹ H₂SO₄, F₄ residual organic carbon after reaction with 12 mol l⁻¹ H₂SO₄

Table 11. Oxidizable organic carbon of soils under the tea garden ecosystem

Ecosystem	Oxidizable Organic Carbon (g kg ⁻¹)					
	Depth	Location	Very labile	Labile	Less labile	Residual
Tea gardens	0-20 cm	Moraghat	10.36a	6.58	3.16	3.55b
		Ellenbari	7.45	7.40a	2.04	1.29a
		Nimti	10.71a	7.86	0.26a	4.02b
		Kumargram	5.82	3.42	0.02a	0.68a
		Mean	8.59	6.32	1.37	2.39
		SE(m)±	0.106	0.125	0.083	0.240
		LSD (<i>P</i> =0.05)	0.368	0.432	0.286	0.832
	20-40 cm	Moraghat	7.30a	5.10b	2.00	2.34b
		Ellenbari	5.87	7.35	0.27a	8.22
		Nimti	7.35a	5.26b	0.94b	1.77b
		Kumargram	5.41	2.14a	0.95b	0.63a
		Mean	6.48	4.96	1.04	3.24
		SE(m)±	0.101	0.156	0.104	0.209
		LSD (<i>P</i> =0.05)	0.349	0.539	0.360	0.724
	40-60 cm	Moraghat	6.63a	5.66a	0.79	1.67b
		Ellenbari	5.15	7.50	0.13a	1.42b
		Nimti	7.65	3.72	2.17	2.08
		Kumargram	3.88	1.33	0.35a	0.07a
		Mean	5.83	4.55	0.86	1.31
		SE(m)±	0.159	0.183	0.098	0.090
		LSD (<i>P</i> =0.05)	0.549	0.635	0.340	0.312
	Location	Grant mean	6.97	5.28	1.09	2.31
		SE(m)±	0.067	0.084	0.050	0.118
		LSD (<i>P</i> =0.05)	0.196	0.247	0.148	0.347
	Depth	SE(m)±	0.058	0.073	0.044	0.103
		LSD (<i>P</i> =0.05)	0.170	0.214	0.128	0.301
	Location X Depth	SE(m)±	0.116	0.146	0.087	0.205
		LSD (<i>P</i> =0.05)	0.340	0.428	0.256	0.602

Means with common letters are not significantly different at $P \leq 0.05$, according to Fisher's Protected Least Significant Difference (LSD) test using the algorithm of Studentized range test (Hsu, 1996).

F₁ organic carbon oxidizable under 6 mol l⁻¹ H₂SO₄, F₂ the difference in oxidizable organic carbon extracted between 9 mol l⁻¹ and 6 mol l⁻¹ H₂SO₄, F₃ the difference in oxidizable organic carbon extracted between 12 mol l⁻¹ and 9 mol l⁻¹ H₂SO₄, F₄ residual organic carbon after reaction with 12 mol l⁻¹ H₂SO₄

4.3 Effect of Land-use on Different Carbon Fractions in Soils

The forms of organic carbon (very labile, labile, less labile and non-labile C) have been shown in the tables 12-15 at different depths (0-40 cm and 40-60 cm) of soils. Under the fallow land situation, the very labile carbon (Table 12) has the minimum fractions (2.27 gkg^{-1}) in Balarampur soil and was maximum (11.28 gkg^{-1}) in Kharibari soil. It was observed that the non-labile carbon was minimum (0.16 gkg^{-1}) in Kumargram soil at 0-40 cm depth while the very labile carbon (40-60 cm) was highest in Kharibari soil (0.60 gkg^{-1}). The average of the less labile carbon was 0.98 gkg^{-1} in 0-40cm depth, whereas that of very labile carbon was 5.94 gkg^{-1} in 0-40 cm depth. It was observed that the different organic fractions were relatively higher in the surface (0-40cm) soil than the soil depth of above 40 cm. the order was very labile>Non-labile>less labile at both the surface and subsurface soil. The carbon balance under the fallow land situation may vary in accordance with the period of abandonment (Kuraganova *et al.*,2008) and that may lead to the increase of the organic matter content in soil (Chen *et al.*,2010). The very labile and labile carbon fractions could qualify the four per mile concept (0.55 % and 0.42%) while the less labile (0.069%) and non-labile (0.14%) could not reach the target.

Among the oxidisable organic carbon fractions (Table 13), the very labile carbon was lowest (2.43 gkg^{-1}) while the same was maximum (9.44) in Kharibari soil at the 0-40 cm depth. Again, the less labile carbon was found minimum (0.17 gkg^{-1}) at Kumargram soil and maximum (0.93 gkg^{-1}) at Balarampur soil. At Kharibari, the less labile carbon (0.03 gkg^{-1}) at 40-60 cm depth was minimum, while that of the very labile carbon was 8.21 gkg^{-1} under the cultivated land. There was a difference of the carbon fractions under forestland and cultivated situation might be due to the conversion of forests into cropland resulting the decrease of the soil organic carbon stock for disturbance and lower inputs of non-soluble carbon materials in crop land than the forest (Banger *et al.*,2015) land situation. The very labile carbon fractions only could qualify the four per mile concept among the other organic fractions. This might be due to the manipulation of the surface and sub surface soils under the cultivation practices leading to the change in the carbon stock in the soils.

It has been observed (Table 14) that less labile carbon in 0-40 cm depth was lowest (0.16 gkg^{-1}) in Buxa while the very labile fraction was maximum (13.15 gkg^{-1}) in Gorumara forest soil. However, the less labile carbon in 40-60 cm depth was lowest (0.01 gkg^{-1}) in Mahananda soil and labile carbon has highest value (10.92 gkg^{-1}) in Gorumara soil. It was apparent that the less labile carbon was minimum (1.14 gkg^{-1}) and very labile carbon was

highest (8.78 gkg^{-1}) at among the all forest land situation. While understanding the non-labile soil carbon status in soil, the increased loss of mass for the highly decomposable litter can result in a loss of soil organic carbon (SOC) with the high deposition of nitrogen (Kolbe et al, 2016). The differences in carbon pools might be due to the higher degree of macro-aggregates in forest soil over that of the cultivated land (Shrestha *et al.*, 2006). The trend to qualify the four per thousand concept by the very labile and labile pools of the SOC under the forest ecosystem over that of less labile (0.88%) and non-labile (0.62%) fractions might be due to the changing degree of decomposition at the forest ecosystem sustained with several sources of carbon deposition (leaf fall etc).

While understanding the oxidisable carbon fractions under the tea garden, it was observed that the very labile carbon (Table 15) varied from $5.61\text{--}9.03 \text{ gkg}^{-1}$ with an average of 7.54 gkg^{-1} at 0-40 cm depth of soil. The less labile carbon was found maximum (2.60 gkg^{-1}) in Moraghat tea garden. The non-labile carbon was 0.07 gkg^{-1} in Kumargram soil while that of the labile was 7.50 gkg^{-1} in Ellenbari tea garden areas at 40-60 cm depth of soil. The trend of magnitude of the different organic fractions was very labile > labile > non-labile > less labile. While comparing with the four per thousand concept, it was observed that the verylabile (0.67%) and the labile pools (0.51%) qualified for the carbon status over the less labile and non-labile carbon fractions at the tea garden ecosystem.

4.4 Distribution of soil carbon fractions and GIS mapping

The distribution of carbon fractions at three depths (0-20 cm, 20-40 cm and 40-60 cm) in different landuses of Terai region of West Bengal, India are shown in Figures-5, 6 and 7.

The different carbon fractions has been shown through GIS-based mapping using ArcGIS R (Figure 5.) Among the different forms of carbon (CaCO_3 – bound, active carbon and particulate organic carbon), it was observed (Figure 3) that CaCO_3 - bound fractions was higher in forest soil than the fallow land while the active carbon was higher in forest soil than the cultivated land at 0-20 cm depth of soil. The POC was relatively higher in tea garden soil than that of the cultivated land. The distribution of carbon pools (CaCO_3 – bound, active carbon and particulate organic carbon) were shown by the GIS mapping (Figure 6).

At the soil depth of 20-40 cm the CaCO_3 - bound carbon fractions was maximum in the cultivated land and minimum in forest land, while the active carbon fractions was

maximum in forest land and minimum in the cultivated land. The POC was maximum in cultivated land and minimum in forest land situation.

At the soil depth of 40-60 cm the CaCO_3 - bound carbon fractions was maximum in the cultivated land and minimum in forest land while the active carbon was relatively higher at the tea garden than the cultivated land. The POC was maximum in the cultivated land and minimum in fallow land situation.

The changes in minerelisable carbon (Figure 4) under different land use pattern (Forest, Cultivated, Fallow and Tea garden) showed that SRR at 0-3 days after incubation (DAI), at 3-10 DAI and at 10-24 DAI was maximum in fallow land and minimum in cultivated land at 0-20 cm of the soil depth while the same was higher in cultivated at 0-3 DAI and 3-10 DAI at 20-40 cm depth of soils. The observation showed that carbon minerelization was affected by the duration of the incubation period and landuse pattern. In general, the carbon minerelization increased with the days of incubation period upto ten days irrespective of landuse pattern, but the rate of increase was decreased with the progress of incubation, stating that the carbon minerelization was faster at the initial period of incubation and then slowed down gradually as the time progressed and with the depth of the soil, the rate was decreased. A general trend of minimum minerelisable carbon (MC) was observed in the tea gardens at 40-60 cm depth of soils. The minerelisable carbon under different land use pattern were shown by the GIS mapping (Figure 5).

The POC and mineralisable carbon were related to each other and are influenced by the management practices. The POC reflected the practices related to conservation that are expected to promote accumulation or stabilization of organic matter (long term carbon sequestration).

Table 12. Labile and recalcitrant carbon pools of soils under the fallow land ecosystem

Ecosystem	Oxidizable Organic Carbon (g kg ⁻¹)						TOC
	Depth	Location	Very labile	Labile	Less labile	Non-labile	
Fallow land	0-40 cm	Binnaguri	6.74a	5.49a	1.64a	2.62a	16.50
		Balarampur	2.27	3.72	0.22	0.16	6.00a
		Kumargram	3.47	1.53	0.35	0.60	5.90a
		Kharibari	11.28	6.92	1.71a	4.19	24.10
		Mean	5.94	4.41	0.98	1.89	13.10
		SE(m)±	0.106	0.102	0.033	0.144	0.144
		LSD (<i>P</i> =0.05)	0.368	0.354	0.116	0.500	0.498
		Binnaguri	5.56a	5.97a	0.35a	1.37a	13.20a
	40-60 cm	Balarampur	1.48	1.58	0.25a	0.03	3.30
		Kumargram	3.16	2.60	0.10a	0.55	6.40
		Kharibari	10.15	5.56a	0.86	1.56a	18.10
		Mean	5.09	3.93	0.39	0.88	10.30
		SE(m)±	0.053	0.158	0.129	0.146	0.143
		LSD (<i>P</i> =0.05)	0.184	0.547	0.448	0.507	0.494
		Grand mean	5.51	4.17	0.69	1.39	11.70
		SE(m)±	0.067	0.107	0.066	0.114	0.115
		LSD (<i>P</i> =0.05)	0.204	0.325	0.200	0.346	0.348
	Location	SE(m)±	0.048	0.076	0.047	0.081	0.081
		LSD (<i>P</i> =0.05)	0.144	0.230	0.142	0.244	0.246
	Depth	SE(m)±	0.095	0.152	0.093	0.161	0.162
		LSD (<i>P</i> =0.05)	0.289	0.460	0.283	0.489	0.492
	Location X Depth	SE(m)±					
		LSD (<i>P</i> =0.05)					

Means with common letters are not significantly different at $P \leq 0.05$, according to Fisher's Protected Least Significant Difference (LSD) test using the algorithm of Studentized range test (Hsu, 1996).

Table 13. Labile and recalcitrant carbon pools of soils under the cultivated ecosystem

Ecosystem	Oxidizable Organic Carbon (g kg ⁻¹)						TOC
	Depth	Location	Very labile	Labile	Less labile	Non-labile	
Cultivated Soils	0-40 cm	Binnaguri	6.02	5.23a	0.64b	1.16	13.00
		Balarampur	2.43	4.26	0.93	1.53a	8.80a
		Kumargram	6.84a	0.74	0.17a	0.64	8.40a
		Kharibari	9.44	6.84	0.53b	2.20	19.00
		Mean	6.18	4.27	0.57	1.38	12.30
		SE(m)±	0.082	0.135	0.071	0.040	0.285
		LSD (<i>P</i> =0.05)	0.284	0.468	0.246	0.137	0.985
		Binnaguri	3.88b	2.19ab	2.43	1.40	9.90b
	40-60 cm	Balarampur	0.56a	3.32bc	0.70	3.53	8.90b
		Kumargram	3.83b	0.71a	0.42	0.70	5.70a
		Kharibari	8.21	5.71c	0.30	2.78a	17.00
		Mean	4.12	2.98	NS	2.10	10.40
		SE(m)±	0.152	0.700	0.763	0.077	0.297
		LSD (<i>P</i> =0.05)	0.527	2.421	2.639	0.267	1.027
		Grand mean	5.15	3.63	0.77	1.74	11.30
		SE(m)±	0.082	0.346	NS	0.046	0.192
		LSD (<i>P</i> =0.05)	0.250	1.051	1.141	0.141	0.583
	Location	SE(m)±	0.058	0.245	NS	0.033	0.136
		LSD (<i>P</i> =0.05)	0.177	0.743	0.807	0.099	0.412
	Depth	SE(m)±	0.117	NS	NS	0.066	0.272
		LSD (<i>P</i> =0.05)	0.353	1.486	1.614	0.199	0.825
	Location X Depth	SE(m)±					
		LSD (<i>P</i> =0.05)					

Means with common letters are not significantly different at $P \leq 0.05$, according to Fisher's Protected Least Significant Difference (LSD) test using the algorithm of Studentized range test (Hsu, 1996).

Table 14. Labile and recalcitrant carbon pools of soils under the forest ecosystem

Ecosystem	Oxidizable Organic Carbon (g kg ⁻¹)						TOC
	Depth	Location	Very labile	Labile	Less labile	Non labile	
Forest soil	0-40 cm	Gorumara	13.15	9.70	1.27	3.45a	27.60a
		Mahananda	11.20a	9.08a	0.52ab	7.02	27.80a
		Buxa	9.70	4.82	0.16a	1.67a	18.30
		Chilapata	9.30	3.83	0.59b	2.74a	16.40
		Mean	10.84	6.86	0.63	3.72	22.50
		SE(m)±	0.078	0.162	0.115	0.371	0.360
		LSD (<i>P</i> =0.05)	0.268	0.561	0.399	1.283	1.245
		Gorumara	9.03	10.92	5.14	1.16a	26.20
	40-60 cm	Mahananda	5.69a	2.22	0.01a	9.75	17.70a
		Buxa	6.17b	5.31a	0.71b	2.58a	14.80
		Chilapata	5.97ab	3.72	0.72b	1.38a	11.80
		Mean	6.72	5.54	1.65	3.72	17.60
		SE(m)±	0.086	0.153	0.112	0.523	0.518
		LSD (<i>P</i> =0.05)	0.298	0.529	0.387	1.811	1.791
		Grand mean	8.78	6.20	1.14	3.72	20.10
		SE(m)±	0.074	0.107	0.080	0.313	0.309
	Location	LSD (<i>P</i> =0.05)	0.223	0.324	0.243	0.949	0.938
		SE(m)±	0.052	0.076	0.057	NS	0.219
	Depth	LSD (<i>P</i> =0.05)	0.158	0.229	0.172	0.671	0.663
		SE(m)±	0.104	0.151	0.113	0.443	0.437
	Location X Depth	LSD (<i>P</i> =0.05)	0.316	0.458	0.344	1.342	1.326

Means with common letters are not significantly different at $P \leq 0.05$, according to Fisher's Protected Least Significant Difference (LSD) test using the algorithm of Studentized range test (Hsu, 1996).

Table 15. Labile and recalcitrant carbon pools of soils under the tea gardens ecosystem

Ecosystem	Oxidizable Organic Carbon (g kg ⁻¹)						TOC
	Depth	Location	Very labile	Labile	Less labile	Non-labile	
Tea gardens	0-40 cm	Moraghat	8.85a	5.85	2.60	2.95b	20.20a
		Ellenbari	6.69	7.38	1.14	4.76	19.90a
		Nimti	9.03a	6.58a	0.62a	2.90b	19.10
		Kumargram	5.61	2.77	0.49a	0.66a	9.50
		Mean	7.54	5.64	1.21	2.81	17.20
		SE(m)±	0.077	0.122	0.066	0.170	0.169
		LSD (<i>P</i> =0.05)	0.266	0.423	0.229	0.587	0.586
		Moraghat	6.6c	5.66c	0.79b	1.67b	14.80a
	40-60 cm	Ellenbari	5.2b	7.50d	0.13a	1.42b	14.20
		Nimti	7.7d	3.72b	2.17c	2.08c	15.60
		Kumargram	3.9a	1.33a	0.35a	0.07a	5.50
		Mean	5.83	4.55	0.86	1.31	12.50
		SE(m)±	0.159	0.183	0.098	0.090	0.088
		LSD (<i>P</i> =0.05)	0.549	0.635	0.340	0.312	0.305
		Grand mean	6.70	5.10	1.04	2.06	14.90
		SE(m)±	0.084	0.105	0.055	0.095	0.095
	Location	LSD (<i>P</i> =0.05)	0.254	0.319	0.168	0.289	0.287
		SE(m)±	0.059	0.074	0.039	0.067	0.067
	Depth	LSD (<i>P</i> =0.05)	0.180	0.226	0.119	0.204	0.203
		SE(m)±	0.119	0.149	0.078	0.135	0.134
	Location X Depth	LSD (<i>P</i> =0.05)	0.360	0.451	0.238	0.409	0.405

Means with common letters are not significantly different at $P \leq 0.05$, according to Fisher's Protected Least Significant Difference (LSD) test using the algorithm of Studentized range test (Hsu, 1996).

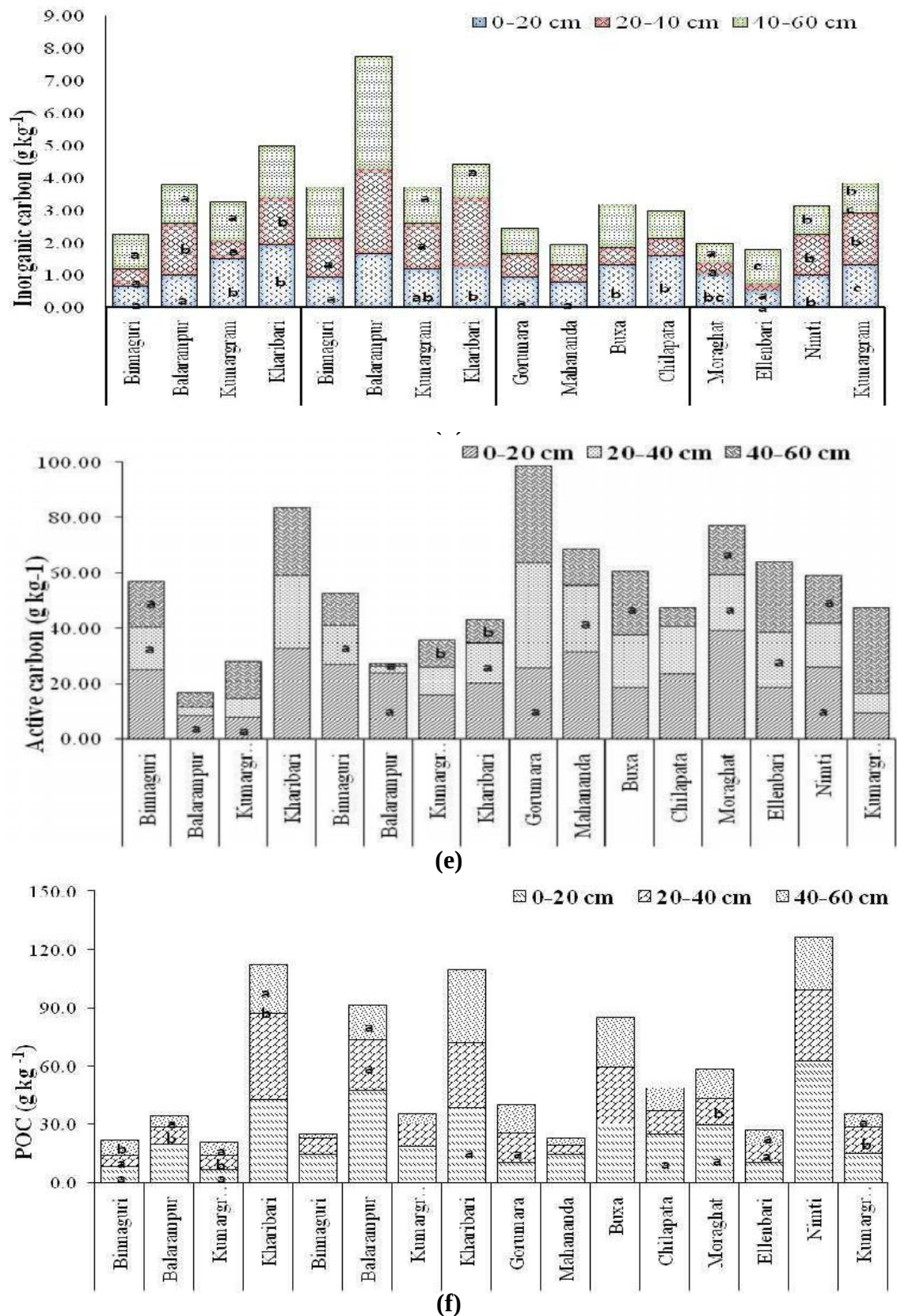


Fig. 3. Inorganic Carbon fractions in soils under different landuse systems. The distribution of inorganic carbon (d), active carbon (e) and POC (f) in soil at different depths (0-20, 20-40 and 40-60 cm) under different cultivated lands. Means with common letters are not significantly different at $P \leq 0.05$, according to Fisher's Protected Least Significant Difference (LSD) test using the algorithm of Studentized range test (Hsu, 1996).

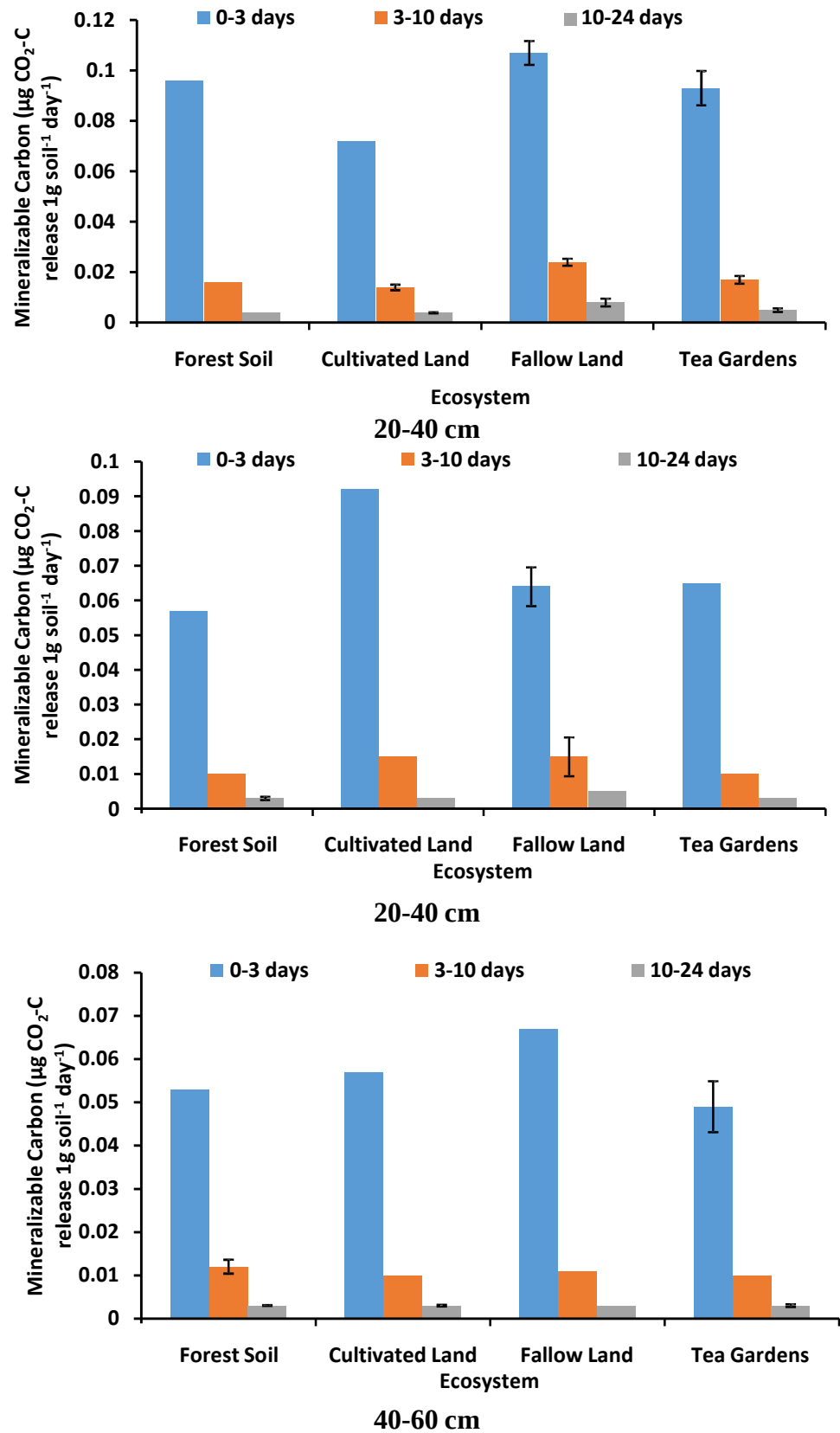


Fig. 4. Mineralisable carbon ($\mu\text{gCO}_2\text{-C released 1gsoil}^{-1}\text{day}^{-1}$) fractions in soils under different landuse systems. Error bar indicates the standard deviation ($p=0.05$). The changes in minerelisable carbon at different incubation periods (0-3, 3-10 and 10-24 days) and depth of soils (0-20, 20-40 and 40-60 cm). Significant differences were observed in some of the ecosystems (Tea gardens, Fallow land) with the given period of incubation while the changes were not significant in most of the cases at the initial period of incubation.

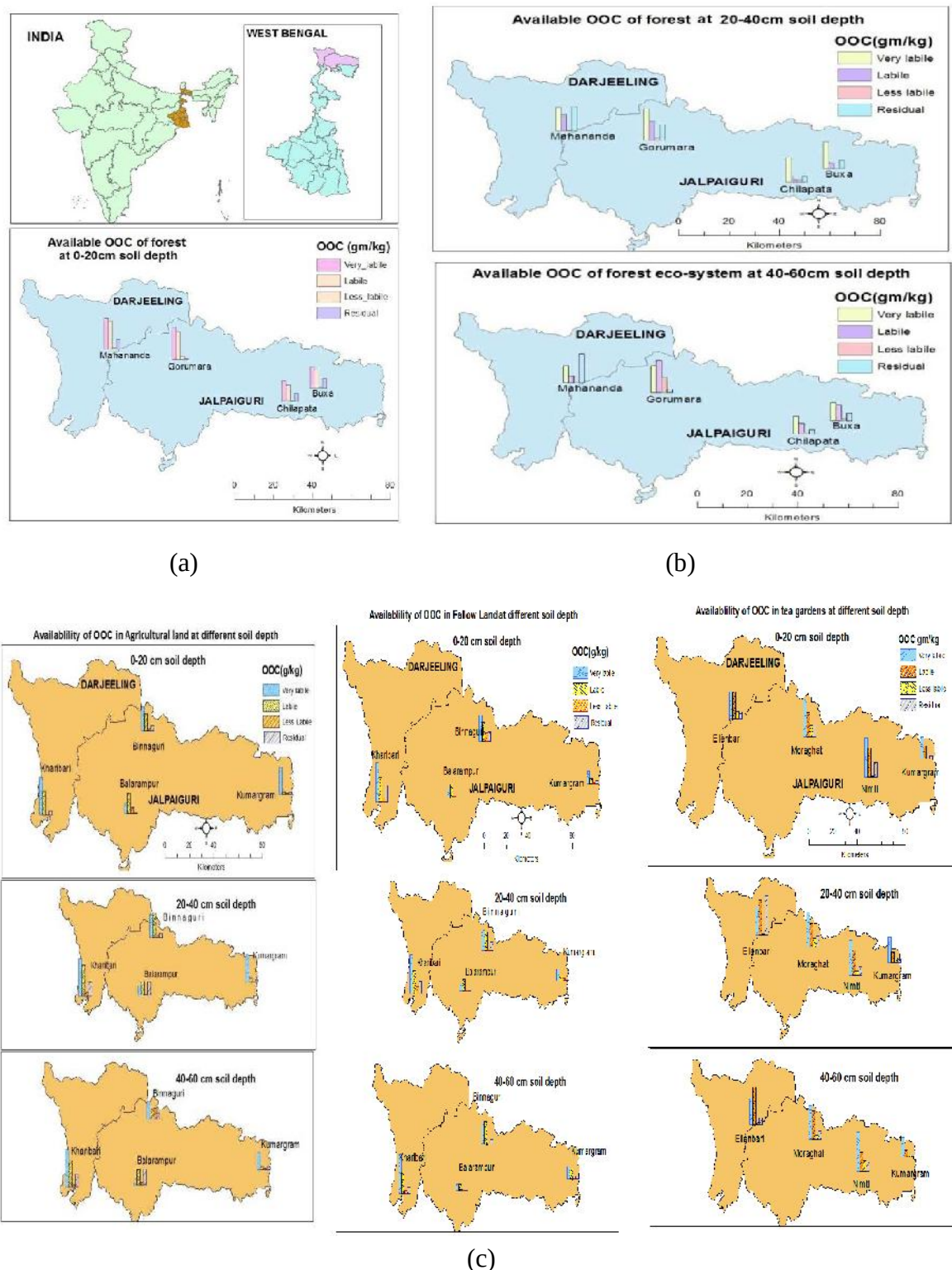


Fig. 5. The GIS mapping of the carbon fractions under different land use situation. The location map (a) of the study area under different ecosystems. The fractions of oxidisable organic carbon (very labile, labile, less labile, residual) in soil at different soil depths (0-20, 20-40 and 40-60 cm) under different agro - ecosystems (b and c) locating the distribution of carbon pools through GIS mapping.

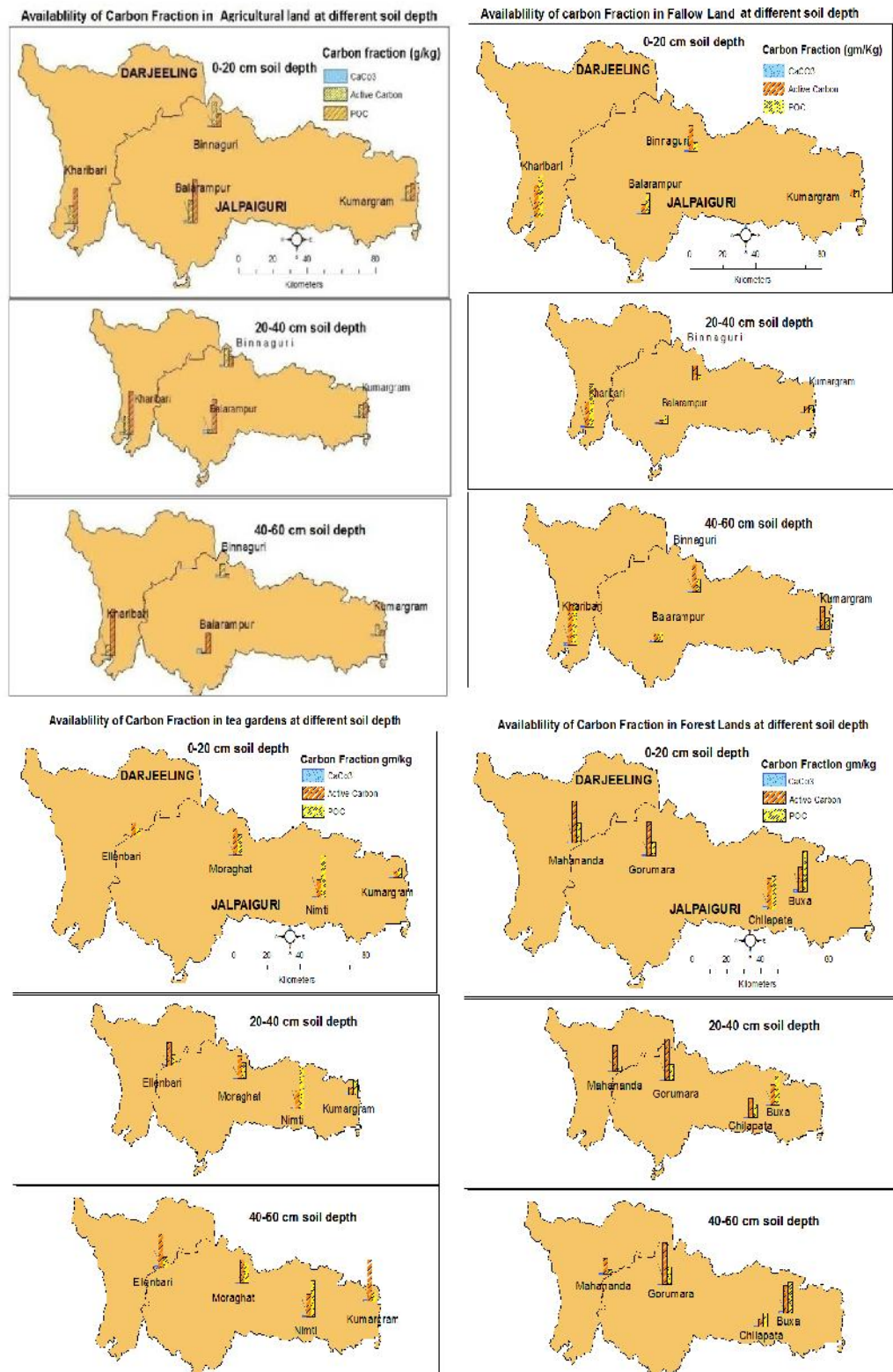


Fig. 6. The GIS mapping of the carbon fractions under different land use situation showing the distribution of the inorganic (CaCO_3), active carbon and POC of soils. The variation with the soil depths and dominance of the respective carbon pools at different ecosystems.

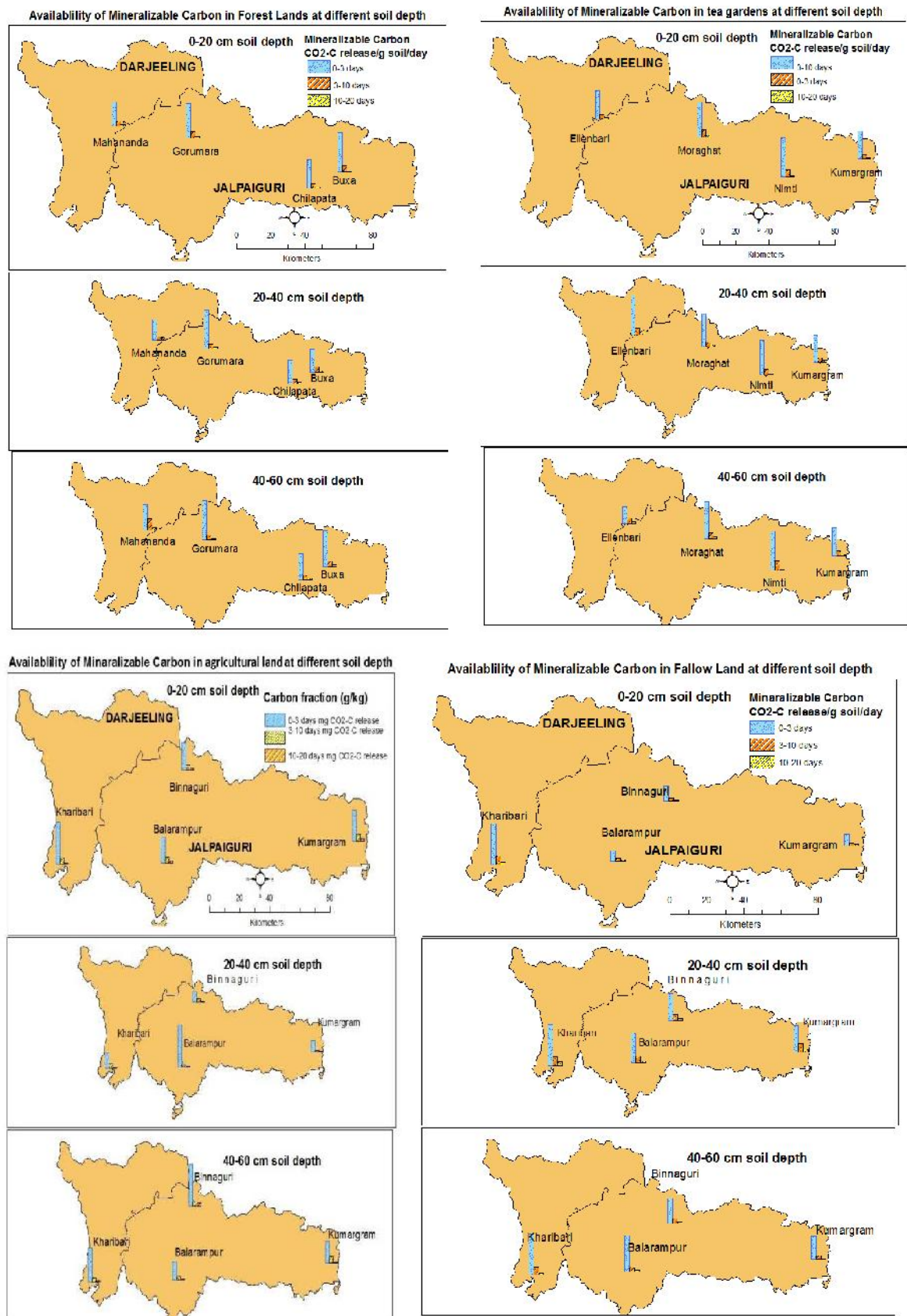


Fig. 7. The GIS mapping of the mineralisable carbon fractions under different land use situation. The changes of the mineralisable carbon with the period of incubation were observed at varying soil depths under different agro ecosystems.

Because of the logarithmic nature of carbon with depth, the majority of the carbon fractions are found above 40 cm depth containing most of the labile carbon sources for more accessible to microbial decomposition, while the soil at depth being relatively old were least influenced by management practices as found at the surface. The carbon fractions were dominant at forest and tea garden than the cultivated and fallow land areas. The Zero tillage (ZT) operation would improve the carbon stock over the conventional tillage (CT) practices.

4.5 Effect of tillage and organic residues on carbon fractions of soil and yield of wheat

On the study of physico-chemical properties of the field experimental soils it was revealed that (Table 16) soils are acidic in nature with moderate organic carbon and nutrient contents at initial stage and changed the values during experiments. Texture of the soils were sandy loam in nature.

Available N-P-K in soils at CRI, Flowering, Milking stage and at Harvest of wheat

During both the first and second year trial it was observed that available N, P, K, were maximum in zero tillage compare to conventional tillage and decreased with crop growth and reached lowest at harvest (Table 17 to 40).

CRI stage

The available nitrogen (kg ha^{-1}) in soils of experimental field (Table 17) at CRI stage of wheat at different treatment plots varied from 140.07 to 296.87 in Conventional Tillage (CT) and 150.53 to 399.32 in Zero Tillage (ZT). Significant difference in treatments and tillage practices were observed which was more prominent among the treatments T_9 , T_6 and T_3 where farmyard manure (FYM) and or paddy straw (PS) were applied in both CT and ZT. The available nitrogen in soil in ZT was higher compare to the CT practices.

Mean value of available nitrogen for the treatment T_9 , T_6 , T_3 and T_1 (control) were 18.3%, 26.1%, 24% and 11.6% respectively greater in ZT compare to CT. It was found that, (Table 18) available nitrogen (kg ha^{-1}) under different treatment was highest in case of T_9 treatment in ZT (344.96) and CT (291.65) compare to other treatment which may be due to the less disturbance of the soils at the ZT over that of the CT, irrespective of the different treatments.

The treatments had the significance influence on residue and FYM. It revealed that available phosphorus (kg ha^{-1}) in soils of experimental field (Table 19) at CRI stage of wheat at different treatment plots varied from 31.82 to 78.64 in Conventional Tillage (CT) operation and 33.27 to 82.26 in Zero Tillage (ZT) operations. Significant

difference in treatments and tillage practices were observed which was more prominent among the treatments T_9 , T_6 and T_3 where farmyard manure (FYM) and or paddy straw (PS) were applied in both CT and ZT. The higher mean value (pooled data) of available nitrogen in ZT was observed compare to CT operations (Table 19).

Experimental results depicted that, (Table 20) the available phosphorus (kg ha^{-1}) under different treatment was highest in case of T_9 in ZT (78.38) and CT (69.06) compare to other treatments, might be due to the less mobilization of the fixed phosphates under the influence of the applied FYM and paddy straw in soils. Mean value of available phosphorus for the treatment T_9 , T_6 , T_3 and T_1 (control) were 13.5%, 10.8%, 22.5% and 2.7% respectively greater in ZT compare to CT.

Soils of the experimental field showed available potassium (kg ha^{-1}) (Table 21) at CRI stage of wheat at different treatment varied from 87.98 to 217.65 in Conventional Tillage (CT) operation and 114.86 to 229.97 in Zero Tillage (ZT) operations. Significant differences in treatments and tillage practices were observed. Treatment, residue and residue X FYM had significant differences. Year and year X residue was non-significant for ZT.

The pooled data (Table 22) of available potassium (kg ha^{-1}) in soil under different treatment was highest in case of T_9 treatment in ZT (218.77) and CT (207.57) compare to other treatment might be due to the effect of the conservation tillage (ZT) on fixing potassium in soils over the CT. Pool data of mean value of available potassium for the treatment T_9 , T_6 , T_3 and T_1 (control) were 5.4%, 7.3%, 7.9% and 20.6% respectively greater in ZT compare to CT.

Flowering stage:

The treatment levels had significantly influence on soil available nitrogen (kg ha^{-1}). In soils of the experimental field (Table 23) at flowering stage of wheat at different treatment plots it was varied from 131.71 to 259.24 in Conventional Tillage (CT) and from 127.53 to 336.60 in Zero Tillage (ZT) operations. Prominent significant difference in treatments and tillage practices were observed among the treatments T_9 , T_6 and T_3 in both CT and ZT. It was also observed that, higher mean value of available nitrogen in ZT compare to CT .

Table 24 depicts that available nitrogen (kg ha^{-1}) under different treatment was highest in case of T_9 treatment in ZT (289.56) and CT (242.52) compare to other treatment (pooled data). Practice, year, residue , FYM and practice X year had significant different

values. Mean value of pooled data of available nitrogen for the treatment T₉, T₆, T₃ and T₁ (control) were 19.4%, 27.9%, 28.9% and 8.5% respectively higher in ZT compare to CT.

The available phosphorus (kg ha⁻¹) in soils of the experimental field (Table 25) at flowering stage of wheat at different treatment plots varied from 30.73 to 87.50 in Conventional Tillage (CT) operation and 40.68 to 91.12 in Zero Tillage (ZT) operations. This might be due to the available phosphorus content of the soil which was significantly influenced by application of phosphorus and by the interaction effect of FYM and phosphorus.

Significant difference in treatments and tillage practices were observed which was more prominent among the treatments T₉, T₆ and T₃ where farmyard manure (FYM) and or paddy straw (PS) were applied in both CT and ZT. It was also observed that, higher mean value of available phosphorus in ZT compare to CT operations.

Table 26 revealed that available phosphorus (kg ha⁻¹) under different treatment (pooled value) was highest in case of T₉ treatment in ZT (86.33) and CT (79.46) compare to other treatment. Mean value of available phosphorus for the treatment T₉, T₆, T₃ and T₁ (control) were 8.6%, 0.98%, 17.0% and 5.6% respectively greater in ZT compare to CT.

Variation of the available potassium (kg ha⁻¹) in soils of experimental field (Table 27) at Flowering stage of wheat at different treatment plots was from 49.65 to 154.93 in Conventional Tillage (CT) operation and 74.29 to 172.48 in Zero Tillage (ZT) operations. Clear Significant difference in treatments and tillage practices were observed among the treatments T₉, T₆ and T₃ where farmyard manure (FYM) and or paddy straw (PS) were applied in both CT and ZT. It was also observed that, higher mean value of available potassium in ZT compare to CT operations.

Mean value of available potassium for the treatment T₉, T₆, T₃ and T₁ (control) were 13.9%, 7.9%, 8.3% and 21.9% respectively more in ZT compare to CT. The pooled data of (Table 28) available potassium (kg ha⁻¹) under different treatment was highest in case of T₉ treatment in ZT (170.62) and CT (149.71) compare to other treatment. Practice, year, residue and FYM had significant influence for both year.

Milking stage:

The effect of tillage, FYM, PS, residue of cultivation were significant with respect to available soil nitrogen. (Table 29) At Milking stage of wheat at different treatment plots varied from 121.26 to 217.43 in Conventional Tillage (CT) operation and 127.53 to 290.60

in Zero Tillage (ZT) operations. Treatment showed non-significant relation in first year under CT operation. The mean value of available nitrogen in ZT was higher compare to CT operations.

Pooled data of (Table 30) available nitrogen (kg ha^{-1}) under different treatment was highest in case of T_9 treatment in ZT (248.79) and CT (211.16) compare to other treatment. Mean value of available potassium for the treatment T_9 , T_6 , T_3 and T_1 (control) were 17.8%, 18.9%, 22.5% and 13.2% respectively more in ZT compare to CT.

It was observed that the available phosphorus (kg ha^{-1}) in soils of experimental field (Table 31) at Milking stage of wheat at different treatment plots varied from 24.59 to 64.00 in Conventional Tillage (CT) operation and 27.66 to 70.51 in Zero Tillage (ZT) operations. Most of the cases it was observed that significant difference in treatments and tillage practices were observed in T_9 , T_6 and T_3 where farmyard manure (FYM) and or paddy straw (PS) were applied in both CT and ZT.

Pooled data of mean value of available phosphorus for the treatment T_9 , T_6 , T_3 and T_1 (control) were 10.1%, 5.9%, 34.0% and 23.7% respectively more in ZT compare to CT. It was also found that, (Table 32) available phosphorus (kg ha^{-1}) under different treatment was highest in case of T_9 treatment in ZT (69.1) and CT (62.83) compare to other treatment and control (T_1).

The available potassium (kg ha^{-1}) in soils of experimental field (Table 33) at Milking stage of wheat at different treatment plots varied from 55.63 to 146.72 in Conventional Tillage (CT) operation and 60.85 to 153.46 in Zero Tillage (ZT) operations. Significant difference in treatments and tillage practices were observed which was more prominent among the treatments T_9 , T_6 and T_3 where farmyard manure (FYM) and or paddy straw (PS) were applied in both CT and ZT. It was also observed that, higher mean value of available potassium in ZT compare to CT operations.

Table 34 showed that available potassium (kg ha^{-1}) in soils under different treatment was highest in case of T_9 treatment in ZT (150.83) and CT (127.50) compare to control. Increase in mean value of available potassium for the treatment T_9 , T_6 , T_3 and T_1 (control) were 18.2%, 8.5%, 2.7% and 9.9% respectively were observed in ZT compare to CT.

Harvest stage:

During both the first and second year trial it was observed that the available nitrogen (kg ha^{-1}) in soils of experimental field (Table 35) at Harvest of wheat at different treatment plots varied from 94.08 to 223.70 in Conventional Tillage (CT) operation and 110.81 to 234.15 in Zero Tillage (ZT) operations. Treatment, residue, FYM had significant influence whereas residue X FYM had non-significant value. Year X residue and year X FYM showed significant value for both the year of experiment.

The pooled data on (Table 36) available nitrogen (kg ha^{-1}) under different treatment was highest in case of T_9 treatment in ZT (204.89) and CT (186.07) compare to other treatment. The available nitrogen of soils at harvest revealed that during both the two years of practice ZT was found to have the highest available nitrogen in soils than CT. Mean value of available nitrogen for the treatment T_9 , T_6 , T_3 and T_1 (control) were 10.4%, 31.8%, 19.0% and 16.7% respectively more in ZT compare to CT.

The treatment levels had significantly influence on soil available phosphorus. FYM, treatment and residue had significant value whereas residue X FYM showed non-significant interactions. Year, year X residue, year X FYM and year X residue X FYM also showed non-significant interactions. The available phosphorus (kg ha^{-1}) in soils of experimental field (Table 37) varied from 12.47 to 50.80 in Conventional Tillage (CT) operation and 13.02 to 56.77 in Zero Tillage (ZT) operations.

Mean value of available phosphorus (pooled data) for the treatment T_9 , T_6 , T_3 and T_1 (control) were 10.4%, 4.4%, 22.6% and 10.8% respectively more in ZT compare to CT. It was noted that, (Table 38) available phosphorus (kg ha^{-1}) under different treatment was highest in case of T_9 treatment in ZT (54.87) and CT (49.72) compare to other treatment. This result was at par with the findings of by Majumder *et al.*, 2007 as organic inputs greatly influence nutrient cycling to maintain soil quality and its productivity.

The available potassium (kg ha^{-1}) in soils of experimental field (Table 39) at Harvest of wheat at different treatment plots varied from 42.56 to 124.69 in Conventional Tillage (CT) operation and 44.05 to 131.41 in Zero Tillage (ZT) operations. Significant difference in treatments and tillage practices were observed which was more prominent among the treatments T_9 , T_6 and T_3 where farmyard manure (FYM) and or paddy straw (PS) were applied in both CT and ZT. It was also observed that, higher mean value of available potassium in ZT compare to CT operations. There was an increase in mean value of

available potassium for the treatment T₉, T₆, T₃ and T₁ (control) were 13.8%, 32.9%, 7.6% and 22.1% respectively in ZT compare to CT (Table 40).

From pooled data it was found that, (Table 40) available potassium (kg ha⁻¹) under different treatment was highest in case of T₉ treatment in ZT (126.19) and CT (110.88) compare to other treatment. The available N, P, K soil at harvest revealed that during both the two years of practice ZT was found to have the highest available N, P, K in soils than CT method tillage.

Organic carbon and Labile carbon at CRI, Flowering, Milking stage and at Harvest

During both the first and second year trial it was observed that available organic carbon and labile carbon were maximum in zero tillage compare to conventional tillage and increased with crop growth and reached highest at harvest (Table 41 to 56).

CRI stage:

The organic carbon (g kg⁻¹) in soils of experimental field (Table 41) at CRI stage of wheat at different treatment plots varied from 6.65 to 10.16 in Conventional Tillage (CT) operation and 8.03 to 9.84 in Zero Tillage (ZT) operations. Treatment and residue was non-significant whereas FYM showed significant interactions for both the tillage system.

It was also found that, (Table 42) organic carbon (g kg⁻¹) under different treatment was highest in case of T₃ treatment in ZT (9.82) and CT (9.90 for T₉) compare to other treatment. T₃ treatment contained 100% FYM +0% paddy straw which may decomposed to give more organic inputs in the soils. There was an increase of organic carbon to its initial value under CT (37.11%) and ZT (33.4%) similar to the result obtained by by Majumder *et al.*, 2008 (Table 16 and Table 42).

The Labile carbon (g kg⁻¹) in soils of experimental field (Table 43) at CRI stage of wheat at different treatment plots varied from 0.46 to 1.48 in Conventional Tillage (CT) operation and 0.50 to 1.54 in Zero Tillage (ZT) operations. Significant difference in treatments and tillage practices were observed which was more prominent among the treatments T₉, T₆ and T₃ where farmyard manure (FYM) and or paddy straw (PS) were applied in both CT and ZT.

Table 44 depicts Labile carbon (g kg⁻¹) under different treatment was highest in case of T₉ treatment in ZT (1.48) and CT (1.39) compare to other treatment. Practice, residue

and FYM showed significant changes. It was also found that there was an increase in mean value of labile carbon for the treatment T_9 , T_6 , T_3 and T_1 (control) were 6.5%, 12.6%, 16.2% and 3.6% respectively more in ZT compare to CT.

Flowering stage:

The organic carbon (g kg^{-1}) in soils of experimental field (Table 45) at Flowering stage of wheat at different treatment plots varied from 7.78 to 11.13 in Conventional Tillage (CT) operation and 9.18 to 13.12 in Zero Tillage (ZT) operations.

Practice, year, residue and FYM were significant (pooled data). Table 46 showed that organic carbon (g kg^{-1}) under different treatment was highest in case of T_9 treatment in ZT (12.95) and CT (11.01) compare to other treatment. Mean value of organic carbon for the treatment T_9 , T_6 , T_3 and T_1 (control) were 17.6%, 16.2%, 21.4% and 17.8% respectively more in ZT compare to CT.

The Labile carbon (g kg^{-1}) in soils of experimental field (Table 47) at Flowering stage of wheat at different treatment plots varied from 0.67 to 2.12 in Conventional Tillage (CT) operation and 0.72 to 2.21 in Zero Tillage (ZT) operations. Significant difference in treatments and tillage practices were observed among the treatments T_9 , T_6 and T_3 where farmyard manure (FYM) and or paddy straw (PS) were applied in both CT and ZT.

Labile carbon (g kg^{-1}) under different treatment was highest in case of T_9 treatment in ZT (1.99) and CT (1.90) compare to other treatment (Table 48). Increase in mean value of labile carbon for the treatment T_9 , T_6 , T_3 and T_1 (control) were 4.7%, 15.4%, 16.8% and 3.5% respectively more in ZT compare to CT.

Milking stage

The organic carbon (g kg^{-1}) in soils of experimental field (Table 49) at Milking stage of wheat at different treatment plots varied from 7.99 to 11.38 in Conventional Tillage (CT) operation and 9.59 to 13.92 in Zero Tillage (ZT) operations. Significant difference in treatments and tillage practices were observed which was more prominent among the treatments T_9 , T_6 and T_3 where farmyard manure (FYM) and or paddy straw (PS) were applied in both CT and ZT.

Mean value of organic carbon for the treatment T_9 , T_6 , T_3 and T_1 (control) were 22.5%, 6.7%, 18.8% and 19.9% respectively more in ZT compare to CT. The organic

carbon (g kg^{-1}) under different treatment was also found higher in case of T_9 treatment in ZT (13.69) and CT (11.18) compare to other treatment (Table 50).

The labile carbon pool was significant in treatment, residue and FYM. The Labile carbon (g kg^{-1}) in soils of experimental field (Table 51) at Milking stage of wheat at different treatment plots varied from 0.92 to 2.57 in Conventional Tillage (CT) operation and 0.99 to 2.69 in Zero Tillage (ZT) operations.

Labile carbon (g kg^{-1}) under different treatment was highest in case of T_9 treatment in ZT (2.49) and CT (2.34) compare to other treatment (Table 52). Pooled data of mean value of labile carbon for the treatment T_9 , T_6 , T_3 and T_1 (control) were 6.4%, 9.5%, 14.4% and 10.3% respectively more in ZT compare to CT.

Harvest:

The organic carbon (g kg^{-1}) in soils of experimental field (Table 53) at Harvest of wheat at different treatment plots varied from 9.55 to 12.74 in Conventional Tillage (CT) operation and 10.84 to 14.67 in Zero Tillage (ZT) operations. Significant difference in treatments and tillage practices were observed which was more prominent among the treatments T_9 , T_6 and T_3 where farmyard manure (FYM) and or paddy straw (PS) were applied in both CT and ZT. Management practices with crop residue returned to the soil cause net build up of the SOC stocks which was observed for T_3 , T_6 and T_9 treatment under ZT as reported by Majumder *et al.*, 2008.

It was found that, (Table 54) organic carbon (g kg^{-1}) under different treatment was highest in case of T_9 treatment in ZT (14.47) and CT (12.54) compare to other treatment. mean value of organic carbon for the treatment T_9 , T_6 , T_3 and T_1 (control) were 15.4%, 4.9%, 8.2% and 12.9% respectively greater in ZT compare to CT.

The Labile carbon (g kg^{-1}) in soils of experimental field (Table 55) at Harvest of wheat at different treatment plots varied from 1.22 to 2.72 in Conventional Tillage (CT) operation and 1.29 to 2.94 in Zero Tillage (ZT) operations. Significant difference in treatments and tillage practices were observed which was more prominent among the treatments T_9 , T_6 and T_3 where farmyard manure (FYM) and or paddy straw (PS) were applied in both CT and ZT.

Table 56 showed that Labile carbon (g kg^{-1}) under different treatment was highest in case of T_9 treatment in ZT (2.84) and CT (2.63) compare to other treatment. Practice, year, residue and FYM were significant whereas practise X year was non-significant from the

results. Pooled data of mean value of labile carbon for the treatment T₉, T₆, T₃ and T₁ (control) were 7.9%, 9.2%, 14.5% and 7.5% respectively more in ZT compare to CT.

From the study of nutrients (N-P-K) under two tillage operation of plants (Table 57) it was observed that, maximum value of nitrogen (kg ha^{-1}) in soils was 73.49 at harvest under CT whereas it was 75.65 under ZT in second year. For both tillage operations maximum value was obtained in second year. Lowest value 25.71 and 28.52 of nitrogen was found at CRI stage for CT and ZT respectively in first year. Maximum value of phosphorus (kg ha^{-1}) was observed 25.71 at harvest under CT where as it was 27.95 under ZT. For both tillage practices maximum value was obtained in second year. Lowest value (kg ha^{-1}) 2.39 and 2.55 of phosphorus was found at CRI stage for CT and ZT respectively in first year. Highest value (kg ha^{-1}) of potassium was 70.83 at harvest under CT where as it was 75.34 under ZT. In both tillage operations maximum value was obtained in second year. Lowest value (kg ha^{-1}) 20.68 and 20.46 of potassium was found at CRI stage for CT and ZT respectively in first year.

From the study of residual status of nutrients (kg ha^{-1}) in the soil (Table 58) it was observed that maximum value of nitrogen found 253.20 at CRI under CT whereas it was 322.89 under ZT in second year. Minimum value 124.51 and 147.04 of nitrogen was found at harvest stage for CT and ZT respectively in first year. It was observed that maximum value (kg ha^{-1}) of phosphorus was found 50.36 at CRI under CT whereas it was 57.13 under ZT in second year. Minimum value (kg ha^{-1}) 26.58 and 33.71 of phosphorus was found at harvest stage for CT and ZT respectively in second year. It was observed that maximum value (kg ha^{-1}) of potassium was found 168.91 at CRI under CT whereas it was 180.40 under ZT in second year. The minimum value (kg ha^{-1}) 81.47 and 95.57 of potassium was found at harvest for CT and ZT respectively in second year. There was a decreasing trend of nutrient from CRI to harvest in both year for each tillage operation. In contrast, organic carbon and labile carbon showed increasing trend (Table 58) from CRI to harvest in both year for each tillage operation. It was observed that maximum value of organic carbon found 11.68 (kg ha^{-1}) at harvest under CT whereas it was 12.77 (kg ha^{-1}) under ZT in second year. Minimum value 8.03(kg ha^{-1}) and 9.22 (kg ha^{-1}) of organic carbon was found at CRI stage for CT and ZT respectively in first year. It was found that, maximum value of labile carbon found 2.24 at harvest under CT whereas it was 2.42 under ZT in second year. Minimum value 0.79 (kg ha^{-1}) and 0.91(kg ha^{-1}) of organic carbon was found at CRI stage for CT and ZT respectively in first year.

Results indicated that no-tillage crop management may be better acceptable practice to increase soil aggregation and C sequestration (Wright and Hons, 2005).

Input of crop residue and reduction in mechanical disturbance from tillage might enhance SOC in agriculture soil (Du *et al.*, 2010).

The content and composition of SOM given as the input from crop and root residues might influence better crop production (Francioso *et al.*, 2000) and the processes of OM decomposition (Mathers and Xu, 2003)

Continuous rice-wheat cropping with balanced fertilisation (N-P-K) along with carbon input caused significant carbon build-up in the soil in both tillage system. The relative efficacy of the amendments for SOC building was in the order: FYM>PS. The organic carbon and labile pool of OC input supplemented through FYM and PS played significant role on the crop yield. The results indicates that of all treatments tested, balanced N-P-K fertilization along with an adequate amount of FYM following zero tillage management is most suitable for the continuous rice-wheat cropping system for improving the SOC stock and sustaining crop productivity.

Soil carbon, available nutrients and yield were higher in zero tillage system compare to conventional tillage system. Application of decomposed paddy straw and farmyard manure showed higher carbon and nutrient addition in both the tillage systems.

Organic ammendments such as farmyard manure, crop residue in the form of paddy straw when applied, a part of their carbon was stabilised into SOC and distributed among different pools of carbon. Stabilisation of carbon was governed by the interplay of factors including substrate biochemistry, climate, carbon loading and soil. The different organic ammendments were likely to differentially affect the amount of carbon stabilized and crop productivity (Yadav *et al.*, 2000; Ladha *et al.*, 2003).

Table 16. The Physico-Chemical properties of the field experimental soils:

a. Physical Characteristics of soil

Characteristics	Physical Characteristics of soil							
	First Year				Second Year			
	Conventional Tillage		Zero Tillage		Conventional Tillage		Zero Tillage	
Texture	Sand (g kg^{-1})	541.70	Sandy Loam	544.20	Sandy Loam	536.30	Sandy Loam	542.30
	Silt (g kg^{-1})	284.90		277.70		283.10		275.10
	Clay (g kg^{-1})	173.40		178.10		180.60		182.60

b. Chemical Characteristics of soil

Characteristics	Chemical Characteristics of soil			
	First Year		Second Year	
	Conventional Tillage	Zero Tillage	Conventional Tillage	Zero Tillage
P^{H} (1:2.5)	5.58	5.98	5.70	5.81
EC (dS m^{-1})	0.18	0.16	0.13	0.12
Organic Carbon (g kg^{-1})	7.22	6.84	7.25	7.49
Active carbon(g kg^{-1})	0.96	1.04	1.06	1.21
Total Carbon(g kg^{-1})	17.47	18.07	16.17	18.43
Nitrogen (kg ha^{-1})	121.26	129.62	135.89	137.98
Phosphorus(kg ha^{-1})	10.31	12.29	12.11	11.39
Potassium(kg ha^{-1})	54.88	48.53	50.40	56.75

Table 17. Effect on treatment on available nitrogen (kg ha^{-1}) in soil at CRI stage of wheat under different tillage methods

Treatment	Available Nitrogen (kg ha^{-1})					
	Conventional tillage			Zero tillage		
	First year	Second year	Mean	First year	Second year	Mean
T ₁	140.07a	183.98a	162.03a	150.53a	211.16a	180.85a
T ₂	152.62ab	206.98ab	179.80ab	171.43ab	282.24b	226.84b
T ₃	188.16bcd	282.24cde	235.20def	221.61c	361.69cd	291.65de
T ₄	246.70e	198.61ab	246.70cde	273.88de	275.97b	274.93cd
T ₅	177.71abc	250.88bcd	214.30bcd	219.52c	328.23bc	273.88cd
T ₆	217.43cde	286.42cde	251.93ef	267.61d	367.96cd	317.79ef
T ₇	144.26ab	238.34abc	191.30abc	190.25b	315.69bc	252.97bc
T ₈	229.97de	296.87de	263.42fg	240.43c	363.78cd	302.11de
T ₉	248.79e	334.51e	291.65g	290.60e	399.32d	344.96f
Treatment wise						
Treatment						Year
SE(m)±	15.748	18.906	12.991	7.267	21.182	11.133
LSD ($P=0.05$)	47.211	56.681	37.336	21.788	63.504	31.996
Residue						Year X Residue
SE(m)±	12.858	10.915	7.500	4.196	12.230	6.428
LSD ($P=0.05$)	27.257	32.725	21.556	12.579	36.664	18.473
FYM						Year X FYM
SE(m)±	12.858	10.915	7.500	4.196	12.230	6.428
LSD ($P=0.05$)	27.257	32.725	21.556	12.579	36.664	18.473
Residue X FYM						Year X Residue X FYM
SE(m)±	22.270	NS	12.991	7.267	NS	11.133
LSD ($P=0.05$)	47.211	56.681	37.336	21.788	63.504	31.996
						LSD ($P=0.05$)
						52.802
						45.250

Table 18. Effect on treatment on available nitrogen (kg ha^{-1}) in soil at CRI stage (pool over practice) of wheat under different tillage methods

Treatment		Pool over practice	
		Available Nitrogen (kg ha ⁻¹)	
		Conventional tillage	Zero tillage
T ₁		162.03a	180.85a
T ₂		179.80ab	226.84b
T ₃		235.20def	291.65de
T ₄		222.66cde	274.93cd
T ₅		214.30bcd	273.88cd
T ₆		251.93ef	317.79ef
T ₇		191.30abc	252.97bc
T ₈		263.42fg	302.11de
T ₉		291.65g	344.96f
Source			
Practice		FYM	Practice X FYM
SE(m)±	3.975	SE(m)±	SE(m)±
LSD (<i>P</i> =0.05)	11.211	LSD (<i>P</i> =0.05)	LSD (<i>P</i> =0.05)
Year		Practice X Year	Practice X Year X Residue
SE(m)±	3.975	SE(m)±	SE(m)±
LSD (<i>P</i> =0.05)	11.211	LSD (<i>P</i> =0.05)	LSD (<i>P</i> =0.05)
Residue		Practice X Residue	Practice X Year X FYM
SE(m)±	4.868	SE(m)±	SE(m)±
LSD (<i>P</i> =0.05)	13.730	LSD (<i>P</i> =0.05)	LSD (<i>P</i> =0.05)
			Practice X Year X Residue X FYM
			SE(m)±
			LSD (<i>P</i> =0.05)

Table 19. Effect on treatment on available phosphorus (kg ha⁻¹) in soil at CRI stage of wheat under different tillage methods

Treatment	Available Phosphorus (kg ha ⁻¹)					
	Conventional tillage			Zero tillage		
	First year	Second year	Mean	First year	Second year	Mean
T ₁	31.82	35.80a	33.81a	33.27a	36.16a	34.72a
T ₂	31.46	39.77abc	35.62a	37.79ab	42.49ab	40.14ab
T ₃	37.79	48.99bc	43.39ab	42.49abc	63.82de	53.16cd
T ₄	30.19	38.33ab	34.26a	38.51ab	40.86ab	39.69ab
T ₅	42.49	44.29abc	43.39ab	50.98bc	58.94cd	54.96cd
T ₆	41.94	71.77d	56.86c	54.06bc	71.95ef	63.01d
T ₇	35.98	45.92abc	40.95ab	44.84abc	49.54bc	47.19bc
T ₈	49.18	49.72c	49.45bc	56.05c	68.16de	62.11d
T ₉	59.48	78.64d	69.06	74.49	82.26f	78.38

Treatment wise									
Treatment							Year		
SE(m)±	NS	3.577	3.839	5.491	4.335	3.610	SE(m)±	1.810	1.702
LSD (P=0.05)	19.168	10.723	11.034	16.462	12.995	10.374	LSD (P=0.05)	5.201	4.891
Residue							Year X Residue		
SE(m)±	3.691	2.065	2.217	3.170	3.539	2.084	SE(m) ±	NS	NS
LSD (P=0.05)	11.066	6.191	6.370	9.504	7.503	5.990	LSD (P=0.05)	9.009	8.471
FYM							Year X FYM		
SE(m)±	NS	2.065	2.217	3.170	3.539	2.084	SE(m)±	3.135	NS
LSD (P=0.05)	11.066	6.191	6.370	9.504	7.503	5.990	LSD (P=0.05)	9.009	8.471
Residue X FYM							Year X Residue X FYM		
SE(m)±	NS	3.577	NS	NS	NS	NS	SE(m)±	NS	NS
LSD (P=0.05)	19.168	10.723	11.034	16.462	12.995	10.374	LSD (P=0.05)	15.604	14.672

Table 20. Effect on treatment on available phosphorus (kg ha⁻¹) in soil at CRI stage (pool over practice) of wheat under different tillage methods

Treatment	Pool over practice		
	Available Phosphorus (kg ha ⁻¹)		
	Conventional tillage		Zero tillage
T ₁	33.81a		34.72a
T ₂	35.62a		40.14ab
T ₃	43.39ab		53.16cd
T ₄	34.26a		39.69ab
T ₅	43.39ab		54.96cd
T ₆	56.86c		63.01d
T ₇	40.95ab		47.19bc
T ₈	49.45bc		62.11d
T ₉	69.06		78.38
Source			
Practice	1.229	FYM	Practice X FYM
SE(m)±	3.467	SE(m)±	SE(m)±
LSD (P=0.05)		LSD (P=0.05)	LSD (P=0.05)
Year	1.229	Practice X Year	Practice X Year X Residue
SE(m)±	3.467	SE(m)±	SE(m)±
LSD (P=0.05)		LSD (P=0.05)	LSD (P=0.05)
Residue	1.506	Practice X Residue	Practice X Year X FYM
SE(m)±	4.246	SE(m)±	SE(m)±
LSD (P=0.05)		LSD (P=0.05)	LSD (P=0.05)
			Practice X Year X Residue X FYM
			SE(m)±
			LSD (P=0.05)

Table 21. Effect on treatment on available potassium (kg ha⁻¹) in soil at CRI stage of wheat under different tillage methods

Treatment	Available Potassium (kg ha ⁻¹)					
	Conventional tillage			Zero tillage		
	First year	Second year	Mean	First year	Second year	Mean
T ₁	87.98a	105.65a	96.82a	114.86a	118.72a	116.79a
T ₂	149.83b	150.08	149.96b	155.22b	154.93b	155.08b
T ₃	174.10cde	182.56bc	178.33c	188.41cde	196.37cd	192.39c
T ₄	171.86cd	120.21a	146.04b	173.97bcd	168.37b	171.17b
T ₅	179.82de	176.59b	178.21c	157.67bc	176.96bc	167.32b
T ₆	178.33de	205.71de	192.02d	192.76de	219.15d	205.96cd
T ₇	163.15bc	168.00b	165.58	164.02bcd	164.27de	164.15b
T ₈	186.42ef	193.76cd	190.09d	194.63de	194.88cd	194.76c
T ₉	197.49f	217.65e	207.57	207.57e	229.97e	218.77d

Treatment wise									
Treatment							Year		
SE(m)±	4.696	5.282	3.455	10.821	8.549	6.798	SE(m)±	NS	NS
LSD (P=0.05)	14.077	15.836	9.929	32.440	25.630	19.538	LSD (P=0.05)	4.680	9.211
Residue							Year X Residue		
SE(m)±	2.711	3.050	1.995	6.247	4.936	3.925	SE(m) ±	2.821	NS
LSD (P=0.05)	8.128	9.143	5.732	18.729	14.797	11.281	LSD (P=0.05)	8.107	15.953
FYM							Year X FYM		
SE(m)±	2.711	3.050	1.995	6.247	4.936	3.925	SE(m)±	2.821	NS
LSD (P=0.05)	8.128	9.143	5.732	18.729	14.797	11.281	LSD (P=0.05)	8.107	15.953
Residue X FYM							Year X Residue X FYM		
SE(m)±	4.696	5.282	3.455	NS	NS	6.798	SE(m)±	4.886	NS
LSD (P=0.05)	8.128	15.836	9.929	32.440	25.630	19.538	LSD (P=0.05)	14.041	27.632

Table 22. Effect on treatment on available potassium (kg ha⁻¹) in soil at CRI stage (pool over practice) of wheat under different tillage methods

Treatment	Pool over practice			
	Available Phosphorus (kg ha ⁻¹)			
	Conventional tillage		Zero tillage	
T ₁	96.82a		116.79a	
T ₂	149.96b		155.08b	
T ₃	178.33c		192.39c	
T ₄	146.04b		171.17b	
T ₅	178.21c		167.32b	
T ₆	192.02d		205.96cd	
T ₇	165.58		164.15b	
T ₈	190.09d		194.76c	
T ₉	207.57		218.77d	
Source				
Practice		FYM		Practice X FYM
SE(m)±		SE(m)±		SE(m)±
LSD (P=0.05)		LSD (P=0.05)		LSD (P=0.05)
Year		Practice X Year		Practice X Year X Residue
SE(m)±		SE(m)±		SE(m)±
LSD (P=0.05)		LSD (P=0.05)		LSD (P=0.05)
Residue		Practice X Residue		Practice X Year X FYM
SE(m)±		SE(m)±		SE(m)±
LSD (P=0.05)		LSD (P=0.05)		LSD (P=0.05)
				Practice X Year X Residue X FYM
				SE(m)±
				LSD (P=0.05)

Table 23. Effect on treatment on available nitrogen (kg ha^{-1}) in soil at flowering stage of wheat under different tillage methods

Treatment	Available Potassium (kg ha^{-1})					
	Conventional tillage			Zero tillage		
	First year	Second year	Mean	First year	Second year	Mean
T ₁	131.71a	163.07	147.39a	127.53a	192.34a	159.94a
T ₂	148.44a	177.71	163.08ab	154.71b	240.43abc	197.57b
T ₃	183.98b	206.98	195.48cd	209.07c	294.78cde	251.93def
T ₄	142.17a	175.62	158.90ab	244.61d	213.25ab	228.93cde
T ₅	148.44a	217.43	182.94bcd	181.89	265.51bcd	223.70bcd
T ₆	200.70b	211.16	205.93d	234.15d	292.69cde	263.42fg
T ₇	133.80a	206.98	170.39abc	150.53b	250.88bcd	200.71bc
T ₈	192.34b	221.61	206.98d	206.98c	298.97de	252.98ef
T ₉	225.79	259.24	242.52	242.52d	336.60e	289.56g

Treatment wise									
Treatment							Year		
SE(m)±	7.301	NS	10.375	5.324	19.036	9.873	SE(m)±	4.891	4.654
LSD ($P=0.05$)	21.888	54.487	29.817	15.963	57.069	28.376	LSD ($P=0.05$)	14.056	13.377
Residue							Year X Residue		
SE(m)±	4.215	10.493	5.990	3.074	10.990	5.700	SE(m) ±	NS	8.061
LSD ($P=0.05$)	12.637	31.458	17.215	9.216	32.949	16.383	LSD ($P=0.05$)	24.346	23.169
FYM							Year X FYM		
SE(m)±	4.215	10.493	5.990	3.074	10.990	5.700	SE(m)±	NS	8.061
LSD ($P=0.05$)	12.637	31.458	17.215	9.216	32.949	16.383	LSD ($P=0.05$)	24.346	23.169
Residue X FYM							Year X Residue X FYM		
SE(m)±	7.301	NS	NS	5.324	NS	9.873	SE(m)±	NS	13.963
LSD ($P=0.05$)	21.888	54.487	29.817	15.963	57.069	28.376	LSD ($P=0.05$)	42.168	40.130

Table 24. Effect on treatment on available nitrogen (kg ha^{-1}) in soil at flowering stage (pool over practice) of wheat under different tillage methods

Treatment			Pool over practice		
			Available Phosphorus (kg ha ⁻¹)		
			Conventional tillage	Zero tillage	
	T ₁		147.39a	159.94a	
	T ₂		163.08ab	197.57b	
	T ₃		195.48cd	251.93def	
	T ₄		158.90ab	228.93cde	
	T ₅		182.94bcd	223.70bcd	
	T ₆		205.93d	263.42fg	
	T ₇		170.39abc	200.71bc	
	T ₈		206.98d	252.98ef	
	T ₉		242.52	289.56g	
Source					
Practice		FYM		Practice X FYM	
SE(m)±	3.330	SE(m)±	4.078	SE(m)±	NS
LSD (<i>P</i> =0.05)	9.391	LSD (<i>P</i> =0.05)	11.502	LSD (<i>P</i> =0.05)	16.266
Year		Practice X Year		Practice X Year X Residue	
SE(m)±	3.330	SE(m)±	4.709	SE(m)±	8.156
LSD (<i>P</i> =0.05)	9.391	LSD (<i>P</i> =0.05)	13.281	LSD (<i>P</i> =0.05)	23.004
Residue		Practice X Residue		Practice X Year X FYM	
SE(m)±	4.078	SE(m)±	NS	SE(m)±	8.156
LSD (<i>P</i> =0.05)	11.502	LSD (<i>P</i> =0.05)	16.266	LSD (<i>P</i> =0.05)	23.004
				Practice X Year X Residue X FYM	
				SE(m)±	NS
				LSD (<i>P</i> =0.05)	39.844

Table 25. Effect on treatment on available phosphorus (kg ha⁻¹) in soil at flowering stage of wheat under different tillage methods

Treatment	Available Potassium (kg ha ⁻¹)					
	Conventional tillage			Zero tillage		
	First year	Second year	Mean	First year	Second year	Mean
T ₁	30.73a	46.64a	38.69a	40.68a	41.04a	40.86a
T ₂	39.05ab	49.72ab	44.39ab	45.92ab	54.06b	49.99ab
T ₃	56.05cde	58.58ab	57.32c	60.02abc	74.12de	67.07de
T ₄	42.31ab	47.73a	45.02ab	50.98abc	58.40bc	54.69bc
T ₅	48.81bcd	56.95ab	52.88bc	56.77abc	67.80cd	62.29cd
T ₆	64.36ef	83.16c	73.76d	66.35cd	82.62ef	74.49e
T ₇	42.67abc	52.97ab	47.82ab	53.69abc	58.21b	55.95bc
T ₈	57.31de	60.75b	59.03c	63.82bcd	78.46e	71.14de
T ₉	71.41f	87.50c	79.46d	81.54d	91.12f	86.33
Treatment wise						
Treatment						Year
SE(m)±	4.579	4.266	3.243	6.576	3.185	3.703
LSD (P=0.05)	13.729	12.790	9.319	19.714	9.548	10.642
Residue						Year X Residue
SE(m)±	2.644	2.463	1.872	3.796	1.839	2.138
LSD (P=0.05)	7.926	7.384	5.380	11.382	5.513	6.144
FYM						Year X FYM
SE(m)±	2.644	2.463	1.872	3.796	1.839	2.138
LSD (P=0.05)	7.926	7.384	5.380	11.382	5.513	6.144
Residue X FYM						Year X Residue X FYM
SE(m)±	NS	NS	NS	NS	NS	NS
LSD (P=0.05)	13.729	12.790	9.319	19.714	9.548	10.642
						SE(m)±
						LSD (P=0.05)
						13.179
						15.050

Table 26. Effect on treatment on available phosphorus (kg ha⁻¹) in soil at flowering stage (pool over practice) of wheat under different tillage methods

Treatment	Pool over practice	
	Available Phosphorus (kg ha ⁻¹)	
	Conventional tillage	Zero tillage
T ₁	38.69a	40.86a
T ₂	44.39ab	49.99ab
T ₃	57.32c	67.07de
T ₄	45.02ab	54.69bc
T ₅	52.88bc	62.29cd
T ₆	73.76d	74.49e
T ₇	47.82ab	55.95bc
T ₈	59.03c	71.14de
T ₉	79.46d	86.33
Source		
Practice	FYM	Practice X FYM
SE(m)±	1.189	SE(m)±
LSD (P=0.05)	3.353	LSD (P=0.05)
Year	Practice X Year	Practice X Year X Residue
SE(m)±	1.189	SE(m)±
LSD (P=0.05)	3.353	LSD (P=0.05)
Residue	Practice X Residue	Practice X Year X FYM
SE(m)±	1.456	SE(m)±
LSD (P=0.05)	4.106	LSD (P=0.05)
		Practice X Year X Residue X FYM
		SE(m)±
		LSD (P=0.05)
		14.225

Table 27. Effect on treatment on available potassium (kg ha⁻¹) in soil at flowering stage of wheat under different tillage methods

Treatment	Available Potassium (kg ha ⁻¹)					
	Conventional tillage			Zero tillage		
	First year	Second year	Mean	First year	Second year	Mean
T ₁	49.65a	79.89a	64.77a	74.29	83.63a	78.96a
T ₂	121.71bc	95.20abc	108.46bc	126.19a	95.57ab	110.88b
T ₃	139.25de	118.35de	128.80de	145.97c	132.91c	139.44de
T ₄	117.23b	86.99ab	102.11b	117.60	97.81ab	107.71b
T ₅	130.67cd	107.52cd	119.10cd	142.99bc	113.49bc	128.24c
T ₆	150.45fg	146.35f	148.40f	160.53d	159.79d	160.16f
T ₇	129.92cd	103.41bcd	116.67c	137.39b	120.59c	128.99cd
T ₈	141.87ef	127.68ef	134.78e	154.19d	132.53c	143.36e
T ₉	154.93g	144.48f	149.71f	172.48	168.75d	170.62f

Treatment wise

Treatment							Year		
SE(m)±	3.125	6.448	3.964	2.726	6.939	3.639	SE(m)±	1.869	1.716
LSD (P=0.05)	9.370	19.330	11.394	8.173	20.804	10.460	LSD (P=0.05)	5.371	4.931
Residue							Year X Residue		
SE(m)±	1.804	3.723	2.289	1.574	4.006	2.101	SE(m) ±	NS	NS
LSD (P=0.05)	5.410	11.160	6.578	4.719	12.011	6.039	LSD (P=0.05)	9.303	8.540
FYM							Year X FYM		
SE(m)±	1.804	3.723	2.289	1.574	4.006	2.101	SE(m)±	NS	2.972
LSD (P=0.05)	5.410	11.160	6.578	4.719	12.011	6.039	LSD (P=0.05)	9.303	8.540
Residue X FYM							Year X Residue X FYM		
SE(m)±	3.125	NS	3.964	2.726	NS	NS	SE(m)±	5.606	5.147
LSD (P=0.05)	9.370	19.330	11.394	8.173	20.804	10.460	LSD (P=0.05)	16.113	14.792

Table 28. Effect on treatment on available potassium (kg ha⁻¹) in soil at flowering stage (pool over practice) of wheat under different tillage methods

Treatment	Pool over practice		
	Available Phosphorus (kg ha ⁻¹)		
	Conventional tillage		Zero tillage
T ₁	64.77a		78.96a
T ₂	108.46bc		110.88b
T ₃	128.80de		139.44de
T ₄	102.11b		107.71b
T ₅	119.10cd		128.24c
T ₆	148.40f		160.16f
T ₇	116.67c		128.99cd
T ₈	134.78e		143.36e
T ₉	149.71f		170.62f

Source		FYM		Practice X FYM	
Practice		SE(m)±	1.549	SE(m)±	2.191
SE(m)±	1.265	LSD (P=0.05)	4.369	LSD (P=0.05)	6.178
LSD (P=0.05)	3.567	Practice X Year		Practice X Year X Residue	
Year		SE(m)±	NS	SE(m)±	NS
SE(m)±	1.265	LSD (P=0.05)	5.045	LSD (P=0.05)	8.738
LSD (P=0.05)	3.567	Practice X Residue		Practice X Year X FYM	
Residue		SE(m)±	NS	SE(m)±	NS
SE(m)±	1.549	LSD (P=0.05)	6.178	LSD (P=0.05)	8.738
LSD (P=0.05)	4.369			Practice X Year X Residue X FYM	
				SE(m)±	NS
				LSD (P=0.05)	15.134

Table 29. Effect on treatment on available nitrogen (kg ha^{-1}) in soil at milking stage of wheat under different tillage methods

Treatment	Available Potassium (kg ha^{-1})					
	Conventional tillage			Zero tillage		
	First year	Second year	Mean	First year	Second year	Mean
T ₁	121.26a	117.08a	119.17a	127.53a	142.17a	134.85a
T ₂	133.80ab	140.07ab	136.94ab	144.26ab	198.61bc	171.44b
T ₃	148.44bc	167.25bc	157.85bc	142.17ab	244.61cde	193.39b
T ₄	152.62bc	144.26ab	148.44bc	213.25e	158.89ab	186.07b
T ₅	129.62ab	171.43bc	150.53bc	165.16bc	223.70cd	194.43bc
T ₆	183.98de	190.25cd	187.12d	211.16de	234.15cd	222.66de
T ₇	127.53ab	160.98bd	144.26b	129.62a	206.98cd	168.30b
T ₈	163.07cd	179.80bcd	171.44cd	188.16cd	252.97de	220.57cd
T ₉	204.89e	217.43d	211.16	206.98de	290.60e	248.79e

Treatment wise

Treatment							Year		
SE(m)±	8.370	13.554	8.096	8.293	15.765	9.159	SE(m)±	3.816	4.317
LSD ($P=0.05$)	25.093	40.634	23.268	24.864	47.263	26.322	LSD ($P=0.05$)	10.968	12.409
Residue							Year X Residue		
SE(m)±	4.832	7.825	4.674	4.788	9.102	5.288	SE(m) ±	NS	7.478
LSD ($P=0.05$)	6.834	23.460	13.434	14.355	27.287	15.197	LSD ($P=0.05$)	18.998	21.492
FYM							Year X FYM		
SE(m)±	4.832	7.825	4.674	4.788	9.102	5.288	SE(m)±	NS	7.478
LSD ($P=0.05$)	6.834	23.460	13.434	14.355	27.287	15.197	LSD ($P=0.05$)	18.998	21.492
Residue X FYM							Year X Residue X FYM		
SE(m)±	8.370	NS	NS	8.293	NS	NS	SE(m)±	NS	12.952
LSD ($P=0.05$)	11.837	40.634	23.268	24.864	47.263	26.322	LSD ($P=0.05$)	32.905	37.226

Table 30. Effect on treatment on available nitrogen (kg ha^{-1}) in soil at milking stage (pool over practice) of wheat under different tillage methods

Treatment		Pool over practice	
		Available Phosphorus (kg ha ⁻¹)	
		Conventional tillage	Zero tillage
	T ₁	119.17a	134.85a
	T ₂	136.94ab	171.44b
	T ₃	157.85bc	193.39b
	T ₄	148.44bc	186.07b
	T ₅	150.53bc	194.43bc
	T ₆	187.12d	222.66de
	T ₇	144.26b	168.30b
	T ₈	171.44cd	220.57cd
	T ₉	211.16	248.79e
Source			
Practice		FYM	Practice X FYM
SE(m)±	2.843	SE(m)±	3.481
LSD (<i>P</i> =0.05)	8.018	LSD (<i>P</i> =0.05)	9.820
Year		Practice X Year	Practice X Year X Residue
SE(m)±	2.843	SE(m)±	4.020
LSD (<i>P</i> =0.05)	8.018	LSD (<i>P</i> =0.05)	11.339
Residue		Practice X Residue	Practice X Year X FYM
SE(m)±	3.481	SE(m)±	NS
LSD (<i>P</i> =0.05)	9.820	LSD (<i>P</i> =0.05)	13.887
			Practice X Year X Residue X FYM
			SE(m)±
			LSD (<i>P</i> =0.05)
			NS
			34.016

Table 31. Effect on treatment on available phosphorus (kg ha^{-1}) in soil at milking stage of wheat under different tillage methods

Treatment	Available Potassium (kg ha^{-1})					
	Conventional tillage			Zero tillage		
	First year	Second year	Mean	First year	Second year	Mean
T ₁	24.59	20.43a	22.51a	27.66	28.02a	27.84a
T ₂	31.46	29.65ab	30.56abc	35.44	36.16a	35.80ab
T ₃	33.99	36.16bc	35.08bc	42.31	51.71b	47.01bcd
T ₄	29.47	28.56ab	29.02ab	32.72	33.45a	33.09ab
T ₅	41.94	36.88bc	39.41bc	49.18	51.16b	50.17cd
T ₆	47.01	62.01d	54.51d	53.15	62.37cd	57.76de
T ₇	37.24	31.82bc	34.53bc	36.70	37.24a	36.97abc
T ₈	43.75	39.95c	41.85c	48.45	52.97bc	50.71cd
T ₉	61.65	64.00d	62.83d	67.80	70.51d	69.16e

Treatment wise									
Treatment							Year		
SE(m)±	NS	3.284	3.967	NS	3.216	4.871	SE(m)±	NS	NS
LSD ($P=0.05$)	22.041	9.845	11.401	28.414	9.642	14.000	LSD ($P=0.05$)	5.375	6.600
Residue							Year X Residue		
SE(m)±	4.245	1.896	2.290	NS	1.857	2.812	SE(m) ±	NS	NS
LSD ($P=0.05$)	12.726	5.684	6.583	16.405	5.567	8.083	LSD ($P=0.05$)	9.309	11.431
FYM							Year X FYM		
SE(m)±	4.245	1.896	2.290	5.472	1.857	2.812	SE(m)±	NS	NS
LSD ($P=0.05$)	12.726	5.684	6.583	16.405	5.567	8.083	LSD ($P=0.05$)	9.309	11.431
Residue X FYM							Year X Residue X FYM		
SE(m)±	NS	3.284	NS	NS	NS	NS	SE(m)±	NS	NS
LSD ($P=0.05$)	22.041	9.845	11.401	28.414	9.642	14.000	LSD ($P=0.05$)	16.124	19.799

Table 32. Effect on treatment on available phosphorus (kg ha^{-1}) in soil at milking stage (pool over practice) of wheat under different tillage methods

Treatment	Pool over practice		
	Available Phosphorus (kg ha^{-1})		
	Conventional tillage	Zero tillage	
T ₁	22.51a	27.84a	
T ₂	30.56abc	35.80ab	
T ₃	35.08bc	47.01bcd	
T ₄	29.02ab	33.09ab	
T ₅	39.41bc	50.17cd	
T ₆	54.51d	57.76de	
T ₇	34.53bc	36.97abc	
T ₈	41.85c	50.71cd	
T ₉	62.83d	69.16e	
Source			
Practice		FYM	Practice X FYM
SE(m)±	1.461	SE(m)±	SE(m)±
LSD ($P=0.05$)	4.120	LSD ($P=0.05$)	LSD ($P=0.05$)
Year		Practice X Year	Practice X Year X Residue
SE(m)±	NS	SE(m)±	SE(m)±
LSD ($P=0.05$)	4.120	LSD ($P=0.05$)	LSD ($P=0.05$)
Residue		Practice X Residue	Practice X Year X FYM
SE(m)±	1.789	SE(m)±	SE(m)±
LSD ($P=0.05$)	5.046	LSD ($P=0.05$)	LSD ($P=0.05$)
			Practice X Year X Residue X FYM
			SE(m)±
			LSD ($P=0.05$)

Table 33. Effect on treatment on available potassium (kg ha⁻¹) in soil at milking stage of wheat under different tillage methods

Treatment	Available Potassium (kg ha ⁻¹)					
	Conventional tillage			Zero tillage		
	First year	Second year	Mean	First year	Second year	Mean
T ₁	55.63a	82.51	69.07a	60.85a	91.09a	75.97a
T ₂	112.00b	90.35	101.18b	116.85b	102.67a	109.76bc
T ₃	139.63c	95.20	117.42c	140.75d	100.43a	120.59cd
T ₄	110.51b	83.63	97.07b	115.73b	94.08a	104.91b
T ₅	139.63c	94.83	117.23c	130.67c	107.52a	119.10cd
T ₆	143.73c	106.40	125.07c	133.28c	138.13bc	135.71e
T ₇	111.63b	87.73	99.68b	115.73b	106.40a	111.07bc
T ₈	130.29	104.53	117.41c	139.63d	116.11ab	127.87de
T ₉	146.72c	108.27	127.50c	153.44	148.21c	150.83
Treatment wise						
Treatment						Year
SE(m)±	3.053	NS	3.928	2.071	8.420	4.230
LSD (P=0.05)	9.153	18.733	11.289	6.209	25.244	12.156
Residue						Year X Residue
SE(m)±	1.763	NS	2.268	1.196	4.862	2.442
LSD (P=0.05)	5.284	10.815	6.518	3.585	14.575	7.018
FYM						Year X FYM
SE(m)±	1.763	3.608	2.268	1.196	4.862	2.442
LSD (P=0.05)	5.284	10.815	6.518	3.585	14.575	7.018
Residue X FYM						Year X Residue X FYM
SE(m)±	3.053	NS	NS	2.071	NS	NS
LSD (P=0.05)	9.153	18.733	11.289	6.209	25.244	12.156
						SE(m)±
						5.555
						LSD (P=0.05)
						15.965
						17.191

Table 34. Effect on treatment on available potassium (kg ha⁻¹) in soil at milking stage (pool over practice) of wheat under different tillage methods

Treatment	Pool over practice	
	Available Phosphorus (kg ha ⁻¹)	
	Conventional tillage	Zero tillage
T ₁	69.07a	75.97a
T ₂	101.18b	109.76bc
T ₃	117.42c	120.59cd
T ₄	97.07b	104.91b
T ₅	117.23c	119.10cd
T ₆	125.07c	135.71e
T ₇	99.68b	111.07bc
T ₈	117.41c	127.87de
T ₉	127.50c	150.83
Source		
Practice		FYM
SE(m)±	1.343	SE(m)±
LSD (P=0.05)	3.789	LSD (P=0.05)
Year		Practice X Year
SE(m)±	1.343	SE(m)±
LSD (P=0.05)	3.789	LSD (P=0.05)
Residue		Practice X Residue
SE(m)±	1.645	SE(m)±
LSD (P=0.05)	4.640	LSD (P=0.05)
		Practice X Year X Residue
		SE(m)±
		LSD (P=0.05)
		Practice X Year X Residue X FYM
		SE(m)±
		LSD (P=0.05)
		Practice X Year X Residue X FYM
		SE(m)±
		LSD (P=0.05)
		16.075

Table 35. Effect on treatment on available nitrogen (kg ha^{-1}) in soil at harvest stage of wheat under different tillage methods

Treatment	Available Potassium (kg ha^{-1})					
	Conventional tillage			Zero tillage		
	First year	Second year	Mean	First year	Second year	Mean
T ₁	94.08a	94.08a	94.08a	110.81a	108.71a	109.76a
T ₂	117.08bc	106.62abc	111.85ab	129.62ab	137.98ab	133.80abc
T ₃	121.26bc	142.17cd	131.72bc	129.62ab	183.98c	156.80bcde
T ₄	146.35d	98.26ab	122.31bc	183.98e	119.17a	151.58cde
T ₅	137.98cd	137.98bcd	137.98c	144.26bc	173.53bc	158.90cde
T ₆	123.35c	152.62d	137.99c	175.62de	188.16c	181.89ef
T ₇	100.35ab	135.89abcd	118.12abc	117.08a	144.26abc	130.67ab
T ₈	131.71cd	146.35cd	139.03c	156.80cd	186.07c	171.44de
T ₉	148.44d	223.70	186.07	175.62de	234.15	204.89f
Treatment wise						
Treatment						Year
SE(m)±	7.473	14.242	8.715	6.855	14.855	9.218
LSD ($P=0.05$)	22.405	42.696	25.048	20.550	44.535	26.492
Residue						Year X Residue
SE(m)±	4.315	8.222	5.032	3.958	8.577	5.322
LSD ($P=0.05$)	12.936	24.651	14.461	11.865	25.712	15.295
FYM						Year X FYM
SE(m)±	4.315	8.222	5.032	3.958	8.577	5.322
LSD ($P=0.05$)	12.936	24.651	14.461	11.865	25.712	15.295
Residue X FYM						Year X Residue X FYM
SE(m)±	7.473	NS	8.715	3.958	NS	NS
LSD ($P=0.05$)	22.405	42.696	25.048	20.550	44.535	26.492
						LSD ($P=0.05$)
						35.423
						37.466

Table 36. Effect on treatment on available nitrogen (kg ha^{-1}) in soil at harvest stage (pool over practice) of wheat under different tillage

Treatment	Pool over practice	
	Available Phosphorus (kg ha^{-1})	
	Conventional tillage	Zero tillage
T ₁	94.08a	109.76a
T ₂	111.85ab	133.80abc
T ₃	131.72bc	156.80bcde
T ₄	122.31bc	151.58cde
T ₅	137.98c	158.90cde
T ₆	137.99c	181.89ef
T ₇	118.12abc	130.67ab
T ₈	139.03c	171.44de
T ₉	186.07	204.89f
Source		
Practice		Practice X FYM
SE(m)±	2.975	SE(m)±
LSD ($P=0.05$)	8.392	LSD ($P=0.05$)
Year		Practice X Year X Residue
SE(m)±	2.975	SE(m)±
LSD ($P=0.05$)	8.392	LSD ($P=0.05$)
Residue		Practice X Year X FYM
SE(m)±	3.644	SE(m)±
LSD ($P=0.05$)	10.278	LSD ($P=0.05$)
		Practice X Year X Residue X FYM
		SE(m)±
		LSD ($P=0.05$)
		35.605

Table 37. Effect on treatment on available phosphorus (kg ha⁻¹) in soil at harvest of wheat under different tillage methods

Treatment	Available Potassium (kg ha ⁻¹)					
	Conventional tillage			Zero tillage		
	First year	Second year	Mean	First year	Second year	Mean
T ₁	12.47a	14.28a	13.38a	13.02a	16.63a	14.83a
T ₂	16.63a	17.36ab	17.00a	17.72a	20.97a	19.35a
T ₃	40.14b	23.86bc	32.00b	38.51b	39.95b	39.23b
T ₄	15.55a	15.55a	15.55a	19.71a	20.07a	19.89a
T ₅	36.16b	24.05bc	30.11b	37.24b	36.88b	37.06b
T ₆	47.01b	47.73d	47.37c	48.63bc	50.26c	49.45c
T ₇	18.62a	19.16ab	18.89a	19.53a	21.51a	20.52a
T ₈	36.70b	26.40c	31.55b	39.77bc	40.32b	40.05b
T ₉	48.63b	50.80d	49.72c	52.97c	56.77c	54.87c

Treatment wise									
Treatment							Year		
SE(m)±	5.244	2.351	2.851	4.523	2.912	2.632	SE(m)±	NS	NS
LSD (P=0.05)	15.722	7.048	8.195	13.559	8.730	7.566	LSD (P=0.05)	3.863	3.566
Residue							Year X Residue		
SE(m)±	3.028	1.357	1.646	2.611	1.681	1.520	SE(m) ±	NS	NS
LSD (P=0.05)	5.244	4.069	4.731	7.828	5.040	4.368	LSD (P=0.05)	6.691	6.177
FYM							Year X FYM		
SE(m)±	3.028	1.357	1.646	2.611	1.681	1.520	SE(m)±	NS	NS
LSD (P=0.05)	5.244	4.069	4.731	7.828	5.040	4.368	LSD (P=0.05)	6.691	6.177
Residue X FYM							Year X Residue X FYM		
SE(m)±	NS	2.351	NS	NS	NS	NS	SE(m)±	NS	NS
LSD (P=0.05)	15.722	7.048	8.195	13.559	8.730	7.566	LSD (P=0.05)	11.590	10.699

Table 38. Effect on treatment on available phosphorus (kg ha⁻¹) in soil at harvest (pool over practice) of wheat under different tillage methods

Treatment	Pool over practice			
	Available Phosphorus (kg ha ⁻¹)			
	Conventional tillage		Zero tillage	
T ₁	13.38a		14.83a	
T ₂	17.00a		19.35a	
T ₃	32.00b		39.23b	
T ₄	15.55a		19.89a	
T ₅	30.11b		37.06b	
T ₆	47.37c		49.45c	
T ₇	18.89a		20.52a	
T ₈	31.55b		40.05b	
T ₉	49.72c		54.87c	
Source				
Practice		FYM		Practice X FYM
SE(m)±		SE(m)±		SE(m)±
LSD (P=0.05)		LSD (P=0.05)		LSD (P=0.05)
Year		Practice X Year		Practice X Year X Residue
SE(m)±		SE(m)±		SE(m)±
LSD (P=0.05)		LSD (P=0.05)		LSD (P=0.05)
Residue		Practice X Residue		Practice X Year X FYM
SE(m)±		SE(m)±		SE(m)±
LSD (P=0.05)		LSD (P=0.05)		LSD (P=0.05)
				Practice X Year X Residue X FYM
				SE(m)±
				LSD (P=0.05)

Table 39. Effect on treatment on available potassium (kg ha⁻¹) in soil at harvest of wheat under different tillage methods

Treatment	Available Potassium (kg ha ⁻¹)					
	Conventional tillage			Zero tillage		
	First year	Second year	Mean	First year	Second year	Mean
T ₁	42.56a	57.12a	49.84a	44.05a	77.65a	60.85a
T ₂	88.11bc	74.67bc	81.39bc	97.07bc	85.49ab	91.28b
T ₃	97.81c	94.08d	95.95d	112.37ef	94.08ab	103.23c
T ₄	88.85bc	69.44ab	79.15b	102.29cd	82.51ab	92.40b
T ₅	97.81c	84.75cd	91.28cd	115.36f	92.96ab	104.16c
T ₆	85.49b	84.75cd	85.12bc	108.64de	117.60c	113.12c
T ₇	84.75b	78.40bc	81.58bc	92.59b	89.60ab	91.10b
T ₈	99.31c	92.96d	96.14d	114.61ef	99.31b	106.96c
T ₉	124.69	97.07d	110.88	131.41	120.96c	126.19

Treatment wise									
Treatment							Year		
SE(m)±	3.777	4.788	3.451	2.217	6.027	3.593	SE(m)±	1.627	1.694
LSD (P=0.05)	11.324	14.355	9.920	6.645	18.068	10.326	LSD (P=0.05)	4.676	4.868
Residue							Year X Residue		
SE(m)±	2.181	2.764	1.993	1.280	3.479	2.074	SE(m) ±	NS	NS
LSD (P=0.05)	6.538	8.288	5.727	3.837	10.431	5.962	LSD (P=0.05)	8.099	8.431
FYM							Year X FYM		
SE(m)±	2.181	2.764	1.993	1.280	3.479	2.074	SE(m)±	NS	2.934
LSD (P=0.05)	6.538	8.288	5.727	3.837	10.431	5.962	LSD (P=0.05)	8.099	8.431
Residue X FYM							Year X Residue X FYM		
SE(m)±	3.777	NS	3.451	2.217	NS	3.593	SE(m)±	4.881	5.081
LSD (P=0.05)	11.324	14.355	9.920	6.645	18.068	10.326	LSD (P=0.05)	14.028	14.603

Table 40. Effect on treatment on available potassium (kg ha⁻¹) in soil at harvest (pool over practice) of wheat under different tillage methods

Treatment	Pool over practice			
	Available Phosphorus (kg ha ⁻¹)			
	Conventional tillage		Zero tillage	
T ₁	49.84a		60.85a	
T ₂	81.39bc		91.28b	
T ₃	95.95d		103.23c	
T ₄	79.15b		92.40b	
T ₅	91.28cd		104.16c	
T ₆	85.12bc		113.12c	
T ₇	81.58bc		91.10b	
T ₈	96.14d		106.96c	
T ₉	110.88		126.19	
Source				
Practice		FYM		Practice X FYM
SE(m)±		SE(m)±		SE(m)±
LSD (P=0.05)		LSD (P=0.05)		LSD (P=0.05)
Year		Practice X Year		Practice X Year X Residue
SE(m)±		SE(m)±		SE(m)±
LSD (P=0.05)		LSD (P=0.05)		LSD (P=0.05)
Residue		Practice X Residue		Practice X Year X FYM
SE(m)±		SE(m)±		SE(m)±
LSD (P=0.05)		LSD (P=0.05)		LSD (P=0.05)
				Practice X Year X Residue X FYM
				SE(m)±
				LSD (P=0.05)

Table 41. Effect on treatment on organic carbon (g kg⁻¹) in soil at CRI stage of wheat under different tillage methods

Treatment	Available Potassium (kg ha ⁻¹)					
	Conventional tillage			Zero tillage		
	First year	Second year	Mean	First year	Second year	Mean
T ₁	6.65	6.90	6.78a	8.03	8.37	8.20a
T ₂	7.39	8.08	7.74ab	9.41	9.82	9.62ab
T ₃	7.98	8.35	8.17b	9.89	9.74	9.82abc
T ₄	7.34	8.56	7.95ab	7.98	8.40	8.19a
T ₅	7.77	8.58	8.18b	8.62	8.87	8.75ab
T ₆	9.20	10.03	9.62c	11.38	11.34	11.36c
T ₇	7.66	8.61	8.14b	8.40	8.19	8.30ab
T ₈	8.62	9.32	8.97bc	9.84	9.90	9.87bc
T ₉	9.63	10.16	9.90c	9.41	9.84	9.63ab

Treatment wise									
Treatment							Year		
SE(m)±	NS	NS	0.443	NS	NS	0.577	SE(m)±	0.209	NS
LSD (P=0.05)	1.869	1.999	1.274	2.588	2.453	1.660	LSD (P=0.05)	0.600	0.782
Residue							Year X Residue		
SE(m)±	NS	0.385	0.256	NS	NS	NS	SE(m) ±	NS	NS
LSD (P=0.05)	1.079	1.154	0.735	1.494	1.416	0.958	LSD (P=0.05)	1.040	1.355
FYM							Year X FYM		
SE(m)±	0.360	0.385	0.256	0.498	0.472	0.333	SE(m)±	NS	NS
LSD (P=0.05)	1.079	1.154	0.735	1.494	1.416	0.958	LSD (P=0.05)	1.040	1.355
Residue X FYM							Year X Residue X FYM		
SE(m)±	NS	NS	NS	NS	NS	NS	SE(m)±	NS	NS
LSD (P=0.05)	1.869	1.999	1.274	2.588	2.453	1.660	LSD (P=0.05)	1.801	2.347

Table 42. Effect on treatment on organic carbon (g kg⁻¹) in soil at CRI stage (pool over practice) of wheat under different tillage methods

Treatment	Pool over practice			
	Available Phosphorus (kg ha ⁻¹)			
	Conventional tillage		Zero tillage	
T ₁	6.78a		8.20a	
T ₂	7.74ab		9.62ab	
T ₃	8.17b		9.82abc	
T ₄	7.95ab		8.19a	
T ₅	8.18b		8.75ab	
T ₆	9.62c		11.36c	
T ₇	8.14b		8.30ab	
T ₈	8.97bc		9.87bc	
T ₉	9.90c		9.63ab	
Source				
Practice		FYM		Practice X FYM
SE(m)±		SE(m)±		SE(m)±
LSD (P=0.05)		LSD (P=0.05)		LSD (P=0.05)
Year		Practice X Year		Practice X Year X Residue
SE(m)±	NS	SE(m)±	NS	SE(m)±
LSD (P=0.05)	0.499	LSD (P=0.05)	0.706	LSD (P=0.05)
Residue		Practice X Residue		Practice X Year X FYM
SE(m)±	0.217	SE(m)±	NS	SE(m)±
LSD (P=0.05)	0.611	LSD (P=0.05)	0.864	LSD (P=0.05)
				Practice X Year X Residue X FYM
				SE(m)±
				LSD (P=0.05)

Table 43. Effect on treatment on labile carbon (g kg⁻¹) in soil at CRI stage of wheat under different tillage methods

Treatment	Available Potassium (kg ha ⁻¹)					
	Conventional tillage			Zero tillage		
	First year	Second year	Mean	First year	Second year	Mean
T ₁	0.46a	0.65a	0.56a	0.50a	0.65a	0.58a
T ₂	0.58b	0.87ab	0.73bc	0.67	0.92bc	0.80b
T ₃	0.84cd	1.14cde	0.99ef	1.05b	1.25a	1.15d
T ₄	0.54b	0.67a	0.61ab	0.56a	0.69a	0.63a
T ₅	0.78c	0.99bcd	0.89de	0.87	1.00b	0.94c
T ₆	1.06	1.31ef	1.19g	1.23	1.45de	1.34
T ₇	0.67	0.93bc	0.80cd	0.76	0.99b	0.88bc
T ₈	0.92d	1.24def	1.08fg	1.09b	1.31cd	1.20d
T ₉	1.29	1.48f	1.39	1.42	1.54e	1.48
Treatment wise						
Treatment						Year
SE(m)±	0.026	0.083	0.044	0.028	0.051	0.030
LSD (P=0.05)	0.077	0.248	0.125	0.084	0.152	0.087
Residue						Year X Residue
SE(m)±	0.021	0.048	0.025	0.016	0.029	0.017
LSD (P=0.05)	0.045	0.143	0.072	0.048	0.088	0.050
FYM						Year X FYM
SE(m)±	0.021	0.048	0.025	0.016	0.029	0.017
LSD (P=0.05)	0.045	0.143	0.072	0.048	0.088	0.050
Residue X FYM						Year X Residue X FYM
SE(m)±	0.036	NS	NS	NS	NS	NS
LSD (P=0.05)	0.077	0.248	0.125	0.084	0.152	0.087
						LSD (P=0.05)

Table 44. Effect on treatment on labile carbon (g kg⁻¹) in soil at CRI stage (pool over practice) of wheat under different tillage methods

Treatment	Pool over practice	
	Available Phosphorus (kg ha ⁻¹)	
	Conventional tillage	Zero tillage
T ₁	0.56a	0.58a
T ₂	0.73bc	0.80b
T ₃	0.99ef	1.15d
T ₄	0.61ab	0.63a
T ₅	0.89de	0.94c
T ₆	1.19g	1.34
T ₇	0.80cd	0.88bc
T ₈	1.08fg	1.20d
T ₉	1.39	1.48
Source		
Practice		Practice X FYM
SE(m)±		SE(m)±
LSD (P=0.05)		LSD (P=0.05)
Year		Practice X Year X Residue
SE(m)±		SE(m)±
LSD (P=0.05)		LSD (P=0.05)
Residue		Practice X Year X FYM
SE(m)±		SE(m)±
LSD (P=0.05)		LSD (P=0.05)
		Practice X Year X Residue X FYM
		SE(m)±
		LSD (P=0.05)

Table 45. Effect on treatment on organic carbon (g kg⁻¹) in soil at flowering stage of wheat under different tillage methods

Treatment	Available Potassium (kg ha ⁻¹)					
	Conventional tillage			Zero tillage		
	First year	Second year	Mean	First year	Second year	Mean
T ₁	7.78	8.39	8.09a	9.18a	9.87a	9.53a
T ₂	8.81	9.28	9.05ab	10.05ab	10.43ab	10.24abc
T ₃	9.02	9.67	9.35b	11.03abcd	11.66abcd	11.35cde
T ₄	8.61	9.23	8.92ab	9.54ab	10.36ab	9.95ab
T ₅	8.87	9.36	9.12ab	10.98abcd	11.41abcd	11.20bcde
T ₆	10.52	10.97	10.75c	12.32cd	12.66cd	12.49ef
T ₇	8.87	9.34	9.11ab	10.36abc	10.95abc	10.66abcd
T ₈	9.85	10.41	10.13bc	11.49bcd	12.02bcd	11.76def
T ₉	10.88	11.13	11.01c	12.78d	13.12d	12.95f

Treatment wise

Treatment							Year		
SE(m)±	NS	NS	0.431	0.683	0.670	0.464	SE(m)±	NS	NS
LSD (P=0.05)	1.914	1.842	1.238	2.047	2.007	1.334	LSD (P=0.05)	0.584	0.629
Residue							Year X Residue		
SE(m)±	NS	NS	0.249	NS	NS	0.268	SE(m) ±	NS	NS
LSD (P=0.05)	1.105	1.063	0.715	1.182	1.159	0.770	LSD (P=0.05)	1.011	1.089
FYM							Year X FYM		
SE(m)±	0.369	0.355	0.249	0.394	0.387	0.268	SE(m)±	NS	NS
LSD (P=0.05)	1.105	1.063	0.715	1.182	1.159	0.770	LSD (P=0.05)	1.011	1.089
Residue X FYM							Year X Residue X FYM		
SE(m)±	NS	NS	NS	NS	NS	NS	SE(m)±	NS	NS
LSD (P=0.05)	1.914	1.842	1.238	2.047	2.007	1.334	LSD (P=0.05)	1.751	1.887

Table 46. Effect on treatment on organic carbon (g kg⁻¹) in soil at flowering stage (pool over practice) of wheat under different tillage methods

Treatment			Pool over practice	
			Available Phosphorus (kg ha ⁻¹)	
			Conventional tillage	Zero tillage
	T ₁		8.09a	9.53a T ₂
	9.05ab		10.24abc T ₃	
	9.35b		11.35cde T ₄	
	8.92ab		9.95ab T ₅	
	9.12ab		11.20bcde T ₆	
	10.75c		12.49ef T ₇	
	9.11ab		10.66abcd T ₈	
	10.13bc		11.76def	
	T ₉		11.01c	12.95f
Source				
Practice		FYM		Practice X FYM
SE(m)±	0.148	SE(m)±	0.181	SE(m)±
LSD (P=0.05)	0.418	LSD (P=0.05)	0.511	LSD (P=0.05)
Year		Practice X Year		Practice X Year X Residue
SE(m)±	0.148	SE(m)±	NS	SE(m)±
LSD (P=0.05)	0.418	LSD (P=0.05)	0.591	LSD (P=0.05)
Residue		Practice X Residue		Practice X Year X FYM
SE(m)±	0.181	SE(m)±	NS	SE(m)±
LSD (P=0.05)	0.511	LSD (P=0.05)	0.723	LSD (P=0.05)
				Practice X Year X Residue X FYM
				SE(m)±
				LSD (P=0.05)

Table 47. Effect on treatment on labile carbon (g kg⁻¹) in soil at flowering stage of wheat under different tillage methods

Treatment	Available Potassium (kg ha ⁻¹)					
	Conventional tillage			Zero tillage		
	First year	Second year	Mean	First year	Second year	Mean
T ₁	0.67a	1.04a	0.86	0.72a	1.06a	0.89a
T ₂	1.03bc	1.37bc	1.20a	1.07b	1.43b	1.25b
T ₃	1.26d	1.60de	1.43c	1.47d	1.87cd	1.67c
T ₄	0.93b	1.19ab	1.06	1.04b	1.40b	1.22b
T ₅	1.13cd	1.47cd	1.30ab	1.33c	1.74c	1.54
T ₆	1.46e	1.78ef	1.62d	1.65e	2.08e	1.87
T ₇	1.13c	1.52cd	1.33bc	1.22c	1.58	1.40
T ₈	1.40e	1.83f	1.62d	1.45d	1.88d	1.67c
T ₉	1.68	2.12	1.90	1.76e	2.21e	1.99
Treatment wise						
Treatment						Year
SE(m)±	0.041	0.069	0.039	0.036	0.048	0.030
LSD (P=0.05)	0.122	0.206	0.111	0.109	0.145	0.086
Residue						Year X Residue
SE(m)±	0.024	0.040	0.022	0.021	0.028	0.017
LSD (P=0.05)	0.070	0.119	0.064	0.063	0.084	0.049
FYM						Year X FYM
SE(m)±	0.024	0.040	0.022	0.021	0.028	0.017
LSD (P=0.05)	0.070	0.119	0.064	0.063	0.084	0.049
Residue X FYM						Year X Residue X FYM
SE(m)±	NS	NS	NS	NS	NS	0.030
LSD (P=0.05)	0.122	0.206	0.111	0.109	0.145	0.086
						SE(m)±
						0.018
						0.053
						NS
						0.091
						NS
						0.091
						NS
						0.091
						NS
						0.042
						0.158
						0.121

Table 48. Effect on treatment on labile carbon (g kg⁻¹) in soil at flowering stage (pool over practice) of wheat under different tillage methods

Treatment	Pool over practice	
	Available Phosphorus (kg ha ⁻¹)	
	Conventional tillage	Zero tillage
T ₁	0.86	0.89a
T ₂	1.20a	1.25b
T ₃	1.43c	1.67c
T ₄	1.06	1.22b
T ₅	1.30ab	1.54
T ₆	1.62d	1.87
T ₇	1.33bc	1.40
T ₈	1.62d	1.67c
T ₉	1.90	1.99
Source		
Practice	FYM	Practice X FYM
SE(m)±	0.012	SE(m)±
LSD (P=0.05)	0.033	0.014
Year	Practice X Year	LSD (P=0.05)
SE(m)±	0.012	0.040
LSD (P=0.05)	0.033	NS
Residue	Practice X Residue	0.046
SE(m)±	0.014	SE(m)±
LSD (P=0.05)	0.040	0.020
		0.056
		NS
		0.080
		NS
		0.080
		NS
		0.138

Table 49. Effect on treatment on organic carbon (g kg⁻¹) in soil at milking stage of wheat under different tillage methods

Treatment	Available Potassium (kg ha ⁻¹)					
	Conventional tillage			Zero tillage		
	First year	Second year	Mean	First year	Second year	Mean
T ₁	7.99	8.08a	8.04a	9.59a	9.69a	9.64a
T ₂	9.28	9.45abc	9.37ab	10.52ab	10.86ab	10.69abc
T ₃	9.48	9.69abcd	9.59ab	11.24abc	11.53abc	11.39bc
T ₄	9.02	9.06ab	9.04ab	10.00ab	10.34ab	10.17ab
T ₅	9.48	9.71abcd	9.60ab	11.03abc	11.17abc	11.10bc
T ₆	10.93	11.14cd	11.04bc	11.60bcd	11.95bcd	11.78cd
T ₇	9.54	9.90abcd	9.72ab	10.93abc	11.43abc	11.18bc
T ₈	15.46	10.49bcd	12.98c	12.89cd	13.04cd	12.97de
T ₉	10.98	11.38d	11.18bc	13.45d	13.92d	13.69e

Treatment wise									
Treatment							Year		
SE(m)±	NS	0.633	0.913	0.664	0.663	0.455	SE(m)±	NS	NS
LSD (P=0.05)	5.146	1.898	2.625	1.990	1.986	1.308	LSD (P=0.05)	1.237	0.616
Residue							Year X Residue		
SE(m)±	NS	0.366	0.527	0.383	0.383	0.263	SE(m) ±	NS	NS
LSD (P=0.05)	2.971	1.096	1.515	1.149	1.147	0.755	LSD (P=0.05)	2.143	1.068
FYM							Year X FYM		
SE(m)±	NS	0.366	0.527	0.383	0.383	0.263	SE(m)±	NS	NS
LSD (P=0.05)	2.971	1.096	1.515	1.149	1.147	0.755	LSD (P=0.05)	2.143	1.068
Residue X FYM							Year X Residue X FYM		
SE(m)±	NS	NS	NS	NS	NS	NS	SE(m)±	NS	NS
LSD (P=0.05)	5.146	1.898	2.625	1.990	1.986	1.308	LSD (P=0.05)	3.712	1.849

Table 50. Effect on treatment on organic carbon (g kg⁻¹) in soil at milking stage (pool over practice) of wheat under different tillage methods

Treatment			Pool over practice	
			Available Phosphorus (kg ha ⁻¹)	
			Conventional tillage	Zero tillage
	T ₁		8.04a	9.64a
	T ₂		9.37ab	10.69abc
	T ₃		9.59ab	11.39bc
	T ₄		9.04ab	10.17ab
	T ₅		9.60ab	11.10bc
	T ₆		11.04bc	11.78cd
	T ₇		9.72ab	11.18bc
	T ₈		12.98c	12.97de
	T ₉		11.18bc	13.69e
Source				
Practice		FYM		Practice X FYM
SE(m)±	0.243	SE(m)±	0.297	SE(m)±
LSD (<i>P</i> =0.05)	0.684	LSD (<i>P</i> =0.05)	0.838	LSD (<i>P</i> =0.05)
Year		Practice X Year		Practice X Year X Residue
SE(m)±	NS	SE(m)±	NS	SE(m)±
LSD (<i>P</i> =0.05)	0.684	LSD (<i>P</i> =0.05)	0.968	LSD (<i>P</i> =0.05)
Residue		Practice X Residue		Practice X Year X FYM
SE(m)±	0.297	SE(m)±	NS	SE(m)±
LSD (<i>P</i> =0.05)	0.838	LSD (<i>P</i> =0.05)	1.185	LSD (<i>P</i> =0.05)
				Practice X Year X Residue X FYM
				SE(m)±
				LSD (<i>P</i> =0.05)

Table 51. Effect on treatment on labile carbon (g kg⁻¹) in soil at milking stage of wheat under different tillage methods

Treatment	Available Potassium (kg ha ⁻¹)					
	Conventional tillage			Zero tillage		
	First year	Second year	Mean	First year	Second year	Mean
T ₁	0.92a	1.21a	1.07a	0.99a	1.36a	1.18a
T ₂	1.42bc	1.67b	1.55bc	1.51b	1.81b	1.66b
T ₃	1.68de	1.92cd	1.80e	1.91c	2.21cd	2.06cd
T ₄	1.35b	1.60b	1.48b	1.45b	1.73b	1.59b
T ₅	1.58cd	1.93cd	1.76de	1.71	2.03c	1.87
T ₆	1.82e	2.13d	1.98f	2.01c	2.33d	2.17d
T ₇	1.51bc	1.79bc	1.65cd	1.54b	1.83b	1.69b
T ₈	1.82e	2.16d	1.99f	1.86c	2.23d	2.05c
T ₉	2.11	2.57	2.34	2.29	2.69	2.49
Treatment wise						
Treatment						Year
SE(m)±	0.056	0.079	0.047	0.050	0.063	0.040
LSD (P=0.05)	0.169	0.237	0.136	0.150	0.190	0.115
Residue						Year X Residue
SE(m)±	0.033	0.046	0.027	0.029	0.037	0.023
LSD (P=0.05)	0.098	0.137	0.078	0.086	0.110	0.066
FYM						Year X FYM
SE(m)±	0.033	0.046	0.027	0.029	0.037	0.023
LSD (P=0.05)	0.098	0.137	0.078	0.086	0.110	0.066
Residue X FYM						Year X Residue X FYM
SE(m)±	NS	NS	0.047	0.050	NS	0.040
LSD (P=0.05)	0.169	0.237	0.136	0.150	0.190	0.115
						SE(m)±
						LSD (P=0.05)
						0.022
						0.064
						NS
						NS
						0.111
						0.094
						NS
						NS
						0.111
						0.094
						NS
						NS
						0.192
						0.163

Table 52. Effect on treatment on labile carbon (g kg⁻¹) in soil at milking stage (pool over practice) of wheat under different tillage methods

Treatment	Pool over practice	
	Available Phosphorus (kg ha ⁻¹)	
	Conventional tillage	Zero tillage
T ₁	1.07a	1.18a
T ₂	1.55bc	1.66b
T ₃	1.80e	2.06cd
T ₄	1.48b	1.59b
T ₅	1.76de	1.87
T ₆	1.98f	2.17d
T ₇	1.65cd	1.69b
T ₈	1.99f	2.05c
T ₉	2.34	2.49
Source		
Practice		Practice X FYM
SE(m)±	0.015	SE(m)±
LSD (P=0.05)	0.041	LSD (P=0.05)
Year		Practice X Year X Residue
SE(m)±	0.015	SE(m)±
LSD (P=0.05)	0.041	LSD (P=0.05)
Residue		Practice X Year X FYM
SE(m)±	0.018	SE(m)±
LSD (P=0.05)	0.051	LSD (P=0.05)
		Practice X Year X Residue X FYM
		SE(m)±
		LSD (P=0.05)
		0.025
		0.072
		NS
		NS
		0.101
		NS
		NS
		0.101
		NS
		NS
		0.175

Table 53. Effect on treatment on organic carbon (g kg⁻¹) in soil at harvest of wheat under different tillage methods

Treatment	Available Potassium (kg ha ⁻¹)					
	Conventional tillage			Zero tillage		
	First year	Second year	Mean	First year	Second year	Mean
T ₁	9.55	10.02	9.79a	10.84a	11.26	11.05a
T ₂	10.74	11.36	11.05abc	11.93ab	12.25	12.09abc
T ₃	11.39	11.68	11.54bcde	12.28ab	12.69	12.49bc
T ₄	10.05	10.72	10.39ab	11.68ab	12.10	11.89ab
T ₅	11.04	11.43	11.24abcd	12.92bc	13.53	13.23bcd
T ₆	12.52	12.94	12.73e	14.16c	12.54	13.35cd
T ₇	11.04	11.51	11.28bcd	12.03ab	12.44	12.24abc
T ₈	12.18	12.74	12.46cde	13.07bc	13.46	13.27cd
T ₉	12.33	12.74	12.54de	14.26c	14.67	14.47d
Treatment wise						
Treatment						Year
SE(m)±	NS	NS	0.506	0.534	NS	0.472
LSD (P=0.05)	2.285	2.128	1.453	1.601	2.387	1.355
Residue						Year X Residue
SE(m)±	NS	NS	0.292	0.308	NS	0.272
LSD (P=0.05)	1.319	1.229	0.839	0.924	0.650	0.783
FYM						Year X FYM
SE(m)±	0.440	0.410	0.292	0.308	NS	0.272
LSD (P=0.05)	1.319	1.229	0.839	0.924	0.650	0.783
Residue X FYM						Year X Residue X FYM
SE(m)±	NS	NS	NS	0.534	NS	NS
LSD (P=0.05)	2.285	2.128	1.453	1.601	1.126	1.355
						LSD (P=0.05)
						2.055
						1.917

Table 54. Effect on treatment on organic carbon (g kg⁻¹) in soil at harvest (pool over practice) of wheat under different tillage methods

Treatment	Pool over practice	
	Available Phosphorus (kg ha ⁻¹)	
	Conventional tillage	Zero tillage
T ₁	9.79a	11.05a
T ₂	11.05abc	12.09abc
T ₃	11.54bcde	12.49bc
T ₄	10.39ab	11.89ab
T ₅	11.24abcd	13.23bcd
T ₆	12.73e	13.35cd
T ₇	11.28bcd	12.24abc
T ₈	12.46cde	13.27cd
T ₉	12.54de	14.47d
Source		
Practice		Practice X FYM
SE(m)±	0.163	SE(m)±
LSD (P=0.05)	0.459	LSD (P=0.05)
Year		Practice X Year X Residue
SE(m)±	NS	SE(m)±
LSD (P=0.05)	0.459	LSD (P=0.05)
Residue		Practice X Year X FYM
SE(m)±	0.199	SE(m)±
LSD (P=0.05)	0.563	LSD (P=0.05)
		Practice X Year X Residue X FYM
		SE(m)±
		LSD (P=0.05)
		1.125
		NS
		1.125
		NS
		1.949

Table 55. Effect on treatment on labile carbon (g kg⁻¹) in soil at harvest of wheat under different tillage methods

Treatment	Available Potassium (kg ha ⁻¹)					
	Conventional tillage			Zero tillage		
	First year	Second year	Mean	First year	Second year	Mean
T ₁	1.22a	1.44a	1.33a	1.29	1.56	1.43
T ₂	1.83bc	2.06bc	1.95b	2.07a	2.34a	2.21a
T ₃	2.15d	2.41d	2.28cd	2.47c	2.74bc	2.61b
T ₄	1.65b	1.91b	1.78b	1.77	2.04	1.91
T ₅	2.17d	2.38d	2.28cd	2.21ab	2.42a	2.32a
T ₆	2.28d	2.51de	2.40d	2.51c	2.73bc	2.62b
T ₇	2.06cd	2.29cd	2.18c	2.11a	2.38a	2.25a
T ₈	2.25d	2.46de	2.36cd	2.40bc	2.67b	2.54b
T ₉	2.54	2.72e	2.63	2.73	2.94c	2.84
Treatment wise						
Treatment						Year
SE(m)±	0.088	0.096	0.063	0.068	0.073	0.049
LSD (P=0.05)	0.264	0.287	0.182	0.205	0.219	0.140
Residue						Year X Residue
SE(m)±	0.051	0.055	0.037	0.039	0.042	0.028
LSD (P=0.05)	0.153	0.166	0.105	0.118	0.126	0.081
FYM						Year X FYM
SE(m)±	0.051	0.055	0.037	0.039	0.042	0.028
LSD (P=0.05)	0.153	0.166	0.105	0.118	0.126	0.081
Residue X FYM						Year X Residue X FYM
SE(m)±	NS	NS	0.063	0.068	0.073	0.049
LSD (P=0.05)	0.264	0.287	0.182	0.205	0.219	0.140
						SE(m)±
						LSD (P=0.05)
						0.257
						0.197

Table 56. Effect on treatment on labile carbon (g kg⁻¹) in soil at harvest (pool over practice) of wheat under different tillage methods

Treatment	Pool over practice	
	Available Phosphorus (kg ha ⁻¹)	
	Conventional tillage	Zero tillage
T ₁	1.33a	1.43
T ₂	1.95b	2.21a
T ₃	2.28cd	2.61b
T ₄	1.78b	1.91
T ₅	2.28cd	2.32a
T ₆	2.40d	2.62b
T ₇	2.18c	2.25a
T ₈	2.36cd	2.54b
T ₉	2.63	2.84
Source		
Practice		Practice X FYM
SE(m)±	0.019	SE(m)±
LSD (P=0.05)	0.053	LSD (P=0.05)
Year		Practice X Year X Residue
SE(m)±	0.019	SE(m)±
LSD (P=0.05)	0.053	LSD (P=0.05)
Residue		Practice X Year X FYM
SE(m)±	0.023	SE(m)±
LSD (P=0.05)	0.064	LSD (P=0.05)
		Practice X Year X Residue X FYM
		SE(m)±
		LSD (P=0.05)
		0.223

Table 57. The status of nutrients (N-P-K) under different tillage operations of plant

Nutrients	First Year								Second Year							
	Conventional Tillage				Zero Tillage				Conventional Tillage				Zero Tillage			
	CRI	Flowering	Milking	Harvest	CRI	Flowering	Milking	Harvest	CRI	Flowering	Milking	Harvest	CRI	Flowering	Milking	Harvest
Nitrogen (kg ha ⁻¹)	26.56	39.71	60.57	72.38	28.52	53.78	69.88	74.72	32.99	42.19	65.98	73.49	41.39	55.44	74.27	75.65
Phosphorus (kg ha ⁻¹)	2.39	5.48	9.46	24.56	2.55	6.57	10.70	26.02	2.89	6.01	10.60	25.71	3.51	8.83	14.35	27.95
Potassium (kg ha ⁻¹)	20.68	35.31	59.65	67.30	20.46	45.88	68.55	70.83	25.40	39.02	63.29	70.96	29.35	46.82	67.23	75.34

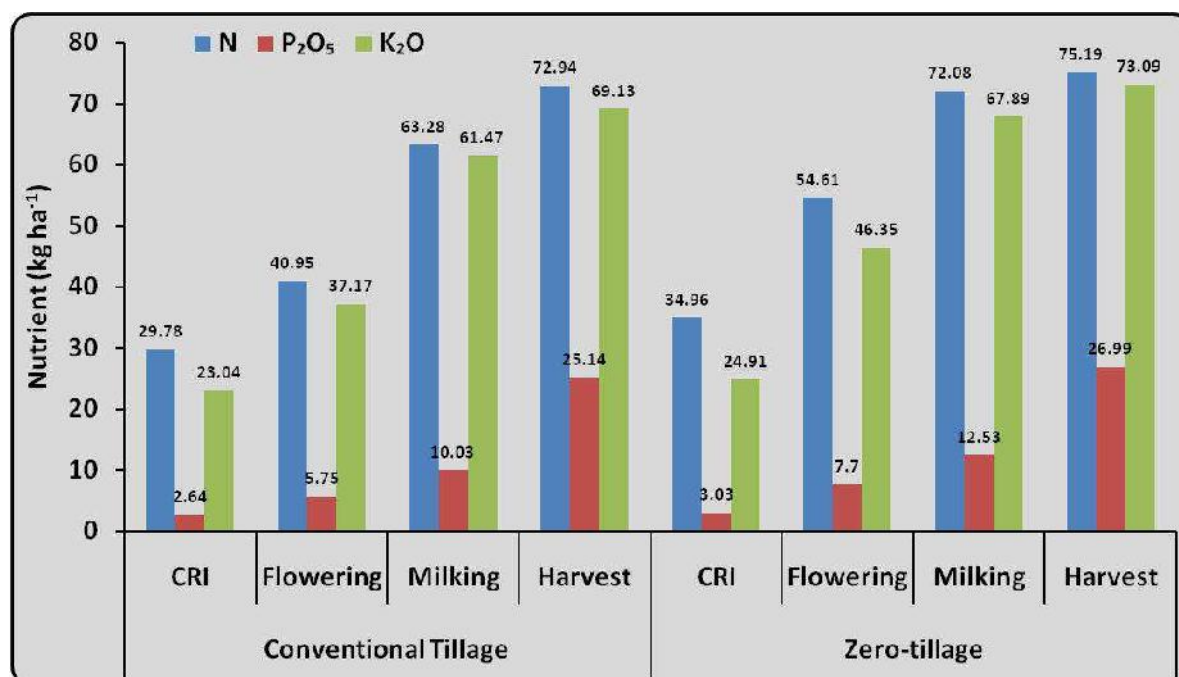


Fig. 8. The status of nutrients (N-P-K) under different tillage operations of plant

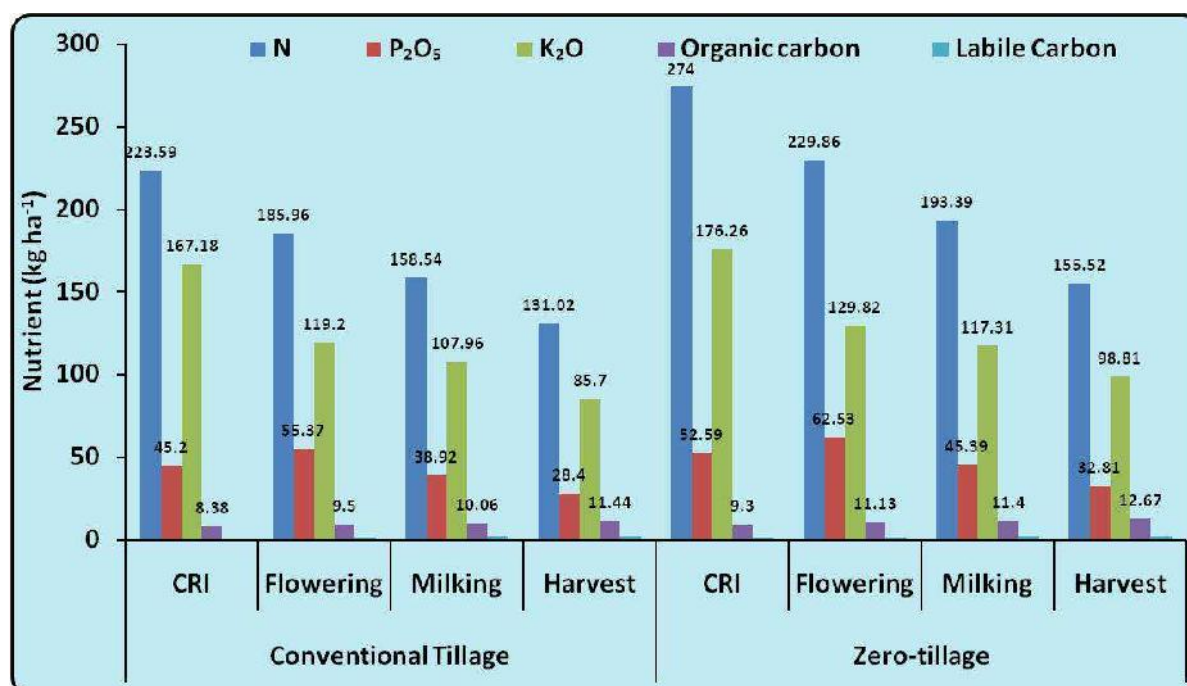


Fig. 9. Residual status of N-P-K, Organic C and Labile Carbon in soil under different tillage operations

Table 58. Residual status of N-P-K, Organic C and Labile Carbon in soil under different tillage operations

Nutrients	First Year								Second Year							
	Conventional Tillage				Zero Tillage				Conventional Tillage				Zero Tillage			
	CRI	Flowering	Milking	Harvest	CRI	Flowering	Milking	Harvest	CRI	Flowering	Milking	Harvest	CRI	Flowering	Milking	Harvest
Nitrogen (kg ha ⁻¹)	193.97	167.49	151.69	124.51	225.10	194.66	169.81	147.04	253.20	204.42	165.39	137.52	322.89	265.05	216.96	164.00
Phosphorus (kg ha ⁻¹)	40.04	50.30	39.01	30.21	48.05	57.75	43.71	31.90	50.36	60.44	38.83	26.58	57.13	67.31	47.07	33.71
Potassium (kg ha ⁻¹)	105.44	120.19	121.00	89.93	172.12	150.05	122.99	102.04	100.91	112.21	94.05	81.47	100.40	122.79	111.05	95.57
Organic Carbon (g kg ⁻¹)	8.03	9.24	10.24	11.20	9.22	10.86	11.25	12.57	8.73	9.75	9.88	11.68	9.38	11.39	11.55	12.77
Labile carbon (g kg ⁻¹)	0.79	1.19	1.58	2.02	0.91	1.30	1.70	2.17	1.03	1.55	1.89	2.24	1.09	1.69	2.02	2.42

4.5.1 Effect of treatments on yield attributes of wheat

The variations of agronomic parameters of wheat (Table 59) were reflected with the treatment combinations and tillage operations. The maximum plant height in first year (102.60 cm) under T₆, spike length (10.10 cm) under T₉, number of tillers (7.13) under T₉ and number of spike per plant (5.87) under T₆ was obtained for CT. In second year, maximum plant height (100.92 cm), spike length (10.56 cm), number of tiller (7.69) and number of spike per plant (6.9) were found for T₉ treatment where full doze of FYM and PS were given as organic input.

Under ZT operation agronomic parameters of wheat (Table 60) on the effect of yield attributes in the first year was observed that, on maximum plant height (105.24 cm), spike length (10.22 cm), number of tiller (7.40) and number of spike per plant (6.9) for the T₉ treatment whereas number of spike per plant (6.02) was under the T₆ treatment. In second year, maximum plant height (104.45cm) under T₆, spike length (10.57 cm) for T₉, number of tiller (8.11) under T₉ and number of spike per plant (6.83) for T₆ were found where FYM and PS were given as organic input.

The maximum 1000 grains test weight (45.1 g), grains yield (57.90 q ha⁻¹) and straw yield (76.09 q ha⁻¹) under T₉ treatment were observed under CT operation in first year (Table 61). In second year, maximum 1000 grains test weight (45.24 g), grains yield (60.13 q ha⁻¹) and straw yield (76.09 q ha⁻¹) under T₉ treatment were observed under CT operation.

Yield attributes under zero tillage operation (Table 62) were maximum for 1000 grains test weight (45.75 g under T₆ treatment), grains yield (59.55 q ha⁻¹ for T₉ treatment) and straw yield (76.70 q ha⁻¹ for T₈ treatment) in first year. In second year, maximum for 1000 grains test weight (46.86 g under T₆ treatment), grains yield (63.49 q ha⁻¹ for T₉ treatment) and straw yield (76.70 q ha⁻¹ for T₈ treatment) were found. Mean value of all three attributes of wheat were greater in ZT compare to CT operations under each treatment. The T₉, T₆ and T₃ treatments with PS and FYM showed greater yield compare to other treatment irrespective of tillage operations.

It was observed that increase in weight of 1000grains test wt., grains yield and straw yield were 3.9%, 4.2% and 2.3% for T₉; 5.65%, 2.3% and 2.8% for T₆; 7.0%, 2.1%, and 3.7% for T₃; 4.1%, 1.3% and 2.3% for T₁ (control) respectively under ZT over CT (Pooled data of Table 61 and 62). On and average grain yield was higher

with N-P-K plus organic amendments than control treatment reported by by Majumder *et al.*, 2008.

Reports of loss of OC content in soils due to cropping are many from subtropical region because of the high temperature (Bhattacharya *et al.*, 2004, Swarup *et al.*, 2000).

Carbon supplementation through FYM and PS increased OC. Accumulation of OC under organic inputs is likely to be influenced by their composition, C/N ratios decomposibility or degradability. The amount of labile fraction of SOC varied significantly among the treatment and depth. The higher values of different C fractions under FYM and PS treatments were resulted to the increased yield C returned to the soil (Majumder *et al.*, 2008).

The labile C and SOC under N-P-K+FYM and N-P-K+PS treatments in particular were associated with the high content of polysaccharide (cellulose and hemicellulose) in FYM and PS that could lead to the production of higher amounts of labile carbon (Senevirtne, 2000).

Table 59. Effect of different treatments on yield attributes (CT) of wheat crop at first and second year

Treatments	Conventional tillage																
	Plant height (cm)			Spike length (cm)			Number of tillers			No of spike plant ⁻¹							
	First year	Second year	Mean	First year	Second year	Mean	First year	Second year	Mean	First year	Second year	Mean					
T ₁	94.87	95.05	94.96	9.14	9.54	9.34	4.73	5.38	5.06	4.65	5.31ab	4.98a					
T ₂	95.47	95.35	95.41	9.31	10.07	9.69	5.47	5.68	5.58	5.20	5.16a	5.18a					
T ₃	98.00	98.21	98.11	9.51	10.20	9.86	6.00	6.55	6.28	5.73	6.36bcd	6.05bc					
T ₄	97.20	96.19	96.70	9.39	10.00	9.70	5.40	5.98	5.69	5.07	5.59abc	5.33ab					
T ₅	100.20	100.25	100.23	9.67	10.00	9.84	6.47	6.95	6.71	5.53	6.59cd	6.06bc					
T ₆	102.60	99.05	100.83	9.90	10.43	10.17	6.73	7.38	7.06	5.87	6.83d	6.35c					
T ₇	96.53	96.62	96.58	9.47	9.62	9.55	5.47	6.18	5.83	5.45	5.99abcd	5.72abc					
T ₈	99.60	98.32	98.96	9.43	10.16	9.80	6.40	6.95	6.68	5.80	6.69cd	6.25c					
T ₉	100.40	100.92	100.66	10.10	10.56	10.33	7.13	7.69	7.41	5.93	6.96d	6.45c					
Treatment wise																	
Treatment												Year					
SE(m)±	NS	NS	NS	NS	NS	NS	0.90	NS	NS	0.39	0.30	SE(m)±	NS	0.130	NS	0.14	
LSD (<i>P</i> =0.05)	9.29	8.81	5.98	0.74	0.73	0.80	2.50	2.69	1.71	1.35	1.17	0.87	LSD (<i>P</i> =0.05)	2.82	0.38	0.80	0.41
Residue												Year X Residue					
SE(m)±	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.23	0.17	SE(m)±	NS	NS	NS	NS	
LSD (<i>P</i> =0.05)	5.37	5.09	3.45	0.49	0.42	0.46	1.44	1.55	0.98	0.78	0.68	0.80	LSD (<i>P</i> =0.05)	4.88	0.65	1.39	0.71
FYM												Year X FYM					
SE(m)±	NS	NS	NS	NS	0.14	0.16	NS	NS	0.34	NS	0.23	0.17	SE(m)±	NS	NS	NS	NS
LSD (<i>P</i> =0.05)	5.37	5.09	3.45	0.43	0.42	0.46	1.44	1.55	0.98	0.78	0.68	0.50	LSD (<i>P</i> =0.05)	4.88	0.65	1.39	0.71
Residue X FYM												Year X Residue X FYM					
SE(m)±	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	SE(m)±	NS	NS	NS	NS
LSD (<i>P</i> =0.05)	9.29	8.81	5.98	0.74	0.73	0.80	2.50	2.69	1.71	1.35	1.17	0.87	LSD (<i>P</i> =0.05)	8.45	1.12	2.41	1.22

Table 60. Effect of different treatments on yield attributes (ZT) of wheat crop at first and second year

Treatments		Zero tillage															
		Plant height (cm)			Spike length (cm)			Number of tillers			No of spike plant ⁻¹						
		First year	Second year	Mean	First year	Second year	Mean	First year	Second year	Mean	First year	Second year	Mean				
T ₁	97.83	98.07	97.95	9.39	9.83	9.61	4.63	5.34	4.99a	4.57	5.05	4.81a					
T ₂	98.47	98.94	98.71	9.48	10.05	9.77	5.83	6.55	6.19abc	5.49	6.13	5.81b					
T ₃	100.03	99.90	99.97	9.56	10.15	9.86	6.07	6.80	6.44abc	5.79	6.50	6.15b					
T ₄	99.57	99.34	99.46	9.71	10.28	10.00	5.43	6.15	5.79ab	5.32	5.80	5.56ab					
T ₅	104.33	102.20	103.27	9.96	10.29	10.13	6.47	7.21	6.84bc	5.65	6.48	6.07b					
T ₆	105.24	104.45	104.85	9.92	10.53	10.23	6.67	7.38	7.03bc	6.02	6.83	6.43b					
T ₇	99.27	99.20	99.24	9.85	10.00	9.93	5.60	6.30	5.95ab	5.63	6.21	5.92b					
T ₈	103.00	101.87	102.44	9.61	10.41	10.01	6.73	7.45	7.09bc	5.92	6.72	6.32b					
T ₉	103.73	101.80	102.77	10.22	10.57	10.40	7.40	8.11	7.76c	5.82	6.65	6.24b					
Treatment wise																	
Treatment												Year					
SE(m)±	NS	NS	NS	NS	NS	NS	NS	NS	0.55	NS	NS	0.31	SE(m)±	NS	0.09	NS	0.15
LSD (<i>P</i> =0.05)	9.32	8.59	5.95	0.66	0.70	0.55	2.36	2.37	1.58	1.39	1.32	0.89	LSD (<i>P</i> =0.05)	2.80	0.26	0.75	0.42
Residue												Year X Residue					
SE(m)±	NS	NS	NS	NS	NS	0.11	NS	NS	NS	NS	NS	NS	SE(m)±	NS	NS	NS	NS
LSD (<i>P</i> =0.05)	5.38	4.96	3.43	0.38	0.40	0.32	1.36	1.37	0.91	0.80	0.76	0.51	LSD (<i>P</i> =0.05)	4.85	0.45	1.29	0.73
FYM												Year X FYM					
SE(m)±	NS	NS	NS	NS	NS	NS	NS	NS	0.317	NS	0.25	0.18	SE(m)±	NS	NS	NS	NS
LSD (<i>P</i> =0.05)	5.38	4.96	3.43	0.38	0.40	0.32	1.36	1.37	0.91	0.80	0.76	0.52	LSD (<i>P</i> =0.05)	4.85	0.45	1.29	0.73
Residue X FYM												Year X Residue X FYM					
SE(m)±	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	SE(m)±	NS	NS	NS	NS
LSD (<i>P</i> =0.05)	9.32	8.59	5.95	0.66	0.70	0.55	2.36	2.37	1.58	1.38	1.32	0.89	LSD (<i>P</i> =0.05)	8.41	0.77	2.23	1.28

Table 61. Effect of different treatments on yield attributes (CT) of wheat crop at first and second year

Treatments	Conventional tillage												
	1000 grains test wt. (g)			Grains yield (q ha ⁻¹)			Straw yield (q ha ⁻¹)						
	First year	Second year	Mean	First year	Second year	Mean	First year	Second year	Mean				
T ₁	39.86	39.91	39.89	53.38	55.34	54.36	60.69	63.60	62.15a				
T ₂	41.16	41.08	41.12	53.45	55.37	54.41	63.82	66.16	64.99ab				
T ₃	44.14b	43.73b	43.94b	56.15	58.77	57.46	65.94	70.47	68.21abc				
T ₄	42.41a	42.55a	42.48a	53.49	55.48	54.49	67.70	68.21	67.96abc				
T ₅	44.65c	44.58cd	44.62bc	56.45	58.57	57.51	69.96	72.27	71.12bc				
T ₆	45.00cd	45.09d	45.05c	57.65	59.70	58.68	71.02	73.21	72.12c				
T ₇	44.00b	44.07bc	44.04b	53.85	55.64	54.75	68.79	68.88	68.84bc				
T ₈	44.93cd	44.93d	44.93c	56.03	58.12	57.08	72.75	73.33	73.04c				
T ₉	45.19d	45.24d	45.22c	57.90	60.13	59.02	70.46	76.09	73.28c				
Treatment	0.15	0.28	0.26	NS	Treatment wise		NS	NS	2.32	Year			
SE(m)±	0.46	0.85	0.73	9.49	NS	NS	10.10	10.09	6.66	SE(m)±	NS	NS	NS
LSD (P=0.05)										LSD (P=0.05)	0.35	2.99	3.14
Residue	0.09	0.16	0.15	NS	NS	NS	1.95	NS	1.34	Year X Residue			
SE(m)±	0.27	0.49	0.42	5.48	5.64	3.66	5.83	5.82	3.85	SE(m)±	NS	NS	NS
LSD (P=0.05)										LSD (P=0.05)	0.60	5.19	5.44
FYM	0.09	0.16	0.15	NS	NS	NS	NS	NS	1.34	Year X FYM			
SE(m)±	0.27	0.49	0.42	5.48	5.64	3.66	5.83	5.82	3.85	SE(m)±	NS	NS	NS
LSD (P=0.05)										LSD (P=0.05)	0.60	5.18	5.44
Residue X FYM	0.15	0.28	0.26	NS	NS	NS	NS	NS	NS	Year X Residue X FYM			
SE(m)±	0.46	0.85	0.73	9.49	9.76	6.34	10.10	10.09	6.66	SE(m)±	NS	NS	NS
LSD (P=0.05)										LSD (P=0.05)	1.04	8.97	9.42

Table 62. Effect of different treatments on yield attributes (ZT) of wheat crop at first and second year

Treatments	Zero tillage												
	1000 grains test wt. (g)			Grains yield (q ha ⁻¹)			Straw yield (q ha ⁻¹)			No of spike plant ⁻¹			
	First year	Second year	Mean	First year	Second year	Mean	First year	Second year	Mean	First year	Second year	Mean	
T ₁	40.38	41.27	40.83	55.39	54.69	55.04	63.57	65.81	64.69a				
T ₂	41.81	42.61	42.21	55.43	56.15	55.79	66.57	68.76	67.67ab				
T ₃	44.96b	46.13b	45.55b	58.46	58.80	58.63	70.32	75.65	72.99bc				
T ₄	42.88a	43.90a	43.39a	55.48	56.09	55.79	72.15	72.38	72.27bc				
T ₅	45.34bc	46.36b	45.85bc	57.80	59.80	58.80	74.41	76.64	75.53c				
T ₆	45.75c	46.86b	46.31c	59.49	60.55	60.02	75.04	77.24	76.14c				
T ₇	44.72b	45.98b	45.35b	55.76	56.76	56.26	72.98	74.28	73.63bc				
T ₈	45.84c	46.69b	46.27c	58.13	60.20	59.17	76.70	76.25	76.48c				
T ₉	45.74c	46.77b	46.26c	59.55	63.49	61.52	74.18	77.97	76.08c				
Treatment wise													
Treatment										Year			
SE(m)±	0.24	0.32	0.20	NS	NS	NS	NS	NS	2.32	SE(m)±	0.10	NS	NS
LSD (P=0.05)	0.72	0.96	0.56	9.49	10.02	6.42	10.06	10.18	6.66	LSD (P=0.05)	0.26	3.03	3.14
Residue										Year X Residue			
SE(m)±	0.14	0.19	0.11	NS	NS	NS	1.94	NS	1.34	SE(m)±	NS	NS	NS
LSD (P=0.05)	0.42	0.56	0.32	5.44	5.79	3.71	5.81	5.88	3.84	LSD (P=0.05)	0.46	5.25	5.43
FYM										Year X FYM			
SE(m)±	0.14	0.19	0.11	NS	NS	NS	NS	NS	1.34	SE(m)±	NS	NS	NS
LSD (P=0.05)	0.42	0.56	0.32	5.44	5.79	3.71	5.81	5.88	3.84	LSD (P=0.05)	0.46	5.25	5.43
Residue X FYM										Year X Residue X FYM			
SE(m)±	0.24	0.32	0.19	NS	NS	NS	NS	NS	NS	SE(m)±	NS	NS	NS
LSD (P=0.05)	0.72	0.96	0.56	9.42	10.02	6.42	10.06	10.18	6.66	LSD (P=0.05)	0.79	9.08	9.41

4.5.2 Uptake of N-P-K in plant at CRI, Flowering, Milking stage and at Harvest

Figure 10 to 25 depicts the treatment wise uptake of nutrients (N-P-K) at different growth stage of plant under CT and ZT for two years.

Total organic carbon (TOC) during second year under treatment T₃, T₆, T₉ was more compare to other treatment (Fig. 10) and T₁ (control). TOC was found higher in ZT compare to CT.

Increase in uptake of nitrogen (kg ha^{-1}) (Fig. 11) was maximum (63%) under CT and 79.3% under ZT was found for control (T₁). The T₃, T₆, T₉ treatment showed higher value of nitrogen uptake (kg ha^{-1}) under both tillage practices at CRI stage. Treatment and residue were significant whereas Residue X FYM was non-significant for uptake.

Phosphorus uptake (kg ha^{-1}) in plant (Fig. 12) at CRI stage showed significant difference for treatment, FYM and Residue X FYM for CT and ZT but Residue X FYM was non-significant for ZT.

Uptake of potassium (kg ha^{-1}) (Fig. 13) in plant at CRI stage also showed similar trend for T₃, T₆, T₉ treatment over control (T₁) under both tillage practice. Treatment, residue and FYM were significant for both the year.

Figure 14 to 25 had similar trend for uptake (kg ha^{-1}) of nitrogen, phosphorus and potassium in plant at flowering, milking and harvest stage. In almost all cases treatment and FYM showed significant results under CT and ZT. The T₃, T₆, T₉ treatment found more uptake of nutrients compare to control (T₁). However, nitrogen and potassium showed non-significant for Residue X FYM at flowering, milking stage and at harvest. Uptake of potassium at harvest was non-significant for treatment and residue for second year under both the tillage. Residue X FYM was non-significant for CT and NT. In all the stages N-P-K uptake was non-significant for year and year X residue. ZT practice showed better than CT at every year and treatment out of which T₃, T₆, T₉ treatment found better than other treatments.

The favourable effect of organics and N uptake was attributed to the release of N during decomposition of organic materials and their uptake by crop was reported by Veeranagappa *et al.*, 2010.

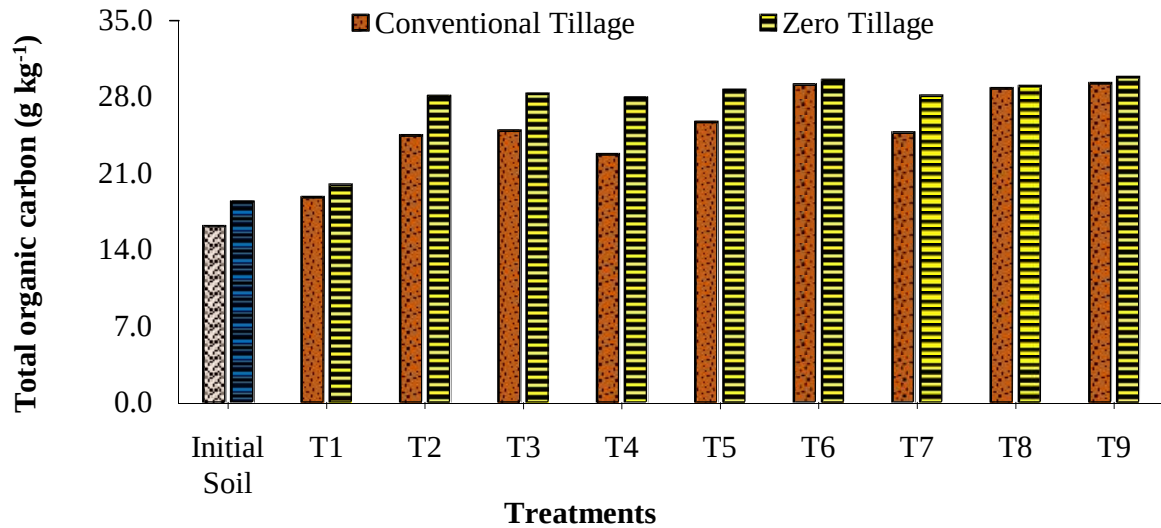


Figure 10. Total organic carbon (g kg^{-1}) during second year under conventional and zero tillage at harvest of wheat

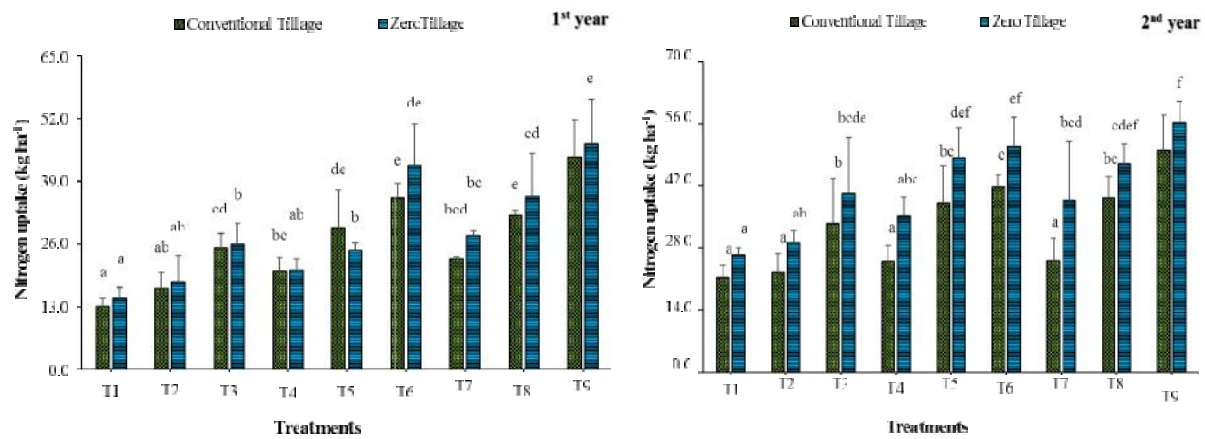


Figure 11. Uptake of nitrogen (kg ha^{-1}) in stem of wheat at CRI stage under conventional and zero tillage practices. The standard deviation of measurement is shown as error bars. Means with common letters are not significantly different at $P \leq 0.05$, according to Fisher's Protected Least Significant Difference (LSD) test using the algorithm of Studentized range test (Hsu, 1996).

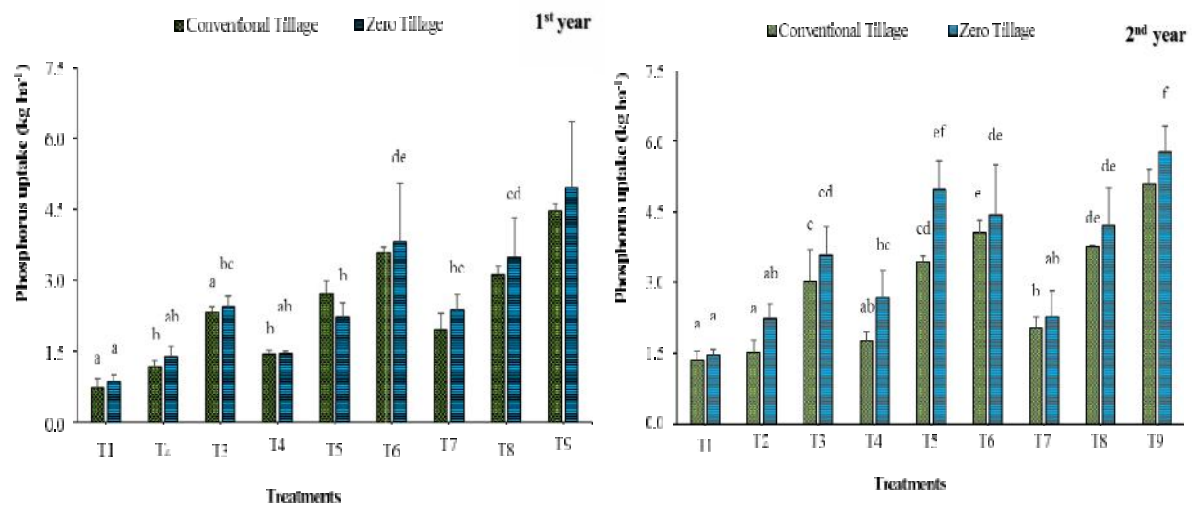


Figure 12. Uptake of phosphorus (kg ha^{-1}) in stem of wheat at CRI stage under conventional and zero tillage practices. The standard deviation of measurement is shown as error bars. Means with common letters are not significantly different at $P \leq 0.05$, according to Fisher's Protected Least Significant Difference (LSD) test using the algorithm of Studentized range test (Hsu, 1996).

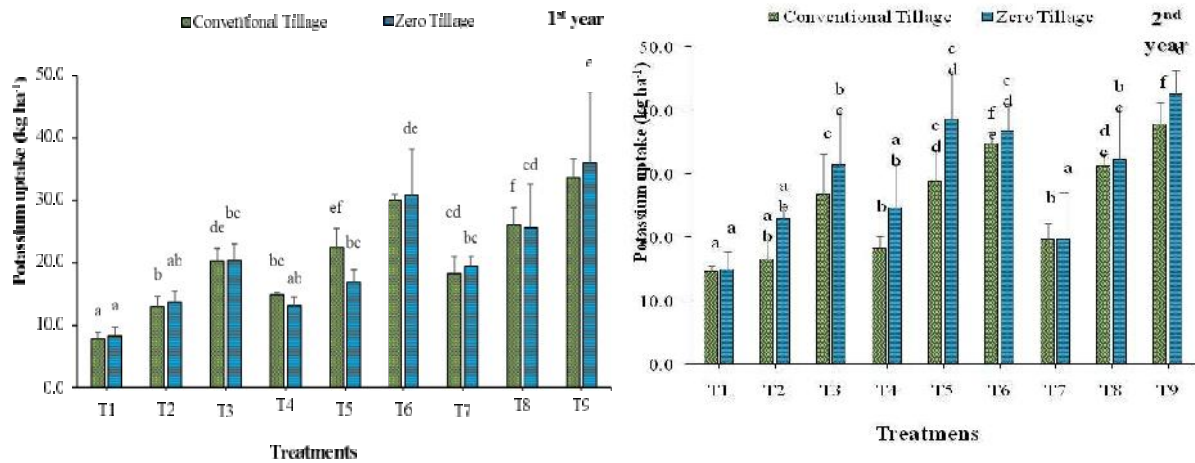


Figure 13. Uptake of potassium (kg ha^{-1}) in stem of wheat at CRI stage under conventional and zero tillage practices. The standard deviation of measurement is shown as error bars. Means with common letters are not significantly different at $P \leq 0.05$, according to Fisher's Protected Least Significant Difference (LSD) test using the algorithm of Studentized range test (Hsu, 1996).

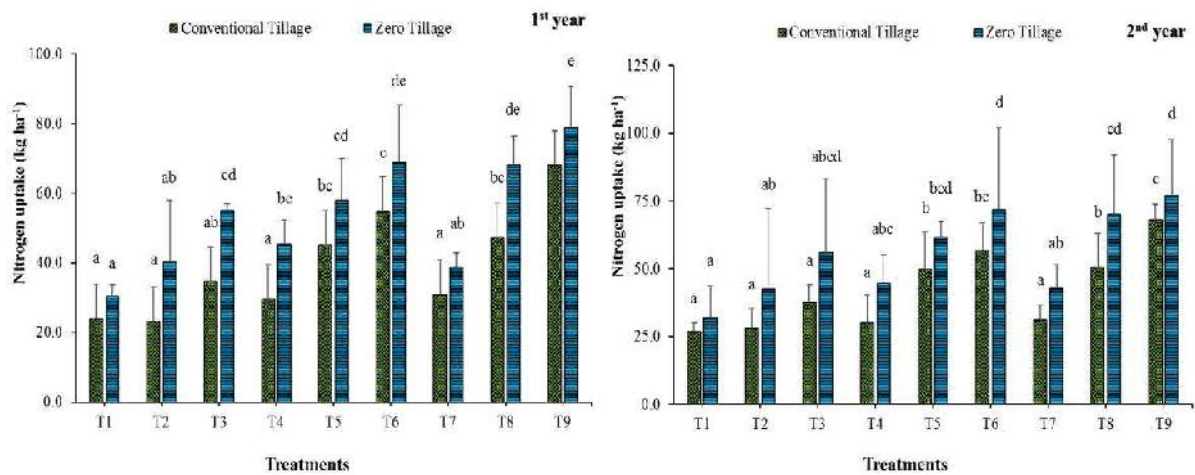


Figure 14. Uptake of nitrogen (kg ha^{-1}) in stem of wheat at flowering stage under conventional and zero tillage practices. The standard deviation of measurement is shown as error bars. Means with common letters are not significantly different at $P \leq 0.05$, according to Fisher's Protected Least Significant Difference (LSD) test using the algorithm of Studentized range test (Hsu, 1996).

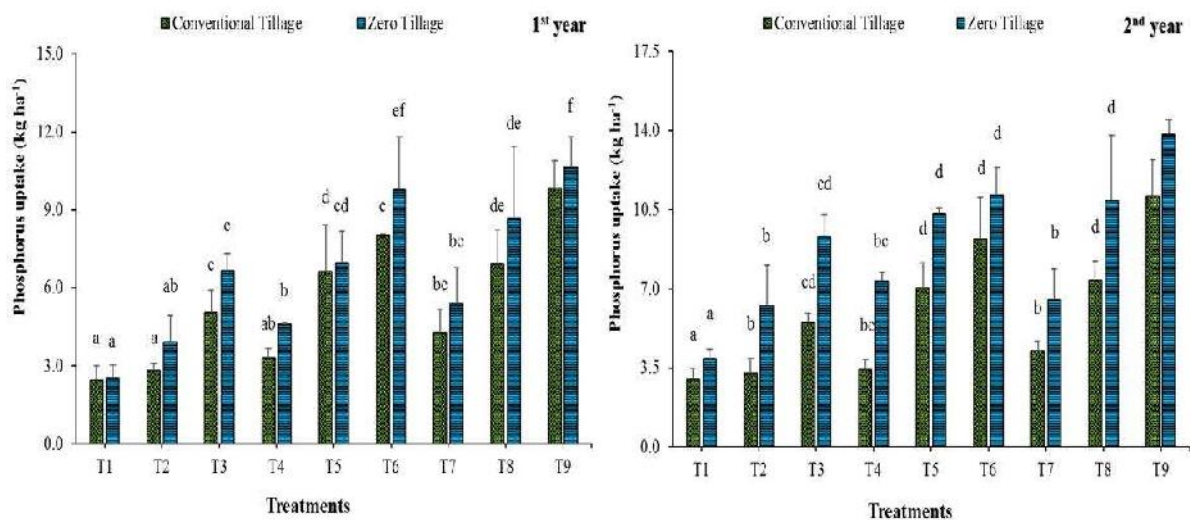


Figure 15. Uptake of phosphorus (kg ha^{-1}) in stem of wheat at flowering stage under conventional and zero tillage practices. The standard deviation of measurement is shown as error bars. Means with common letters are not significantly different at $P \leq 0.05$, according to Fisher's Protected Least Significant Difference (LSD) test using the algorithm of Studentized range test (Hsu, 1996).

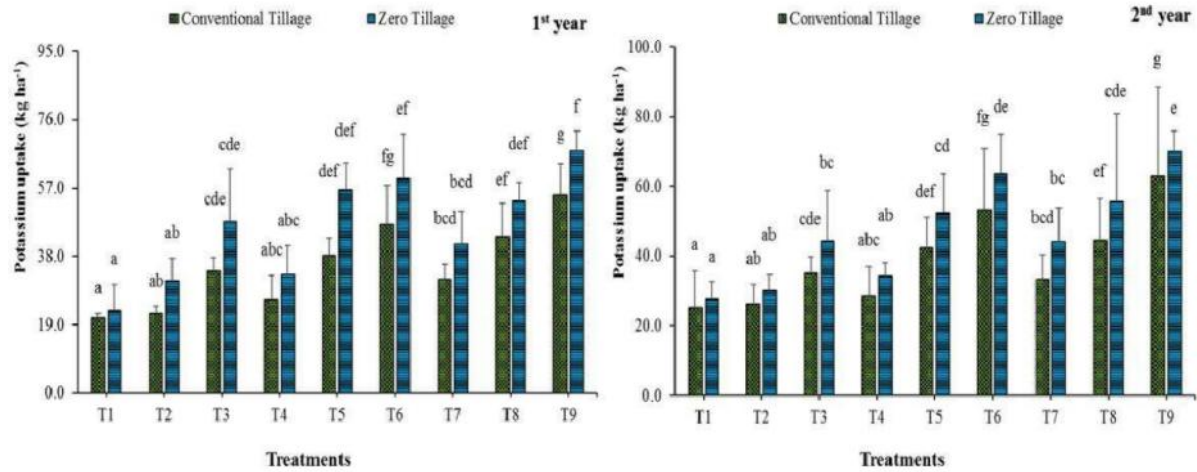


Figure 16. Uptake of potassium (kg ha^{-1}) in stem of wheat at flowering stage under conventional and zero tillage practices. The standard deviation of measurement is shown as error bars. Means with common letters are not significantly different at $P \leq 0.05$, according to Fisher's Protected Least Significant Difference (LSD) test using the algorithm of Studentized range test (Hsu, 1996).

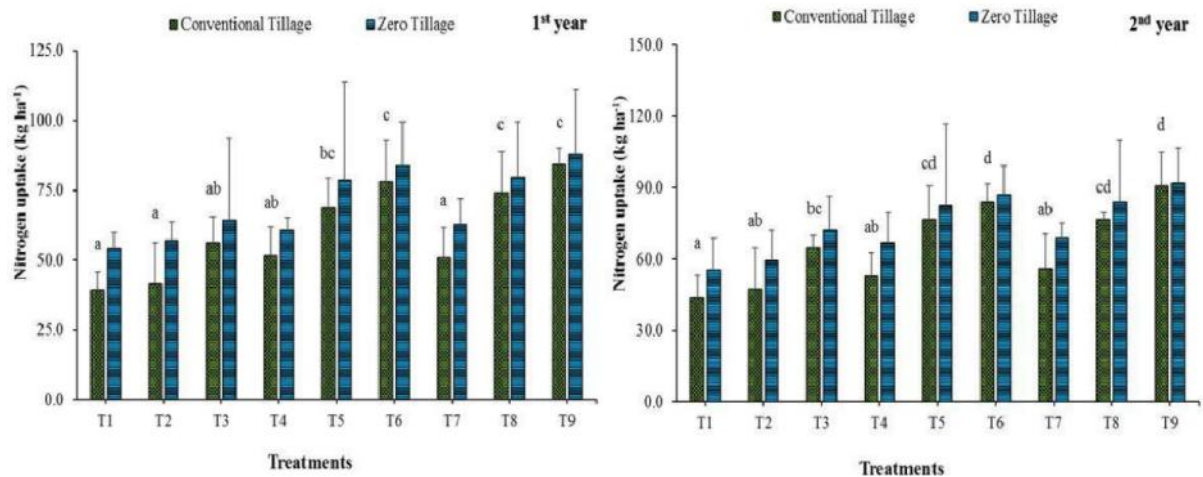


Figure 17. Uptake of nitrogen (kg ha^{-1}) in stem of wheat at milking stage under conventional and zero tillage practices. The standard deviation of measurement is shown as error bars. Means with common letters are not significantly different at $P \leq 0.05$, according to Fisher's Protected Least Significant Difference (LSD) test using the algorithm of Studentized range test (Hsu, 1996).

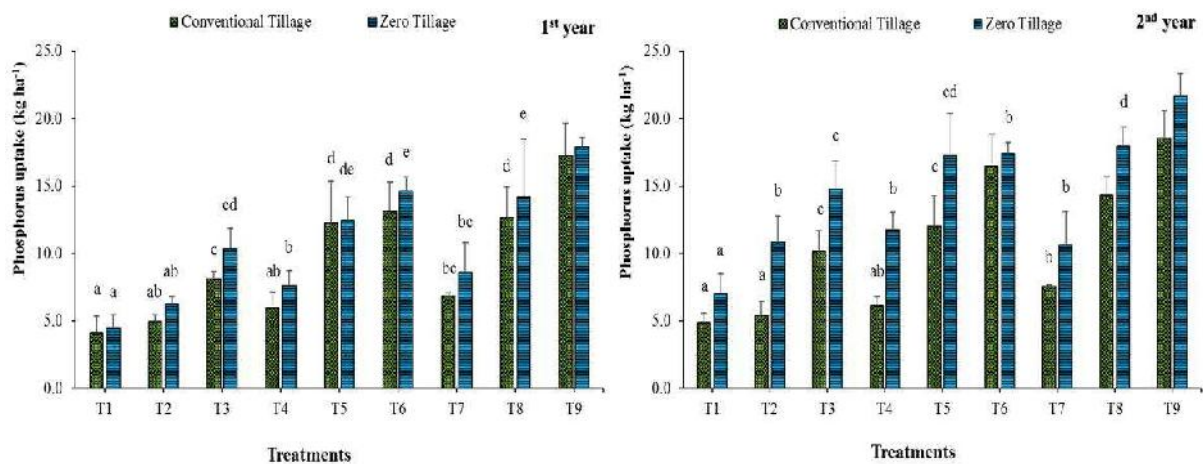


Figure 18. Uptake of phosphorus (kg ha^{-1}) in stem of wheat at milking stage under conventional and zero tillage practices. The standard deviation of measurement is shown as error bars. Means with common letters are not significantly different at $P \leq 0.05$, according to Fisher's Protected Least Significant Difference (LSD) test using the algorithm of Studentized range test (Hsu, 1996).

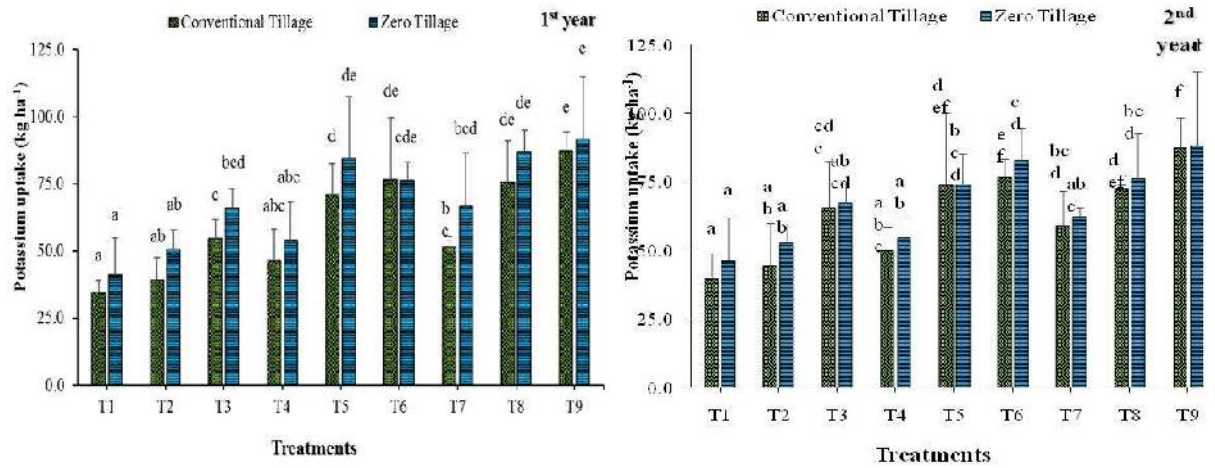


Figure 19. Uptake of potassium (kg ha⁻¹) in stem of wheat at milking stage under conventional and zero tillage practices. The standard deviation of measurement is shown as error bars. Means with common letters are not significantly different at $P \leq 0.05$, according to Fisher's Protected Least Significant Difference (LSD) test using the algorithm of Studentized range test (Hsu, 1996).

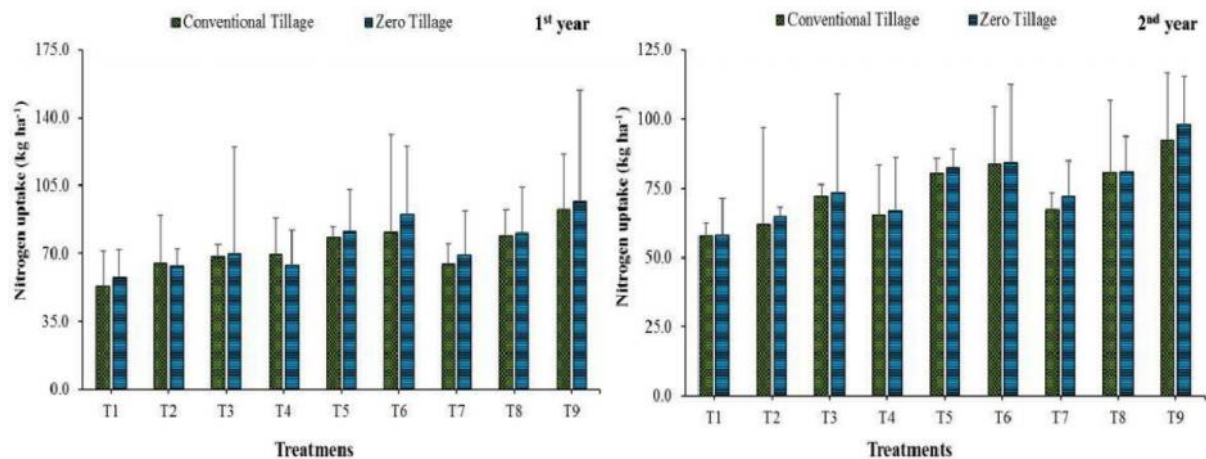


Figure 20. Uptake of nitrogen (kg ha⁻¹) in stem of wheat at harvest under conventional and zero tillage practices. The standard deviation of measurement is shown as error bars. Means with common letters are not significantly different at $P \leq 0.05$, according to Fisher's Protected Least Significant Difference (LSD) test using the algorithm of Studentized range test (Hsu, 1996).

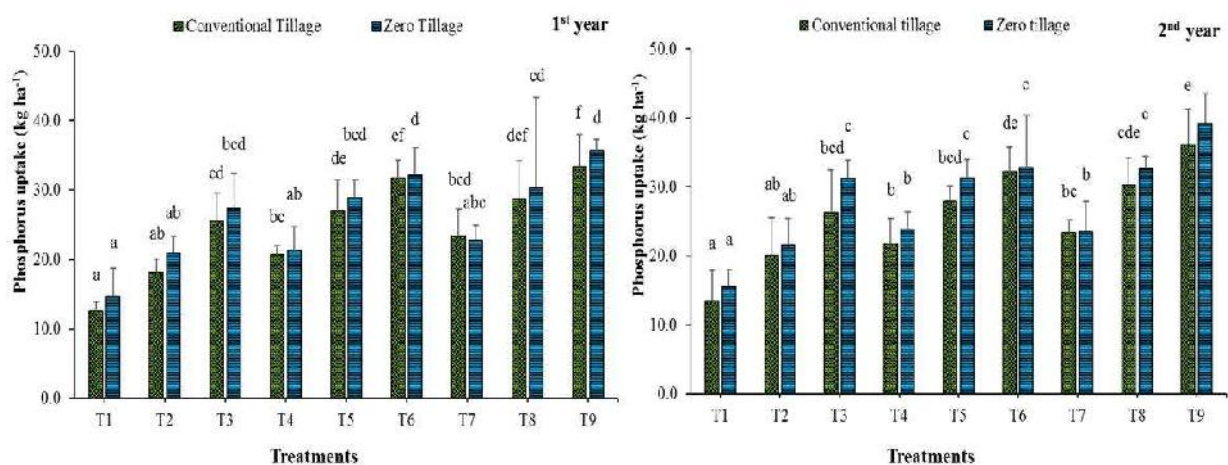


Figure 21. Uptake of phosphorus (kg ha⁻¹) in stem of wheat at harvest under conventional and zero tillage practices. The standard deviation of measurement is shown as error bars. Means with common letters are not significantly different at $P \leq 0.05$, according to Fisher's Protected Least Significant Difference (LSD) test using the algorithm of Studentized range test (Hsu, 1996).

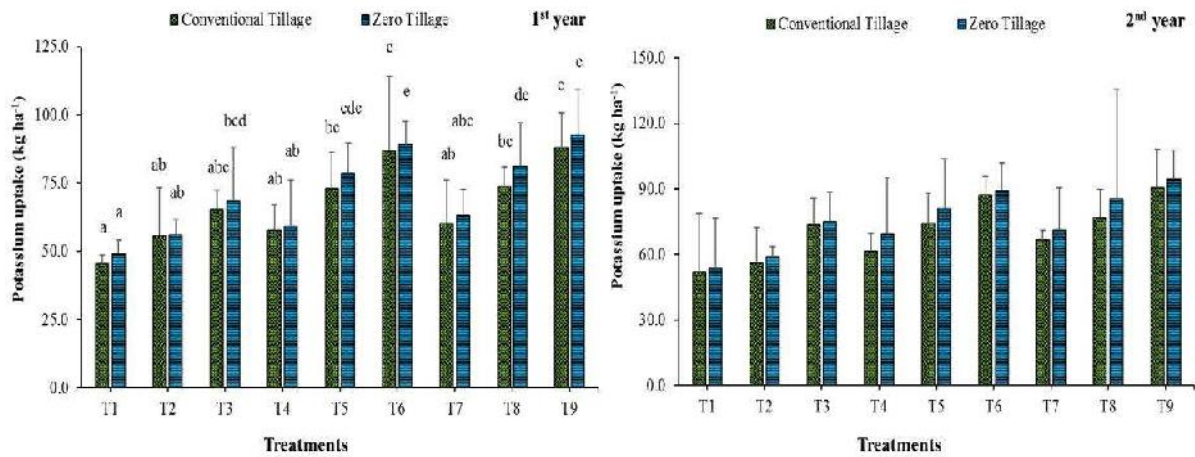


Figure 22. Uptake of potassium (kg ha^{-1}) in stem of wheat at harvest under conventional and zero tillage practices. The standard deviation of measurement is shown as error bars. Means with common letters are not significantly different at $P \leq 0.05$, according to Fisher's Protected Least Significant Difference (LSD) test using the algorithm of Studentized range test (Hsu, 1996).

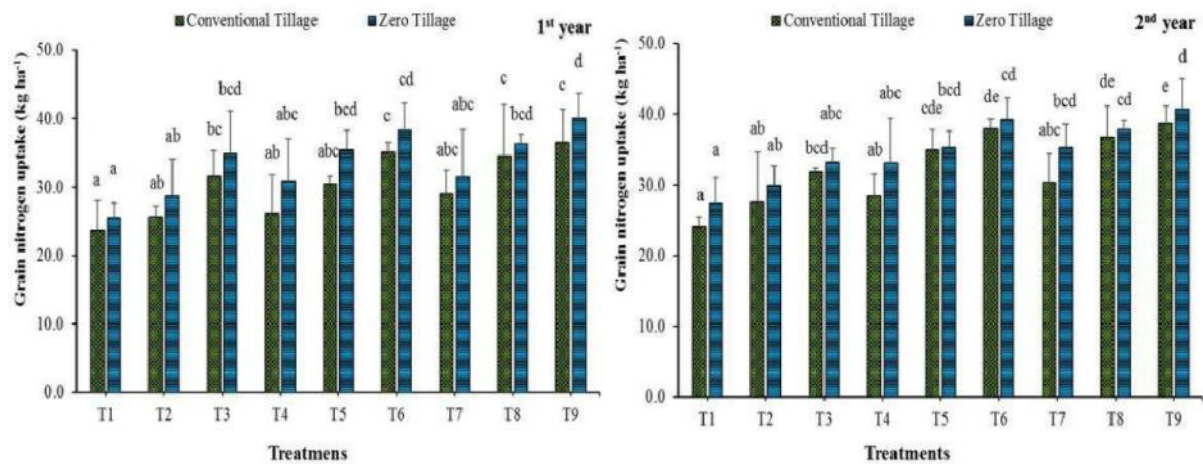


Figure 23. Uptake of nitrogen (kg ha^{-1}) in stem of wheat at harvest under conventional and zero tillage practices. The standard deviation of measurement is shown as error bars. Means with common letters are not significantly different at $P \leq 0.05$, according to Fisher's Protected Least Significant Difference (LSD) test using the algorithm of Studentized range test (Hsu, 1996).

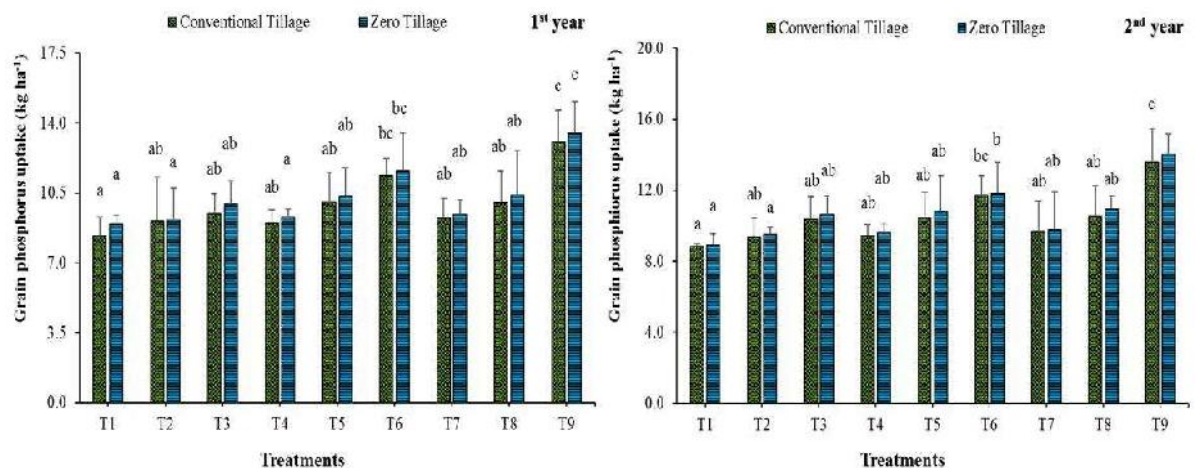


Figure 24. Uptake of phosphorus (kg ha^{-1}) in stem of wheat at harvest under conventional and zero tillage practices. The standard deviation of measurement is shown as error bars. Means with common letters are not significantly different at $P \leq 0.05$, according to Fisher's Protected Least Significant Difference (LSD) test using the algorithm of Studentized range test (Hsu, 1996).

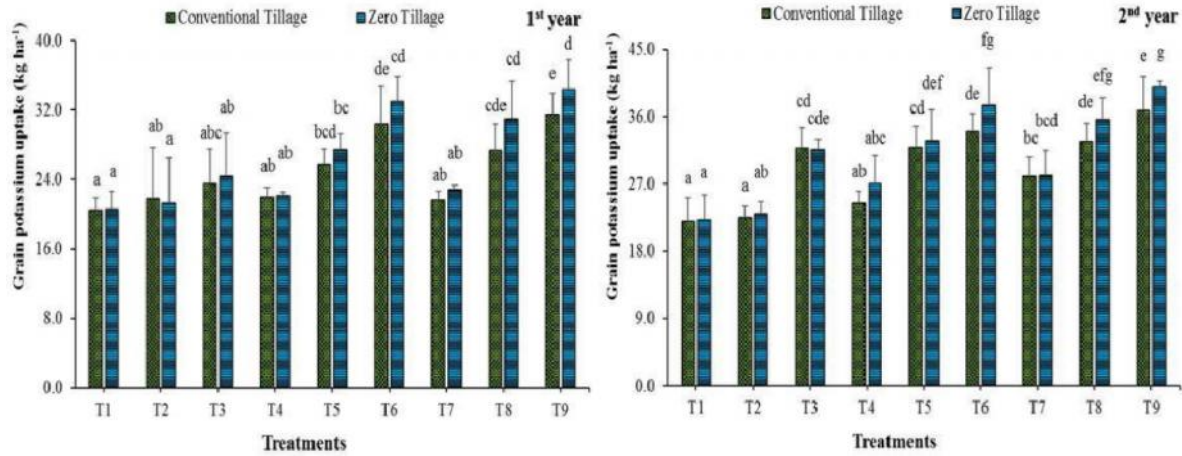


Figure 25. Uptake of potassium (kg ha⁻¹) in stem of wheat at harvest under conventional and zero tillage practices. The standard deviation of measurement is shown as error bars. Means with common letters are not significantly different at $P \leq 0.05$, according to Fisher's Protected Least Significant Difference (LSD) test using the algorithm of Studentized range test (Hsu, 1996).

Changes of temperature and relative humidity of experimental field during the crop growth period

From the meteorological data obtained from Gramin Krishi Mousam Seva Kendra, Pundibari, Coochbehar and IMD (Fig. 26) it was recorded that, minimum temperature in first year was in the month of November, 2014 (10.17°C) and it was also minimum in the month of January, 2016 (9.48°C), i.e. in second year. Maximum temperature was observed during March, 2015 (30.11°C) and in March, 2016 (30.69°C) in the first and second year respectively. Relative humidity was maximum in January, 2015 (90.28%) and in January, 2016 (91.19%) for first and second year respectively. Value of relative humidity was recorded minimum during March, 2015 (55.93%) and March, 2016 (55.52%) in first and second year respectively. Rainfall was recorded in January, 2015 (0.75 mm), i.e. in the first year. It was also recorded that rainfall was in January, 2016 (0.17 mm) in second year. Soil organic carbon equilibrium was governed by the temperature and relative humidity. Rise in the mean temperature reduced the level of soil organic carbon of cultivated soil (Singh *et al.*, 2012).

4.5.3 Effects of treatment on CO₂ balance of leaf temperature of wheat during photosynthesis under conventional tillage and zero tillage.

The effect of treatment on CO₂ balance under ZT (Fig. 27) was measured for five days at flowering stage of wheat for two years. Day three (D₃) had been taken as reference. Data indicated that highest leaf temperature (25.10°C) was recorded for T₂ treatment with CO₂-input value 870.40 ppm. The CO₂-in was minimum for T₁ (651.00 ppm). Treatment T₉ showed leaf temperature 23.10°C with CO₂-input value 673.20 ppm.

Under CT operation (Fig. 28) in first year, it was observed that (on D₃) maximum leaf temperature (25.10°C) was under T₂ with CO₂-out value 861.40 ppm whereas in T₉ treatment leaf temperature was recorded as 23.10°C and value of CO₂-out as 661.50 ppm.

CO₂-in(on D₃) under CT in second year (Fig. 29) was measured. It was observed that maximum temperature (28.1°C) of leaf under T₁ had the value of CO₂-in

841.8 ppm. Leaf temperature under T₉ was 27.5⁰C with the value of CO₂-in as 826.8 ppm.

In Fig. 30, value of leaf temperature under T₁ was 28.1⁰C with CO₂-out value 787.5 ppm at CT operation (second year) whereas T₉ treatment was found 27.5⁰C leaf temperature with 784.6 ppm as CO₂-out.

ZT operation in first year (Fig. 31) recorded highest leaf temperature (27.20⁰C) and CO₂-in value 721.80 ppm under T₁ whereas maximum value of CO₂-in (854.10 ppm) was recorded under T₆ with leaf temperature as 26.30⁰C. Leaf temperature of T₉ was found 22.7⁰C and CO₂-in value was 661.90.

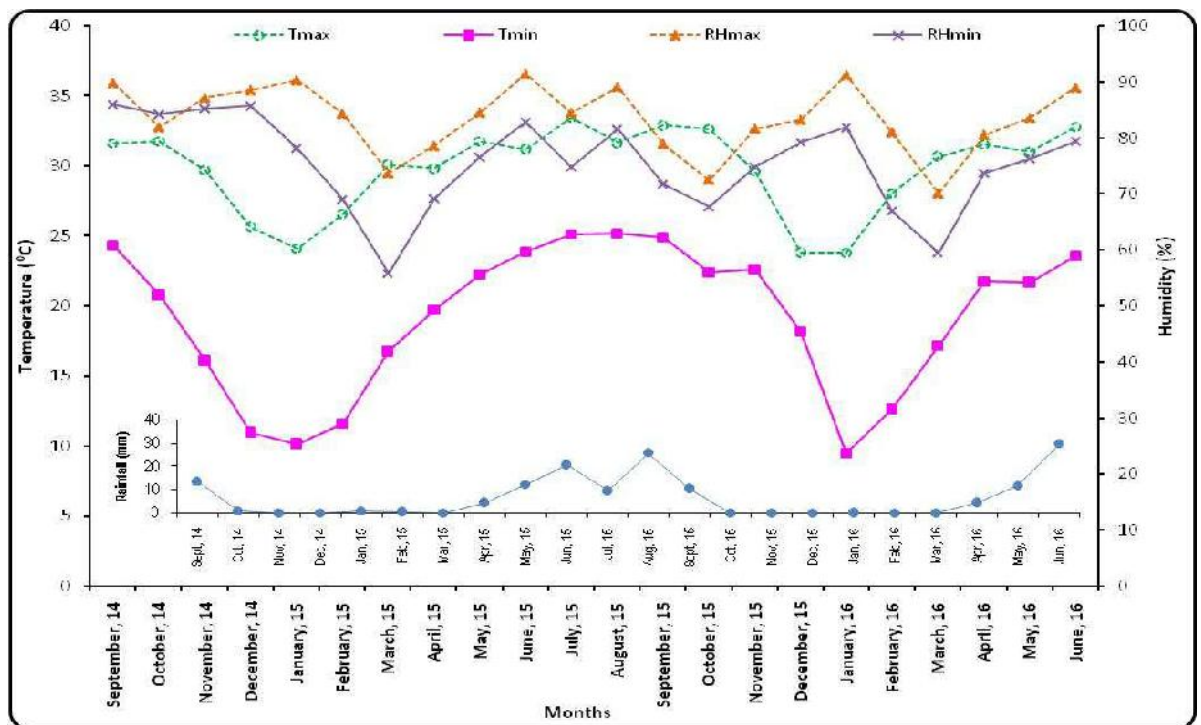
In Fig. 32, the value of CO₂-out was maximum (720.80 ppm) with leaf temperature 25.10⁰C under ZT first year operation. Value of leaf temperature and CO₂-out in T₉ were recorded 22.7⁰C and 659.20 ppm respectively.

Second year ZT operation (Fig. 33) under T₁ recorded 24.9⁰C as leaf temperature and was 832.9 ppm CO₂-in whereas T₉ recorded 25.6⁰C leaf temperature with CO₂-in value 816.7 ppm.

In second year ZT operation, (Fig. 34) CO₂-out was measured as 827.0 ppm with leaf temperature 24.9⁰C for T₁ compare to 777.2 ppm CO₂-out and 25.6⁰C leaf temperature for T₉.

Experimental results showed that balance of CO₂ under different treatment (T₁ to T₉) was different depending on leaf temperature. Treatment T₉ showed better balance in CO₂ release from leaf during photosynthesis than other treatments in various leaf temperature and relative humidity. Zero tillage operation had better balance in CO₂-in and CO₂-out from leaf during photosynthesis compare to conventional tillage.

As temperature acted as a major determinant of microbial processes, co-relation of leaf temperature during photosynthesis and the rates of organic matter decomposition along with CO₂ balance may had significant effect of yield attributes (Schimel *et al.*, 1994). This result may be used for study of the rates of organic matter decomposition with temperature (Waldrop and Firestone, 2004).



Source: Gramin Krishi Mousam Seva Kendra, Pundibari, Coochbehar and IMD.

Fig 26. Changes of temperature and relative humidity during the crop growth period

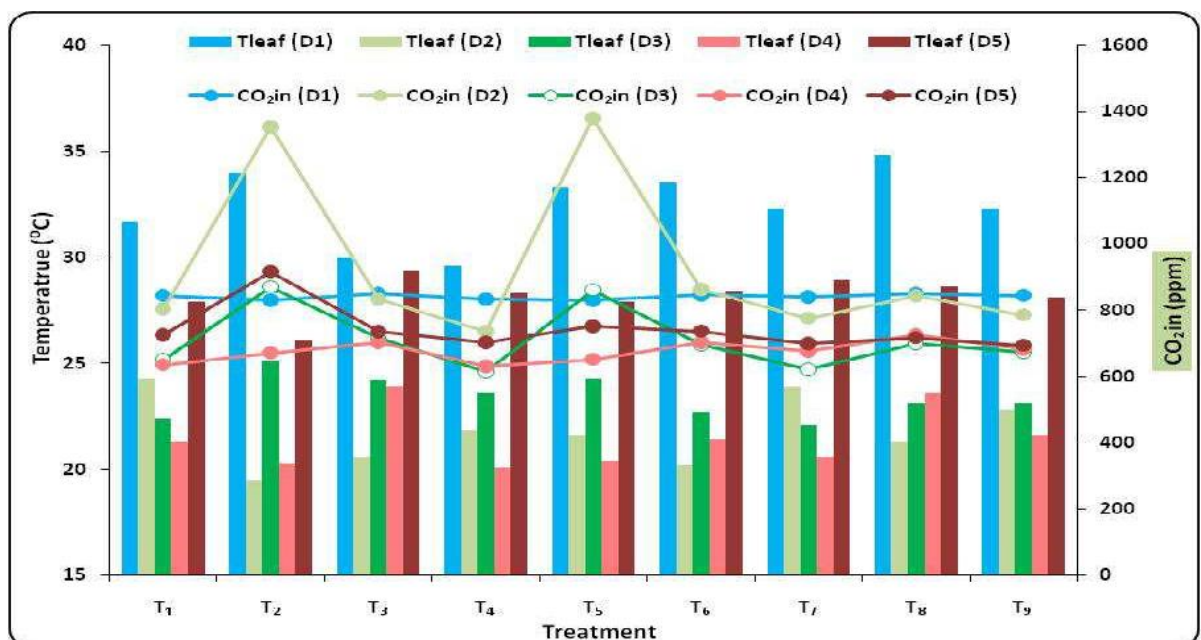


Fig 27. Effects of treatment on CO₂in balance under conventional tillage (1st year) operations

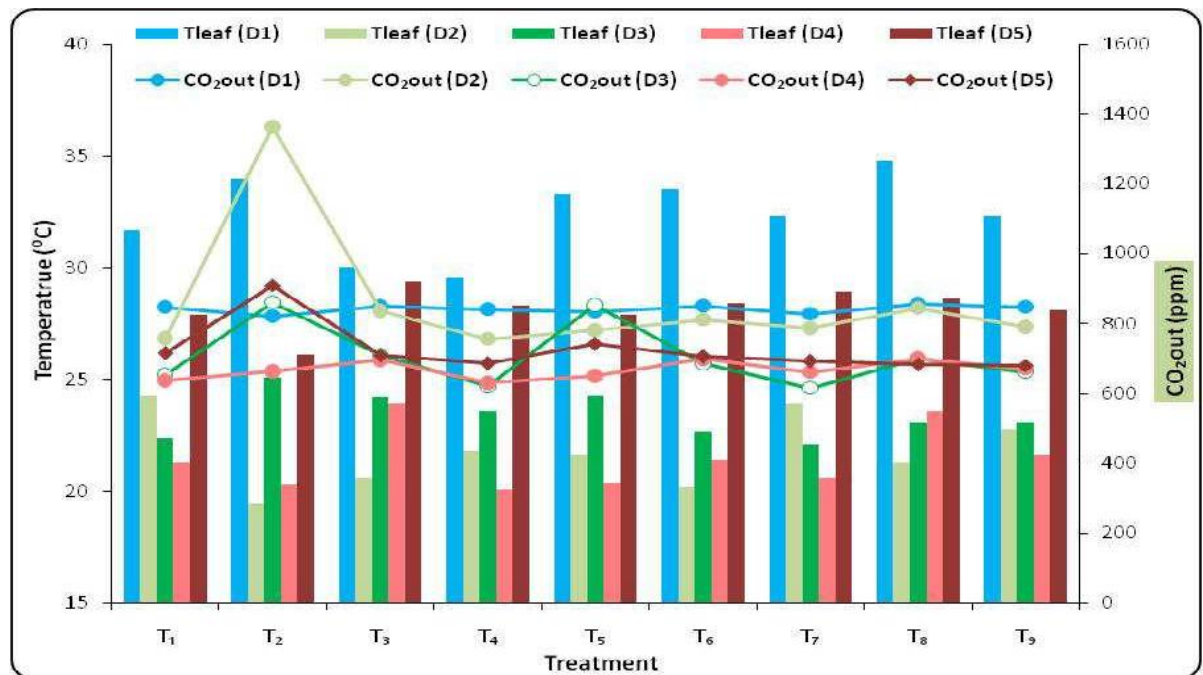


Fig 28. Effects of treatment on CO₂out balance under conventional tillage (1st year) operations

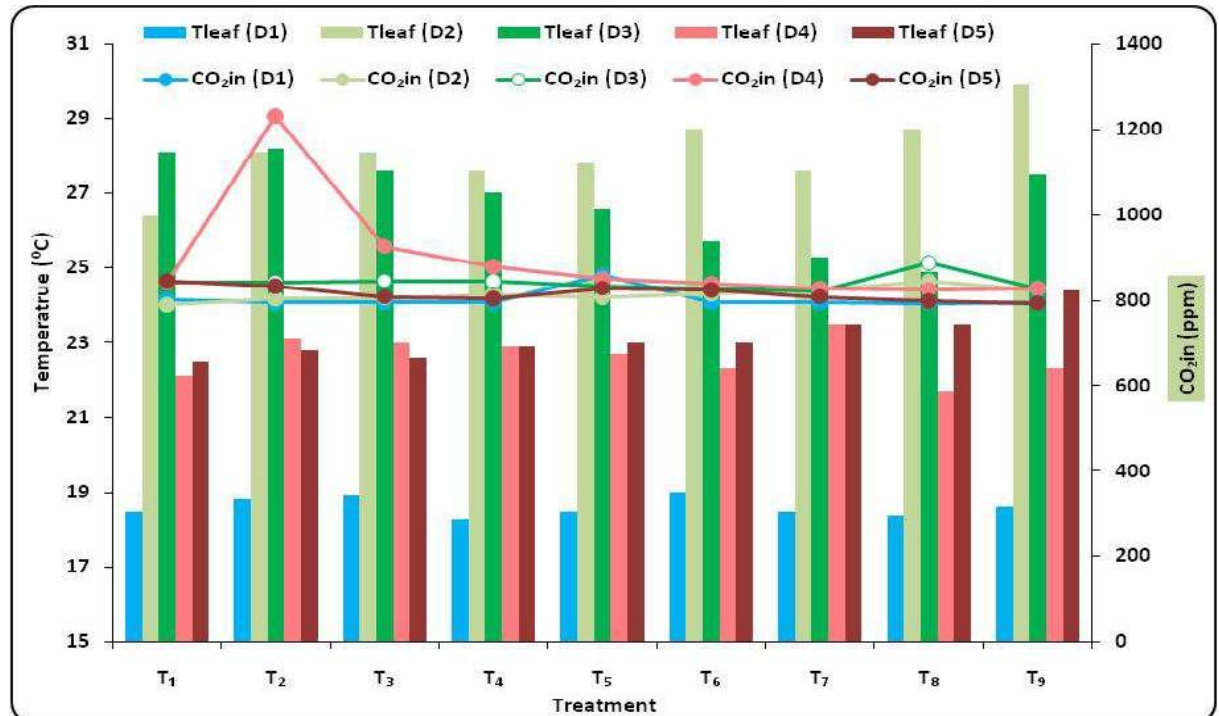


Fig 29. Effects of treatment on CO₂in balance under conventional tillage (2nd year) operations

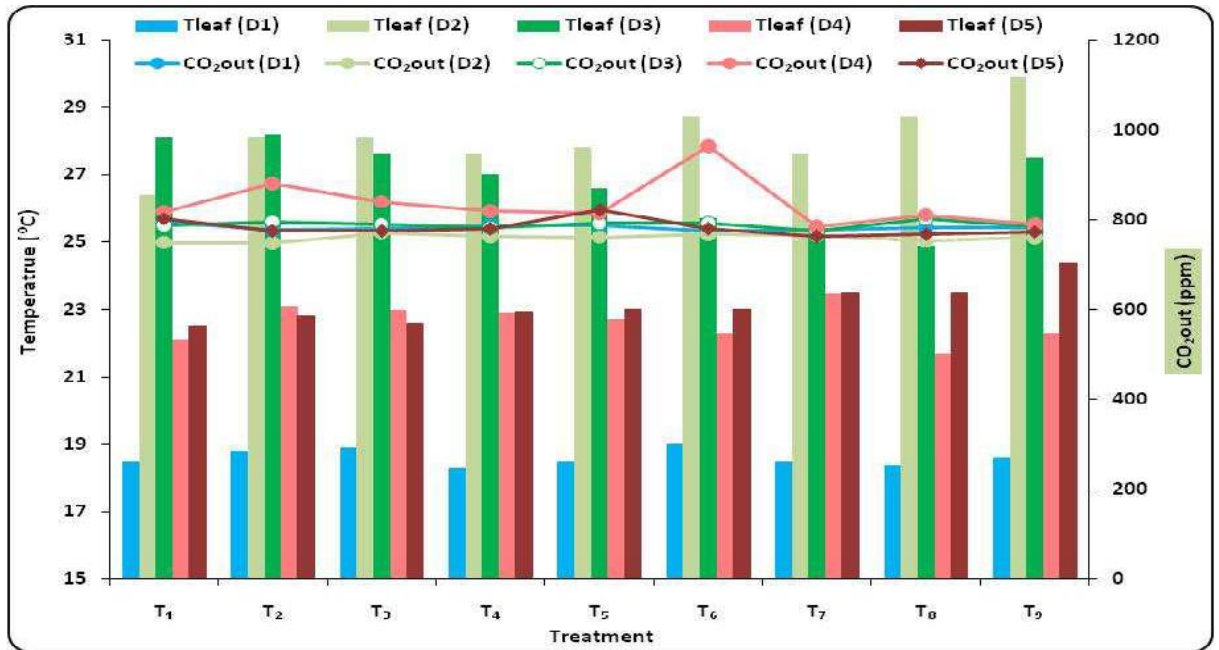


Fig 30. Effects of treatment on CO₂out balance under conventional tillage (2nd year) operations

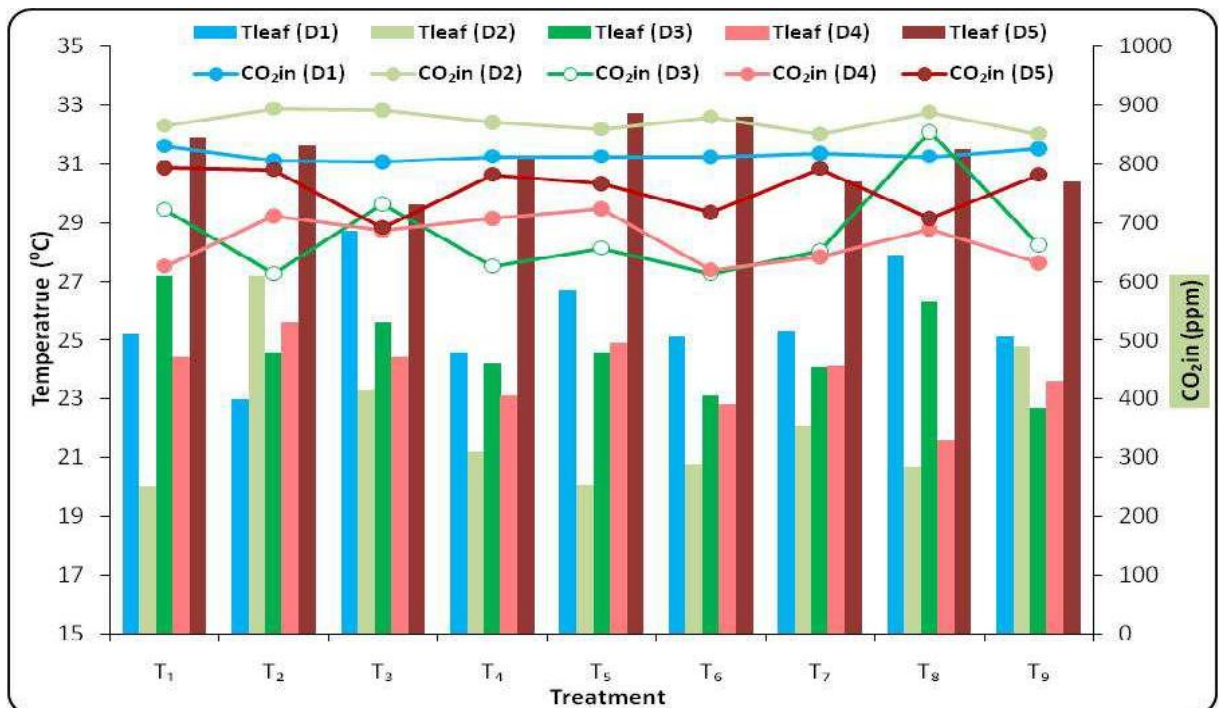


Fig 31. Effects of treatment on CO₂in balance under zero-tillage (1st year) operations

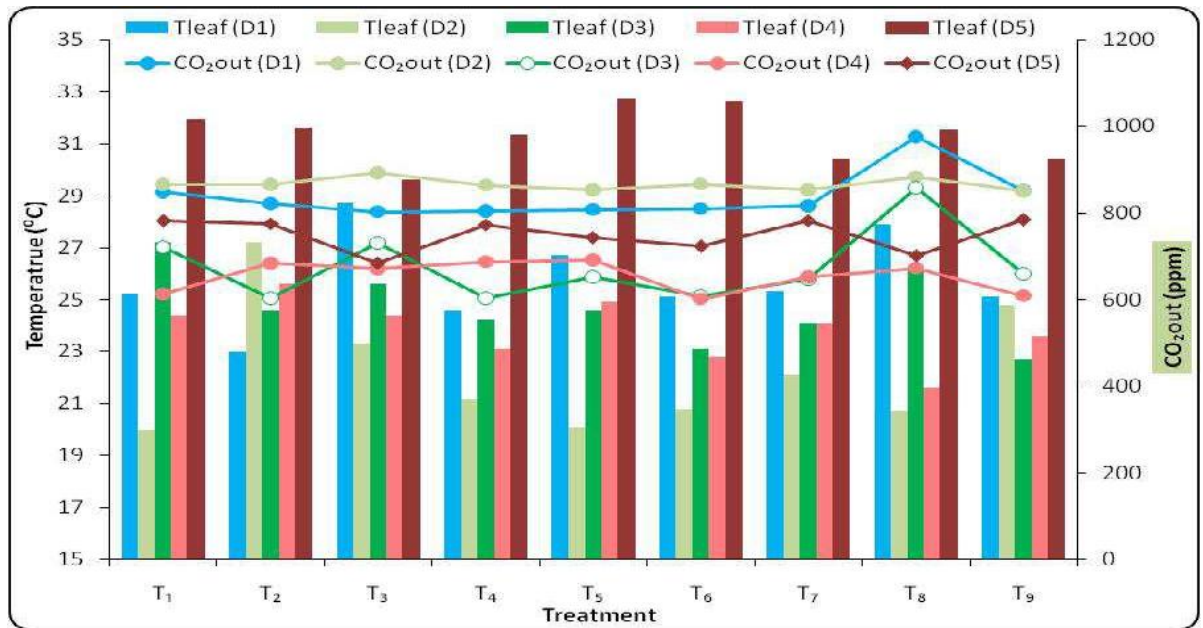


Fig 32. Effects of treatment on CO₂out balance under zero-tillage operations (1st year)

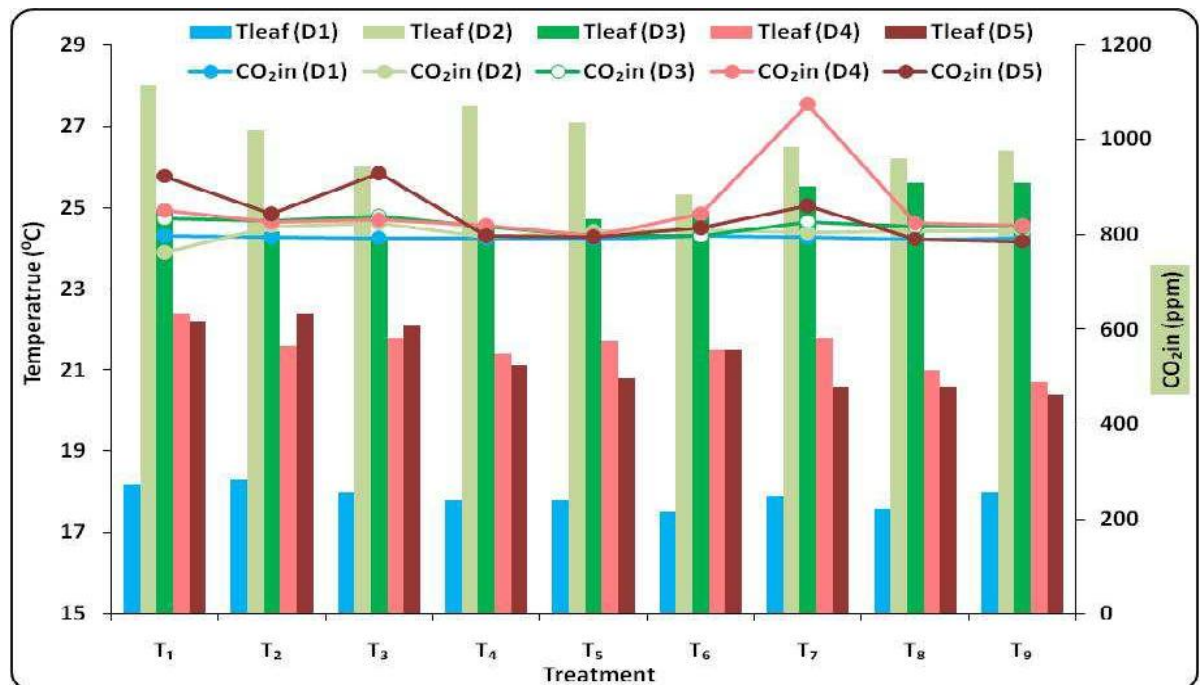


Fig 33. Effects of treatment on CO₂in balance under zero-tillage (2nd year) operations

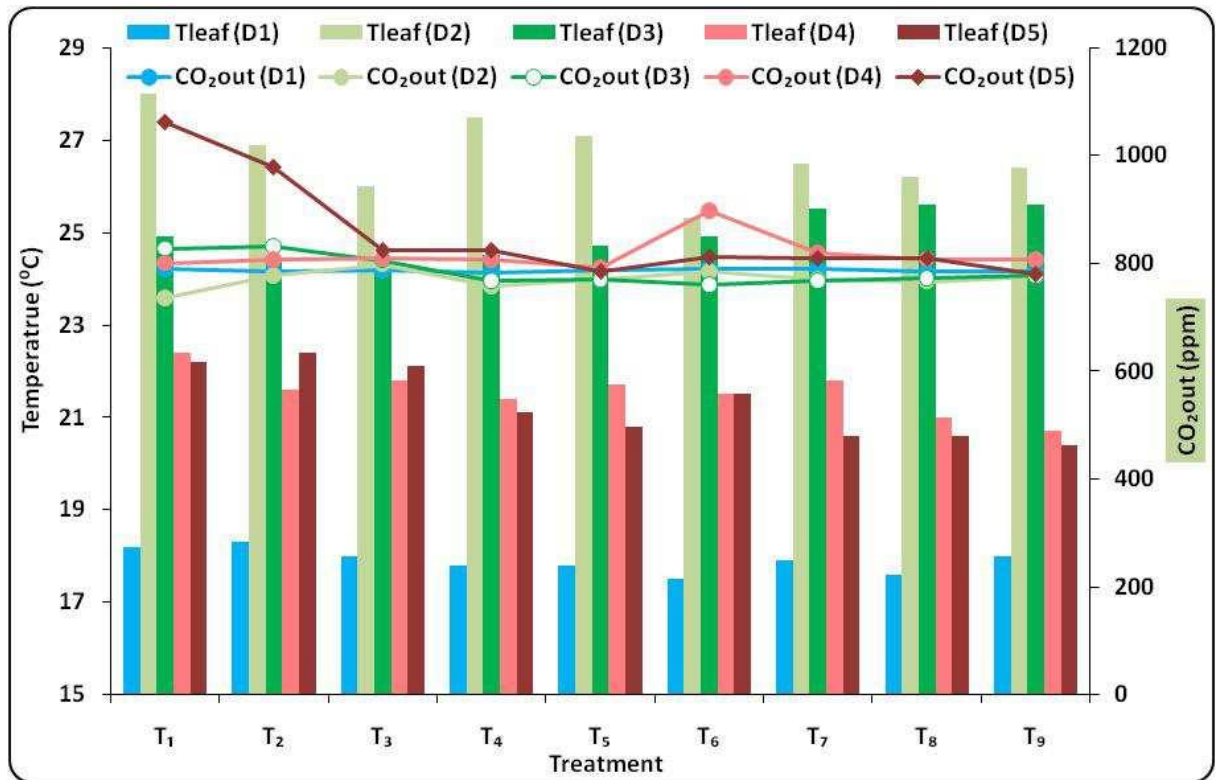


Fig 34. Effects of treatment on CO₂out balance under zero-tillage (2nd year) operations

Chapter 5

SUMMARY AND CONCLUSION

Soil carbon stocks were closely related to agricultural productivity and were affected by changes in land use and thus reflected the global climate change. Depending on formation and decomposition rates of soil organic matter (SOM), the soil- plant systems could act as sinks or sources of atmospheric CO₂. There was much concern about land-use change which might have significant feedbacks on the global C cycle. Land use and management practices might influence soil CO₂ emission by affecting plant growth, soil disturbance, and nutrient levels.

Considering the different climatic conditions and land use pattern under the *Terai* agro-ecosystems, the selection of the sites for collecting soils was done on the basis of different land use and land cover under Terai region of West Bengal. Another field study was undertaken in the instructional farm of Uttar Banga Krishi Viswavidyalaya, Pundibari, Coochbehar for two years.

The physico-chemical properties of soils, carbon fractions (oxidisable organic carbon, labile carbon and its fractions, mineralizable carbon, particulate organic carbon, inorganic carbon, total organic carbon) and carbon mapping were done using

standard methods. Effect of tillage and organic residues on carbon fractions of soil and yield of wheat, recording biometric observations, yield attributing characteristics and balance in CO₂-in and CO₂-out from leaf during photosynthesis were measured by standard methods.

It was found that, the forest soils were acidic in reaction (average pH 5.15). A general trend of increasing the pH with the depth of the soils was observed. The range of pH in soils varied from 4.77 to 5.62. The ECs of the collected soils showed the non-saline characteristics having an average of 0.05 dSm⁻¹. The (Ca⁺² + Mg⁺²) content in soils was low in this zone (average 3.48 meq/l) which indicated the acidic nature of the soil. The available nitrogen (N) trend to decrease with the depth of the soil. The lowest value of N (119.17 kg ha⁻¹) was at 40-60 cm depth of soils under the Chilapata forest. The available phosphorus under the forest ecosystem varied at different locations under study. A general trend of lowering of K content with the soil depths was observed under this ecosystem. The average K content was 108.70 kg ha⁻¹. The maximum K content was at soils of the Gorumara and minimum at the Mahananda forest. Comparatively a lower C/N was observed in soil of Buxa than the others (Gorumara, Mahananda and Chilapata) land situations.

The average pH was 6.24 for the soils of agricultural land and in general, there was a trend of increasing pH with the soil depth. The ECs of the soil samples showed the non-saline character. The exchangeable (Ca⁺² + Mg⁺²) of the soils of Balarampur and Kumargram were relatively higher. The oxidisable organic carbon generally decrease with the depth of the soils. The available nitrogen in soils (0-20 cm depth) was in the order Binnaguri > Kharibari > Balarampur > Kumargram and the content tends to decrease with the increasing depth of the soil. In most of the soils, the total C-H-N-S decreased in the sub-surface layers. The C/N was found in the order as Kharibari > Binnaguri > Kumargram > Kumargram.

The tea soils were acidic with an average pH of 4.78 and ECs of 0.12 dSm⁻¹. A general trend of decrease of the organic carbon with the depth of soils was observed. The available nitrogen, phosphorus and K also varied with the depth of the soils. The total C-H-N-S also varied with the soil depth in this region. The average C/N of the tea garden soils was 9.33.

A general trend of increasing the ($\text{Ca}^{+2} + \text{Mg}^{+2}$) content was observed with the soil depth for fallow lands. The variation of C/N with the soil depth was observed with an average of 7.44 in soils under the fallow land situation.

While comparing the CEC of the soils in all the ecosystems, it was observed that the CEC of soils of Agriculture > Tea garden > Forest > Fallow. This may be due to the difference in the degree of input of nutrients under different ecosystems.

The available N and P content in forest land, fallow land and tea garden soils were quite comparable than under agricultural land. The available K content in soils was found to be in the order as fallow land > tea garden > agriculture land > forest land. From the correlation study, it was observed that soil pH had a significant negative correlation with available N, available P, total carbon, C : N, C : S and C : H.

It was also observed that the non-labile carbon was minimum (0.16 gkg^{-1}) in Kumargram soil at 0-40 cm depth while the very labile carbon (40-60 cm) was highest in Kharibari soil (0.60 gkg^{-1}). It was observed that the different organic fractions were relatively higher in the surface (0-40cm) soil than the soil depth of above 40 cm. the order was very labile > Non-labile > less labile at both the surface and subsurface soil. The carbon balance under the fallow land situation may vary in accordance with the period of abandonment and that may lead to the increase of the organic matter content in soil. There was a difference of the carbon fractions under forestland and cultivated situation might be due to the conversion of forests into cropland resulting the decrease of the soil organic carbon stock for disturbance and lower inputs of non-soluble carbon materials in crop land than the forest (Banger et al., 2015) land situation. It was apparent that the less labile carbon was minimum (1.14 gkg^{-1}) and very labile carbon was highest (8.78 gkg^{-1}) at among the all forest land situation.

It has been observed that less labile carbon in 0-40 cm depth was lowest (0.16 gkg^{-1}) in Buxa while the very labile fraction was maximum (13.15 gkg^{-1}) in Gorumara forest soil. However, the less labile carbon in 40-60 cm depth was lowest (0.01 gkg^{-1}) in Mahananda soil and labile carbon has highest value (10.92 gkg^{-1}) in Gorumara soil.

While understanding the oxidisable carbon fractions under the tea garden, it was observed that the very labile carbon varied from 5.61 - 9.03 gkg^{-1} with an average

of 7.54 gkg^{-1} at 0-40 cm depth of soil. The trend of magnitude of the different organic fractions was very labile>labile>non-labile>less labile.

The distribution of carbon fractions at three depths (0-20 cm, 20-40 cm and 40-60 cm) in different landuses of Terai region of West Bengal, India were also prepared. The different carbon fractions had been shown through GIS-based mapping using Arc GIS. Among the different forms of carbon (CaCO_3 – bound, active carbon and particulate organic carbon), it was observed that CaCO_3 - bound fractions was higher in forest soil than the fallow land while the active carbon was higher in forest soil than the cultivated land at 0-20cm depth of soil. The POC was relatively higher in tea garden soil than that of the cultivated land.

At the soil depth of 20-40 cm the CaCO_3 - bound carbon fractions was maximum in the cultivated land and minimum in forest land, while the active carbon fractions was maximum in forest land and minimum in the cultivated land. The POC was maximum in cultivated land and minimum in forest land situation.

The observation on the changes in minerelisable carbon under different land use pattern showed that carbon minerelization was affected by the duration of the incubation period and landuse pattern. In general, the carbon minerelization increased with the days of incubation period upto ten days irrespective of landuse pattern, but the rate of increase was decreased with the progress of incubation.

The POC and mineralisable carbon were related to each other and were influenced by the management practices. The POC reflected the practices related to conservation that were expected to promote accumulation or stabilization of organic matter (long term carbon sequestration).

This study has also shown the changes in physico-chemical properties, spatial distribution of soil carbon in soils under different landuse determining the fractions of soil carbon (Labile Carbon, Particulate Organic Carbon, Oxidisable Organic Carbon, Inorganic carbon and Mineralizable carbon) with the increasing soil depth.

Study undertaken at Instructional Farm of Uttar Banga Krishi Viswavidyalaya, Pundibari, Coochbehar showed that continuous rice-wheat cropping with balanced fertilisation (N-P-K) along with carbon input caused significant carbon build-up in the soil in both tillage system. The relative efficacy of the amendments for SOC building

was FYM>PS. Organic carbon and labile pool of OC input supplemented through FYM and PS played significant role on the crop yield.

Balanced N-P-K fertilisation along with an adequate amount of FYM following zero tillage management was most suitable for the continuous rice-wheat cropping system for improving the SOC stock and sustaining crop productivity.

Soil carbon, available nutrients and yield were higher in zero tillage system compare to conventional tillage system. Application of decomposed paddy straw and farmyard manure showed higher carbon and nutrient addition in both tillage system.

Mapping of forms of carbon under different landuse pattern in *Terai* region of West Bengal will help for Assessment of the important environmental factors like temperature, humidity, rainfall governing the forms of carbon in soils.

Experimental results also shown that, balance of CO₂ under different treatment (T₁ to T₉) was different on leaf temperature. The T₉ treatment showed better balance in CO₂ release from leaf during photosynthesis than other treatments in various leaf temperature and relative humidity. Zero tillage operation had better balance in CO₂-in and CO₂-out from leaf during photosynthesis compare to conventional tillage. Balance of CO₂ under different treatment (T₁ to T₉) is different on leaf temperature and relative humidity.

Chapter 6

FUTURE SCOPE OF RESEARCH

1. It requires strategies for efficient use of agricultural input for having more yield of the crop with minimum environmental cost.
2. Assessment of biophysical and socio-economic implications of proposed GHG is needed for mitigation options before developing policy for their implementation.
3. Conservation Agriculture practices and their promotion is need on the basis of the priority.
4. Critical carbon input requirements for major agro-ecological regions need to be computed and efforts should be given to promote organic matter addition where ever possible.
5. Preparation of soil carbon mapping of entire *Terai* region of West Bengal is needed.
6. Effective landuse planning, periodic replenishment of soil nutrients in cultivated areas are to be addressed to maintain soil health including carbon status.
7. Study on root density, root biomass and root carbon in forest soil (depthwise) is required to determine C and N dynamics in the soil-plant environmental systems.

REFERENCES

- Aguilera, J.; P. Motavalli,; Valdivia, C.; Gonzales, M. A. 2013. Impacts of cultivation and fallow length on soil carbon and nitrogen availability in the Bolivian Andeanhighland region. *Mountain Research and Development* Vol. 33 No. 4 pp. 391-403
- Ahn, M.Y., A.R. Zimmerman, N. B. Comerford, J.O. Sickman, and S. Grunwald 2009. Carbon mineralization and labile organic carbon pools in the sandy soils of a North Florida watershed. *Ecosystems*. 12: pp. 672–685.
- Ajtay, G.L., P. Ketner, and P. Duvigneaud, 1979. Terrestrial primary production and phytomass. In: *The Global Carbon Cycle*. (Eds.) Bolin, B., Degues, E.T., Kempa, S. and Ketner, P. JohnWiley, Chichester, pp.129-181.
- Akala, V.A., and R. Lal. 2001. Soil organic carbon pools and sequestration rates in reclaimed minesoils in Ohio. *J. Environ. Qual.* 30: pp. 2098–2104.
- Alan J. Franzluebbers. 2010. Achieving Soil Organic Carbon Sequestration with Conservation Agricultural Systems in the Southeastern United States. *Soil Sci. Soc. Am. J.* 74: pp. 347–357.

- Al-Kaisi, M.M., X. Yin, and M.A. Licht. 2005. Soil carbon and nitrogen changes as affected by tillage system and crop biomass in a corn–soybean rotation. *Appl. Soil Ecol.* 30: pp. 174-191.
- Allmaras, R.R., H.H. Schomberg, C.L. Douglas, and T.H. Dao. 2000. Soil organic carbon sequestration potential of adopting conservation tillage in U.S. croplands. *J. Soil Water Conserv.* 55: pp. 365–373.
- Alvarez, C.R., and R. Alvarez. 2000. Short-term effects of tillage systems on active soil microbial biomass. *Biol. Fertil. Soils.* 31: pp. 157–161.
- Alvarez, R., R. Díaz, N. Barbero, O.J. Santanatoglia, and L. Blotta. 1995. Soil organic carbon, microbial biomass and CO₂–C production from three systems. *Soil Tillage Res.* 33: pp. 17–28.
- Amado, T.J.C., C. Bayer, P.C. Conceição, E. Spagnollo, B.H. Costa de Campos, and M. da Veiga. 2006. Potential of carbon accumulation in no-till soils with intensive use and cover crops in southern Brazil. *Soil Sci. Soc. Am. J.* 35: pp. 1599-1607.
- Anderson, J.P.E. (1982). Soil respiration. In AIn A.L. Page et al. (ed.) methods of soil analysis. Part 2. 2nd ed. *Agron. Monogr.* 9. ASA and SSSA, Madison, W.I. pp. 831-871.
- Andrews, J.A., R. Matamala, K.M. Westover, and W.H. Schlesinger. 2000. Temperature effects on the diversity of soil heterotrophs and the delta C-13 of soil-respired CO₂. *Soil Biol. Biochem.* 32: pp.699-706.
- Angers, D.A., A. Recous, and C. Aita. 1997. Fate of carbon and nitrogen in water-stable aggregates during decomposition of ¹³C¹⁵N-labelled wheat straw in situ. *Eur. J. Soil Sci.* 48: pp. 295–300.
- Angers, D.A., and M.R. Carter. 1996. Aggregation and organic matter storage in cool, humid agricultural soils. In M.R. Carter and B.A. Stewart (ed.) Structure and organic matter storage in agricultural soils. Adv. Soil Sci. CRC Press, Boca Raton, FL. pp. 193–211.
- Angers, D.A., N. Bissonnette, A. Légère, and N. Samson. 1993. Microbial and biochemical changes induced by rotation and tillage in a soil under barley production. *Can. J. Soil Sci.* 73: pp. 39-50.

- Antil, R.S., M.H. Gerzabek, G. Haberhauer, and G. Eder. 2005. Long-term effects of cropped vs. fallow and fertilizer amendments on soil organic matter: I. *Organic carbon. J. Plant Nutr. Soil Sci.* 168: pp. 108-116.
- Ardö, J.; Olsson, L. 2004. Soil carbon sequestration in traditional farming in Sudanese dry lands. *Environmental Management*. 33 No. Supplement 1 pp. S318-S329.
- Arevalo, C. B. M., S. X. Chang, J. S. Bhatti, D. Sidders. 2012. Mineralization Potential and Temperature Sensitivity of Soil Organic Carbon under Different Land Uses in the Parkland Region of Alberta, Canada. *Soil Sci. Soc. Am. J.* 76: pp. 241–251.
- Aslam, T., M.A. Choudhary, and S. Saggarr. 1999. Tillage impacts on soil microbial biomass C, N and P, earthworms and agronomy after two years of cropping following permanent pasture in New Zealand. *Soil Tillage Res.* 51: pp. 103-111.
- Atkin, O. K., E. J. Edwards, and B. R. Loveys. 2000. Response of root respiration to changes in temperature and its relevance to global warming. *New Phytologist*. 147: pp. 141-154.
- Baisden, W.T., R. Amundson, A.C. Cook, and D.L. Brenner. 2002. Turnover and storage of C and N in five density fractions from California annual grassland surface soils. *Global Biogeochem. Cycles*. 16(4): pp. 1117. doi:10.1029/2001GB001822.
- Baker, J.M., T.E. Ochsner, R.T. Venterea, and T.J. Griffis. 2007. Tillage and soil carbon sequestration-What do we really know? *Agric. Ecosyst. Environ.* 118: pp. 1-5. doi:10.1016/j.agee.2006.05.014
- Baldock, J.A., and J.O. Skjemstad. 2000. Role of the soil matrix and minerals in protecting natural organic materials against biological attack. *Org. Geochem.* 31: pp. 697–710.
- Balesdent, J., C. Chenu, and M. Balabane. 2000. Relationship of soil organic matter dynamics to physical protection and tillage. *Soil Tillage Res.* 53: pp. 215-230.
- Banger, K., H. Tian, B. Tao, C. Lu, W. Ren, J. Yang. 2015. Magnitude, Spatiotemporal Patterns, and Controls for Soil Organic Carbon Stocks in India during 1901–2010. *Soil Sci. Soc. Am. J.* 79 : pp. 864-875.

- Barton, L., R. Kiese, D. Gatter, K. Butterbach-Bahl, R. Buck, C. Hinz, D.V., Murphy. 2008. Nitrous oxide emissions from a cropped soil in a semi-arid climate. *Global Change Biol.*, 14: pp. 177-192.
- Bauer, A., and A.L. Black. 1981. Soil carbon, nitrogen, and bulk density comparisons in two cropland tillage systems after 25 years and in virgin grassland. *Soil Sci. Soc. Am. J.* 45: pp. 1166-1170.
- Bauer, A., and A.L. Black. 1994. Quantification of the effect of soil organic matter content on soil productivity. *Soil Sci. Soc. Am. J.* 58: pp. 185-193.
- Bauer, P.J., J.R. Frederick, J.M. Novak, and P.G. Hunt. 2006. Soil CO₂ flux from a Norfolk loamy sand after 25 years of conventional and conservation tillage. *Soil Tillage Res.* 90: pp. 205-211.
- Bayer, C., L. Martin-Neto, J. Mielniczuk, A. Pavinato, and J. Dieckow. 2006. Carbon sequestration in two Brazilian Cerrado soils under no-till. *Soil Tillage Res.* 86: pp. 237-245. doi:10.1016/j.still.2005.02.023
- Beare, M.H., P.F. Hendrix, and D.C. Coleman. 1994. Water-stable aggregates and organic matter fractions in conventional and no-tillage soils. *Soil Sci. Soc. Am. J.* 58: pp. 777-786.
- Bellamy, P.H., P.J. Loveland, R.I. Bradley, R.M. Lark, and G.J.D. Kirk. 2005. Carbon losses from all soils across England and Wales 1978–2003. *Nature*, 437: pp. 245–248.
- Benjamin, J.G., D.C. Nielsen, and M.F. Vigil. 2003. Quantifying effects of soil conditions on plant growth and crop production. *Geoderma*, 116: pp. 137-148.
- Bernacchi, C.J., S.E. Hollinger, and T. Meyers. 2005. The conversion of the corn/soybean ecosystem to no-till agriculture may result in a carbon sink. *Global Change Biol.* 11: pp. 1867-1872.
- Bernoux, M., C.C. Cerri, C.E.P. Cerri, M. Siqueira Neto, A. Metay, A.S. Perrin, E. Scopel, T. Razafimbelo, D. Blavet, M.C. Piccolo, M. Pavei, and E. Milne. 2006. Cropping systems, carbon sequestration and erosion in Brazil: A review. *Agric. Sustain. Dev.* 26: pp. 1-8.
- Bernoux, M., M.D.S. Carvalho, B. Volkoff, and C.C. Cerri. 2002. Brazil's soil carbon stocks. *Soil Sci. Soc. Am. J.* 66: pp. 888-896. doi:10.2136/sssaj2002.0888

- Bhattacharyya, T., D.K. Pal, P. Chandran, C. Mandal, S.K. Ray, R.K. Gupta, and K.S. Gajbhiye. 2004. Managing soil carbon stocks in the Indo-Gangetic Plains, India. RWC-CIMMYT, New Delhi.
- Bhattacharyya, T., Ray, S.K., Pal, D.K., Chandran, P., Mandal, C. and Wani, S.P. 2009. Soil Carbon Stocks in India: Issues and Priorities. *Journal of the Indian Society of Soil Science*. 57(4): pp. 461-468.
- Bird, S.B., J.E. Herrick, and M.M. Wander. 2001. Exploiting heterogeneity of soil organic matter in rangelands: Benefits for carbon sequestration. pp. 121–138. In R.F. Follett et al. (ed.) *The potential of United States grazing lands to sequester carbon and mitigate the Greenhouse Effect*. Lewis Publ., Boca Raton, FL.
- Black, C. A. 1965. Methods of soil analysis. Part II, Agron. Ser. No. 9. *American Society of Agronomy Inc.* Madison, Wisconsin, U.S.A.
- Blagodatskaya, E.V., and T.H. Anderson. 1998. Interactive effects of pH and substrate quality on the fungal-to-bacterial ratio and CO₂ of microbial community in forest soils. *Soil Biol. Biochem.* 30: pp. 1269-1274.
- Blair, G.J., R.D.B. Lefroy, and L. Lisle, 1995. Soil carbon fractions based on their degree of oxidation, and the development of a carbon management index for agricultural systems. *Australian Journal of Soil Research*. 46: pp. 1459-1466.
- Blanco-Canqui, H., and R. Lal. 2004. Mechanisms of carbon sequestration in soil aggregates. *Crit. Rev. Plant Sci.* 23: pp. 481-504.
- Blanco-Canqui, H., and R. Lal. 2008. No-tillage and soil profile carbon sequestration: An on-farm assessment. *Soil Sci. Soc. Am. J.* 72: pp. 693-701.
- Blodau, C. 2002. Carbon cycling in peatlands-A review of processes and controls. *Environ. Rev.* 10: pp. 111-134.
- Böhm, C., D. Landgraf and F. Makeschin, 2010. Changes in total and labile carbon and nitrogen contents in a sandy soil after the conversion of a succession fallow to cultivated land. *Journal of Plant Nutrition and Soil Science*. 173(1) : pp. 46-54.
- Bol, R., J. Moering, Y. Kuzyakov, and W. Amelung. 2003. Quantification of priming and CO₂ respiration sources following slurry-C incorporation into two

- grassland soils with different C content. *Rapid Commun. Mass Spectrom.* 17: pp. 2585-2590.
- Bormann, B.T., K. Cromack, and W.O. Russell. 1994. Influences of alder on soils and long-term productivity. In D. Hibbs et al. (ed.) *Biology and management of alder*. Oregon State Univ. Press, Corvallis pp. 47–56.
- Bouycous, G. J. 1962. Hydrometer methods improves for making particle size analysis of soils. *Agronomy. Journal.* 54: pp. 464-465.
- Bowen, C.K., G.E. Schuman, R.A. Olson, and L.J. Ingram. 2005. Influence of topsoil depth on plant and soil attributes of 24-year old reclaimed mined lands. *Arid Land Res. Manage.* 19: pp. 267-284.
- Bowman, R.A., J.D. Reeder, and R.W. Lober. 1990. Changes in soil properties in a Central Plains rangeland soil after 3, 20, and 60 years of cultivation. *Geoderma* 13: pp. 16–28.
- Bowman, R.A., M.F. Vigil, D.C. Nielsen, and R.L. Anderson. 1999. Soil organic matter changes in intensively cropped dryland systems. *Soil Sci. Soc. Am. J.* 63: pp. 186-191.
- Boyle, J.R., and R.F. Powers (ed.). 2001. *Forest soils and ecosystem sustainability: Selected and edited papers from the N. Am. For. Soils Conf., 9th, Tahoe City, CA. 9–14 Aug. 1998.* Elsevier, Amsterdam.
- Boyle, M., W.T. Frankenberger, Jr., and L.H. Stolzy. 1989. The influence of organic matter on soil aggregation and water infiltration. *J. Prod. Agric.* 2: pp. 290-299.
- Bradley, R.I., R. Milne, J. Bell, A. Lilly, C. Jordan, and A. Higgins. 2005. A soil carbon and land use database for the United Kingdom. *Soil Use Manage.* 21: pp. 363-369. doi:10.1079/SUM2005351
- Brady, N.C., and R.R. Weil. 1996. *The nature and properties of soils.* 11th ed. Prentice Hall, Upper Saddle River, NJ.
- Bray, R. H. and Kurtz, L. P. 1945. Determination of total, organic and available forms of phosphorus in soils. *Soil Science.* 59 : pp. 39-45.
- Bremner, J. M. and C. S. Mulvaney. 1982. Nitrogen - Total in A. L. Page *et al.* (ed.). *Methods of Soil Analysis Part 2. Chemical and Microbiological Properties: Am. Soc. Agron., Madison, Wisconsin* pp. 711-733.

- Breuer, L., J.A. Huisman, T. Keller, and H.G. Frede. 2006. Impact of a conversion from cropland to grassland on C and N storage and related soil properties: Analysis of a 60-year chronosequence. *Geoderma* 133: pp. 6–18.
- Bronick, C.J., and R. Lal. 2005. Manuring and rotation effects on soil organic carbon concentration for different aggregate size fractions on two soils in northeastern Ohio, USA. *Soil Tillage Res.* 81: pp. 239–252.
- Bruce, J.P., M. Frome, E. Haites, H. Janzen, and R. Lal. 1999. Carbon sequestration in soils. *J. Soil Water Conserv.* 54: pp. 382-389.
- Brye, K.R., and C.J. Kucharik. 2003. Carbon and nitrogen sequestration in two prairie topochronosequences on contrasting soils in southern Wisconsin. *Am. Midl. Nat.* 149: pp. 90-103.
- Buchmann, N. 2000. Biotic and abiotic factors controlling soil respiration rates in *Picea abies* stands. *Soil Biol. Biochem.* 32: pp.1625-35.
- Burney, J.A., S.J. Davis, and D.B. Lobell. 2010. Greenhouse gas mitigation by agricultural intensification. *Proc. Natl. Acad. Sci. USA* 107: pp. 12052-12057. doi:10.1073/pnas.0914216107
- Cai, L. Z.; X. D. Ying, F. M. Yi, S. X. Zhong, X. J. Rong, 2007. Effects of land-use change on vertical distribution and storage of soil organic carbon in north subtropical areas. *Forest Research, Beijing*, 20(6) : 744-749.
- Caldeira, K., M.G. Morgan, D. Baldocchi, P.G. Brewer, C.A. Chen, G. Nabuurs, N. Nakicenovic, and G.P. Robertson. 2004. A portfolio of carbon management options. In C.B. Field and M.R. Raupach (ed.) *The global carbon cycle*. Island Press, Washington, DC pp. 103–128.
- Calderon, F.J., and L. Jackson. 2002. Rototillage, disking, and subsequent irrigation: Effects on soil nitrogen dynamics, microbial biomass, and carbon dioxide efflux. *J. Environ. Qual.* 31: pp. 752-758.
- Cambardella, C.A., A.M. Gajda, J.W. Doran, B.J. Wienhold, and T.A. Kettler. 2001. Estimation of particulate and total organic matter by weight loss-on-ignition. In R. Lal et al. (ed.) *Assessment methods for soil carbon*. Lewis Publ., Boca Raton, FL p. 349-359.

- Cambardella, C.A., and E.T. Elliott. 1992. Particulate soil organic-matter changes across a grassland cultivation sequence. *Soil Sci. Soc. Am. J.* 56: pp. 777-783.
- Cambardella, C.A., and E.T. Elliott. 1993. Carbon and nitrogen distribution in aggregates from cultivated and native grassland soils. *Soil Sci. Soc. Am. J.* 57: pp. 1071-1076.
- Campbell, C.A., and R.P. Zentner. 1993. Soil organic matter as influenced by crop rotations and fertilization. *Soil Sci. Soc. Am. J.* 57: pp. 1034-1040.
- Campbell, C.A., B.G. McConkey, R.P. Zentner, F.B. Dyck, F. Selles, and D. Curtin. 1995. Carbon sequestration in a Brown Chernozem as affected by tillage and rotation. *Can. J. Soil Sci.* 75: pp. 449-458.
- Campbell, C.A., B.G. McConkey, V.O. Biederbeck, R.P. Zentner, S. Tessier, and D.L. Hahn. 1997. Tillage and fallow frequency effects on selected soil quality attributes in a coarse-textured Brown Chernozem. *Can. J. Soil Sci.* 77: pp. 497-505.
- Carbon Dioxide Information Analysis Center. 2008. Atmospheric CO₂ records from sites in the SIO air sampling network. Available at cdiac.esd.ornl.gov/trends/co2/sio-keel.html (verified 15 Nov. 2008). CDIAC, Oak Ridge, TN.
- Carter, M.R. 2002. Soil quality for sustainable land management: Organic matter and aggregation interactions that maintain soil functions. *Agron. J.* 94: pp. 38-47.
- Carter, M.R. 2005. Long-term tillage effects on cool-season soybean in rotation with barley, soil properties and carbon and nitrogen storage for fine sandy loams in the humid climate of Atlantic Canada. *Soil Tillage Res.* 81: pp. 109-120.
- Cerri, C.E.P., M. Easter, K. Paustian, K. Killian, K. Coleman, M. Bernoux, P. Falloon, D.S. Powlson, N.H. Batjes, E. Milne, and C.C. Cerri. 2007. Predicted soil organic carbon stocks and changes in the Brazilian Amazon between 2000 and 2030. *Agric. Ecosyst. Environ.* 122: pp. 58-72. doi:10.1016/j.agee.2007.01.008
- Chan, K. Y., A. Bowman, and A. Oates, 2001. Oxidizable organic carbon fractions and soil quality changes in an Oxic Paleustalf under different pasture leys. *Soil Science.* 166: pp. 61-67.

- Chao, C. G.; H. Z. Li, 2003. Effect of land use on microbial biomass-C, -N and -P in red soils. *Journal of Zhejiang University (Science)*. 4 (4) : pp. 480-484.
- Chapman, S. K., R. U. Palanivel, J. A. Langley. 2012. Soil Carbon Stability Responds to Land-Use and Groundcover Management in Southern Appalachian Cultivated lands. *Soil Sci. Soc. Am. J.* 76: pp. 2221-2229.
- Chattopadhyay, T., S. K. Reza, D. J. Nath, U. Baruah and Dipak Sarkar, 2012. Effect of land use on soil microbial biomass carbon and nitrogen content in the soils of Jorhat district, Assam. *Agropedology*. 22(2) : pp. 119-122.
- Chen D. D., S. H. Zhang, S. K. Dong, X. T. Wang, G. Z. Du. 2010. Effect of land-use on soil nutrients and microbial biomass of an alpine region on the northeastern Tibetan plateau, China. *Land Degradation & Development*. 21(5): pp. 446-452.
- Chen, D. D.; S. H. Zhang, S. K. Dong, X. T. Wang, G. Z. Du, 2010. Effect of land-use on soil nutrients and microbial biomass of an alpine region on the north eastern Tibetan plateau, China. *Land Degradation & Development*. 21(5) : pp. 446-452.
- Chenu, C., Y. LeBissonnais, and D. Arrouays. 2000. Organic matter influence on clay wettability and soil aggregate stability. *Soil Sci. Soc. Am. J.* 64: pp. 1479-1486.
- Chevallier, T., E. Blanchart, A. Albrecht, and C. Feller. 2004. The physical protection of soil organic carbon in aggregates: A mechanism of carbon storage in a Vertisol under pasture and marketgardening (Martinique, West Indies). *Agric. Ecol. Environ.* 103: pp. 375-387.
- Chhabra, A., S. Patria, and V. K. Dadhwal, 2003. Soil organic carbon pool in Indian forests. *Forest Ecological Management*. 173: pp. 187-199.
- Choi, Y., and Y. Wang. 2004. Dynamics of carbon sequestration in a coastal wetland using radiocarbon measurements. *Global Biogeochem. Cycles* 18(4): GB4016, doi:10.1029/2004GB002261.
- Christensen, B.T. 2001. Physical fractionation of soil and structural and functional complexity in organic matter turnover. *Eur. J. Soil Sci.* 52: pp. 345–353.

- Christopher, S.F., and R. Lal. 2007. Nitrogen management affects carbon sequestration in North American cropland soils. *Crc. Crit. Rev. Plant Sci.* 26: pp. 45-64.
- Chung, H., K. J. Ngo, A. Plante, J. Six. 2010. Evidence for Carbon Saturation in a Highly Structured and Organic-Matter-Rich Soil. *Soil Sci. Soc. Am. J.* 74: pp. 130-138.
- Coleman, D.C., R. Andrews, J.E. Ellis, and J.S. Singh. 1976. Energy flow and partition in selected managed and natural ecosystems. *Agro-Ecosystems*, 3: pp.45-54.
- Collins, H.P., E.T. Elliott, K. Paustian, L.C. Bundy, W.A. Dick, D.R. Huggins, A.J.M. Smucker, and E.A. Paul. 2000. Soil carbon pools and fluxes in long-term corn belt cultivated lands. *Soil Biol. Biochem.* 32: pp. 157-168.
- Compton, J.E., and R.D. Boone. 2000. Long-term impacts of agriculture on soil carbon and nitrogen in New England forests. *Ecology*. 81: pp. 2314-2330.
- Costa, F. S., Bayer, C., Albuquerque, J. A. and Fontoura, S. M. V. 2004. Aumento de matéria orgânica num Latossolo Bruno em plantio direto. *Ci. Rural*. 34: pp. 587-589.
- Curtin, D., H. Wang, F. Selles, B.G. McConkey, and C.A. Campbell. 2000. Tillage effects on carbon fluxes in continuous wheat and fallow-wheat rotations. *Soil Sci. Soc. Am. J.* 64: pp. 2080-2086.
- Dadhwal, V.K. and Nayak, S.R. 1993. Preliminary estimate of biogeochemical cycle of carbon for India. *Science and Culture*. 59: pp. 9-13.
- Davidson, E.A., and I.L. Ackerman. 1993. Changes in soil carbon inventories following cultivation of previously untilled soils. *Biogeochemistry*. 20: pp.161–193.
- Davis, A., M.H. Stolt, and J.E. Compton. 2004. Spatial distribution of soil carbon in southern New England hardwood forest landscapes. *Soil Sci. Soc. Am. J.* 68: pp. 895-903.
- de Koning, G. H. J., Veldkamp, E. and Lopez-Ulloa, M. 2003. Quantification of carbon sequestration in soils following pasture to forest conversion in northwestern Ecuador. *Global Biogeochem. Cycles*. 17: 1098, doi:10.1029/2003GB002099.

- de Moraes Sa, J. C., J. B. dos Santos, R. Lal, A. de Moraes, F. Tivet, M. F. Machado Sa, C. Briedis, A. de Oliveira Ferreira, G. Eurich, A. Farias, T. Friedrich. 2013. Soil-Specific Inventories of Landscape Carbon and Nitrogen Stocks under No-Till and Native Vegetation to Estimate Carbon Offset in a Subtropical Ecosystem. *Soil Sci. Soc. Am. J.* 77: pp. 2094-2110.
- Deen, W. and P.K. Kataki. 2003. Carbon sequestration in a long-term conventional versus conservation tillage experiment. *Soil Tillage Res.* 74: pp. 143-150.
- Denef, K., J. Six, R. Merckx, and K. Paustian. 2004. Carbon sequestration in microaggregates of no-tillage soils with different clay mineralogy. *Soil Sci. Soc. Am. J.* 68: pp. 1935-1944.
- Diaz, S. M., J.L. Garcia, M.C. Antolin and J.L. Araus 2002. Effects of Soil Drought and Atmospheric Humidity on Yield, Gas Exchange, and Stable Carbon Isotope Composition of Barley, *Springer*.
- Dick, W.A. 1983. Organic carbon, nitrogen, and phosphorus concentrations and pH in soil profiles as affected by tillage intensity. *Soil Sci. Soc. Am. J.* 47: pp. 102-107.
- Dick, W.A., R.L. Blevins, W.W. Frye, S.E. Peters, D.R. Christenson, F.J. Pierce, and M.L. Vitosh. 1998. Impacts of agricultural management practices on C sequestration in forest-derived soils of the eastern Corn Belt. *Soil Tillage Res.* 47: pp. 235-244.
- Dolan, M.S., C.E. Clapp, R.R. Allmaras, J.T. Baker, and J.A. Molina. 2006. Soil organic carbon and nitrogen in a Minnesota soil as related to tillage, residue and nitrogen management. *Soil Tillage Res.* 89: pp. 221-231.
- Doran, J. W., E. T. Elliott and K. Paustian, 1999. Soil microbial activity, nitrogen cycling, and long-term changes in organic carbon pools as related to fallow tillage management. *Soil & Tillage Research.* 49(1/2) : pp. 3-18.
- Doran, J.W., E.T. Elliott, and K. Paustian. 1998. Soil microbial activity, nitrogen cycling, and long-term changes in organic carbon pools as related to fallow tillage management. *Soil Tillage Res.* 49: pp. 3-18.
- Doyle, G.L., C.W. Rice, D.E. Peterson, and J. Steichen. 2004. Biologically defined soil organic matter pools as affected by rotation and tillage. *Environ. Manage.* 33: pp. S528-S538. doi:10.1007/s00267-003-9160-z

- Du, Z., T. Ren and C. Hu. 2010. Tillage and Residue Removal Effects on Soil Carbon and Nitrogen Storage in the North China Plain. *Soil Sci. Soc. Am. J.* 74: pp. 196-202.
- enriched compost on yield and nutrient uptake of rice (*Oryza sativa L.*). *European*
- Entry, J.A., R.E. Sojka and G.E. Shewmaker. 2002. Management of irrigated agriculture to increase organic carbon storage in soils. *Soil Sci. Soc. Am. J.* 66: pp. 1957-1964.
- Entry, J.A., R.E. Sojka, and G.E. Shewmaker. 2004. Irrigation increases inorganic carbon in agricultural soils. *Environ. Manage.* 33: pp. S309-S317.
- Eswaran, H., E. Van den Berg, and P. Reich. 1993. Organic carbon in soils of the world. *Soil Sci. Soc. Am. J.* 57: pp. 192–194.
- Fabrizzi, K.P., A. Moron, and F.O. Garcia. 2003. Soil carbon and nitrogen organic fractions in degraded vs. non-degraded Mollisols in Argentina. *Soil Sci. Soc. Am. J.* 67: pp. 1831-1841.
- Farahani, H.J., G.A. Peterson, and D.G. Westfall. 1998. Dryland cropping intensification: A fundamental solution to efficient use of precipitation. *Adv. Agron.* 64: pp. 197-223.
- Fei, W. H.; J. X. Yong, G. Bing, H. Tao, S. Fang and J. X. Tang 2013. Response of greenhouse gas emission to application of carbon and nitrogen in soils different in land use. *Acta Pedologica Sinica.* 50(6) : pp. 1172-1182
- Feigl, B. J., J. Melillo, and C. C. Cerri, 1995. Changes in the origin and quality of soil organic matter after pasture introduction in Rondonia (Brazil). *Plant and Soil.* 175: pp. 21-29.
- Ferris, H. 2005. Carbon channels and food web structure. *J. Nematol.* 37: pp. 369 (abstr.).
- Fidalgo, E.C.C., V.M. Benites, P.L.O.A. Machado, B.E. Madari, M.R. Coelho, I.B. Moura, and C.X. Lima. 2007. Carbon stock in Brazilian soils. (In Portuguese.) Boletim de Pesquisae Desenvolvimento, Embrapa, Centro Nacional de Pesquisa de Solos. Rio de Janeiro, RJ, Brazil.
- Fontana, M., A. Berner, P. Mäder, F. Lamy, P.I. Boivin. 2015. Soil Organic Carbon and Soil Bio-Physicochemical Properties as Co-Influenced by Tillage Treatment. *Soil Sci. Soc. Am. J.* 79: pp. 1435-1445.

- Franchini, J.C., C.C. Crispino, R.A. Souza, E. Torres, and M. Hungria. 2007. Microbiological parameters as indicators of soil quality under various soil management and crop rotation systems in southern Brazil. *Soil Tillage Res.* 92: pp. 18-29. doi:10.1016/j. still.2005.12.010
- Francioso, O., C. Ciavatta, S. Sanchez-Cortes, V. Tugnoli, L. Sitti, and C. Gessa. 2000. Spectroscopic characterization of soil organic matter in long-term amendment trials. *Soil Sci.* 165: pp. 495-504.
- Frank, A.B., M.A. Liebig, and D.L. Tanaka. 2006. Management effects on soil CO₂ efflux in northern semiarid grassland and cropland. *Soil Tillage Res.* 89: pp. 78-85.
- Franzluebbers, A. J. and J. A. Stuedemann, 2002. Particulate and non-particulate fractions of soil organic carbon under pastures in the Southern Piedmont USA. *Environ. Poll.* 116: pp. 553-562.
- Franzluebbers, A.J. 2002a. Soil organic matter stratification ratio as an indicator of soil quality. *Soil Tillage Res.*, 66: pp. 95-106.
- Franzluebbers, A.J., F.M. Hons, and D.A. Zuberer. 1995. Soil organic carbon, microbial biomass, and mineralizable carbon and nitrogen in sorghum. *Soil Sci. Soc. Am. J.* 59: pp. 460-466.
- Franzluebbers, A.J., F.M. Hons, and D.A. Zuberer. 1995. Tillage and crop effects on seasonal dynamics of soil CO₂ evolution, water content, temperature, and bulk density. *Appl. Soil Ecol.* 2: pp. 95-109.
- Franzluebbers, A.J., G.W. Langdale, and H.H. Schomberg. 1999. Soil carbon, nitrogen, and aggregation in response to type and frequency of tillage. *Soil Sci. Soc. Am. J.* 63: pp. 349-355.
- Franzluebbers, A.J., J.A. Stuedemann, H.H. Schomberg, and S.R. Wilkinson. 2000a. Soil organic C and N fractions under long-term pasture management in the Southern Piedmont USA. *Soil Biol. Biochem.* 32: pp. 469-478.
- Freibauer, A., M.D.A. Rounsevell, P. Smith, and J. Verhagen. 2004. Carbon sequestration in the agricultural soils of Europe. *Geoderma.* 122: pp. 1-23.
- Freibauer, A., M.D.A. Rounsevell, P. Smith, and J. Verhagen. 2004. Carbon sequestration in the agricultural soils of Europe. *Geoderma.* 122: pp. 1–23.

- Fu, S., D.C. Coleman, R. Schartz, R. Potter, P.F. Hendrix, and D.A. Crossley. 2000. ^{14}C distribution in soil organisms and respiration after the decomposition of crop residue in conventional tillage and no-till cultivated lands at Georgia Piedmont. *Soil Tillage Res.* 57: pp. 31-41.
- Fung, I.Y., S.C. Doney, K. Lindsay, and J. John. 2005. Evolution of carbon sinks in a changing climate. *Proc. Natl. Acad. Sci.* 102: pp. 11201-11206.
- Gale, W.J. and C.A. Cambardella. 2000. Carbon dynamics of surface residue- and root-derived organic matter under simulated no-till. *Soil Sci. Soc. Am. J.* 64: pp. 190-195.
- Gale, W.J., C.A. Cambardella, and T.B. Bailey. 2000a. Surface residue- and root-derived carbon in stable and unstable aggregates. *Soil Sci. Soc. Am. J.* 64: pp. 196-201.
- Gale, W.J., C.A. Cambardella, and T.B. Bailey. 2000b. Root-derived carbon and the formation and stabilization of aggregates. *Soil Sci. Soc. Am. J.* 64: pp. 201-207.
- Gami, S.K., J.K. Ladha, H. Pathak, M.P. Shah, E. Pasuquin, S.P. Pandey, P.R. Hobbs, D. Joshy, and R. Mishra. 2001. Long-term changes in yield and soil fertility in a twenty-year rice–wheat experiment in Nepal. *Biol. Fertil. Soils*, 34: pp. 73-78.
- Gang, Y. D., Y. D. Dong, P.G. Lan, Z. Qian, C. Xuan, P. Wei, S. Jian, X.S. Ying, L. J. Zhi, 2013. Fertility dynamics of three types of tea garden soils in western Sichuan, China. *Pakistan Journal of Agricultural Sciences*. 50(1) : pp. 29-35.
- Garcia, R. A., Y. Li and C. A. Rosolem. 2013. Soil Organic Matter and Physical Attributes Affected by Crop Rotation Under No-till. *Soil Sci. Soc. Am. J.* 77: pp. 1724-1731.
- Ghani, A., M. Dexter, and K. W. Perrott, 2003. Hot-water extractable carbon in soils: a sensitive measurement for determining impacts of fertilization, grazing, and cultivation. *Soil Biol. Biochem.* 35: pp. 1231-1243.
- Giardina, C. P., M. G. Ryan, R. M. Hubbard, and D. Binkley, 2001. Tree species and soil textural controls on carbon and nitrogen mineralization rates. *Soil Science Society of America Journal*. 65: pp. 1272-9.

- Giardina, C.P., D. Binkley, M.G. Ryan, J.H. Fownes and R.S. Senock. 2004. Belowground carbon cycling in a humid tropical forest decreases with fertilization. *Oecologia* 139: pp. 545-550.
- Giardina, C.P., K.C. Ryan, D. Binkley, and J.H. Fownes. 2003. Primary production and carbon allocation in relation to nutrient supply in a tropical experimental forest. *Glob. Change Biol.* 9: 1438-1450.
- Goh, K.M. 2004. Carbon sequestration and stabilization in soils: Implications for soil productivity and climate change. *Soil Sci. Plant Nutr.* 50: pp. 467-476.
- Goidts, E. and B. van Wesemael. 2007. Regional assessment of soil organic carbon changes under agriculture in Southern Belgium (1955–2005). *Geoderma*. 141: pp. 341-354.
- Gower, S.T., K.A. Vogt, and C.C. Grier. 1992. Carbon dynamics of rocky mountain Douglas-fir: Influence of water and nutrient availability. *Ecol. Monogr.* 62: pp. 43-65.
- Grace, P.R., M. Colunga-Garcia, S.H. Gage, G.P. Robertson, and G.R. Safi R. 2006. The potential impact of agricultural management and climate change on soil organic carbon of the North Central Region of the United States. *Ecosystems*. 9: pp. 816-827.
- Gray, J. M., T. F.A. Bishop, B. R. Wilson. 2016. Factors Controlling Soil Organic Carbon Stocks with Depth in Eastern Australia. *Soil Sci. Soc. Am. J.* 79: pp. 1741-1751.
- Gregorich E.G. and M. H. Beare. 2007. Physically uncompleased organic matter in soil sampling and method of analysis, 2nd Edn., Canadian Society of Soil Science, CRS Press – Taylor and Francis Group, pp. 607-616.
- Gregorich, E. G. and M. R. Carter. 1997. Soil quality for crop production and ecosystem health. *Dev. Soil Sci.*, Vol. 25. Elsevier, New York.
- Vieira, F. C. B., Bayer, C., Zanatta, J. A., Dieckow, J., Mielniczuk, J. and He, Z. L. 2007.
- Gregorich, E.G., M.R. Carter, D.A. Angers, C.M. Monreal, and B.H. Ellert. 1994. Towards a minimum data set to assess soil organic matter quality in agricultural soils. *Can. J. Soil Sci.* 74: pp. 367-385.

- Grunwald, S. 2008. Role of soils to sequester carbon. In S. Mulkey *et al.* (ed.) Opportunities for greenhouse gas reduction through forestry and agriculture in Florida. School of Nat. Resour. and Environ., Univ. of Florida, Gainesville.
- Gulde, S., H. Chung, W. Amelung, C. Chang, and J. Six. 2008. Soil carbon saturation controls labile and stable carbon pool dynamics. *Soil Sci. Soc. Am. J.* 72: pp. 605-612. doi:10.2136/sssaj2007.0251
- Guo, L.B., and R.M. Gifford. 2002. Soil carbon stocks and land use change: Meta analysis. *Global Change Biol.* 8: pp. 345-360.
- Haile-Mariam, S., W. Cheng, D.W. Johnson, J.T. Ball, and E.A. Paul. 2000. Use of carbon-13 and carbon-14 to measure the effects of carbon dioxide and nitrogen fertilization on carbon dynamics in ponderosa pine. *Soil Sci. Soc. Am. J.* 64: pp. 1984-1993.
- Halpern, M. T., J. K. Whalen, C. A. Madramootoo. 2010. Long-Term Tillage and Residue Management Influences Soil Carbon and Nitrogen Dynamics. *Soil Sci. Soc. Am. J.* 74: pp. 1211-1217.
- Halvorson, A.D., B.J. Weinhold, and A.L. Black. 2002. Tillage, nitrogen, and cropping system effects on soil carbon sequestration. *Soil Sci. Soc. Am. J.* 66: pp. 906-912.
- Hamer, U., and B. Marschner. 2002. Priming effects of sugars, amino acids, organic acids and catechol on the mineralization of lignin and peat. *J. Plant Nutr. Soil Sci.* 165: pp. 261-268.
- Handbook of Soil Analysis - Mineralogical, Organic and Inorganic Methods by Marc Pansu and Jacques Gautheyrou, Springer International Edition, 2003.
- Hansen, J., M. Sato, R. Ruedy, A. Lacis, and V. Oinas. 2000. Global warming in the twenty-first century: An alternative scenario. *Proc. Natl. Acad. Sci.*
- Hanway, J. J. and H. Heidel, 1952. Soil analysis methods as used in Iowa State College Soil testing Laboratory. *Iowa Agric.*, 57: pp. 1-31.
- Hao, X., C. Chang, and C.W. Lindewall. 2001. Tillage and crop sequence effect on organic carbon and total nitrogen content in an irrigated Alberta soil. *Soil Tillage Res.* 62: pp. 167-169.

- Haripal, K; S. Sahoo, 2014 Microbial biomass carbon, nitrogen, and phosphorus dynamics along a chronosequence of abandoned tropical cultivated lands. *International Journal of Current Microbiology and Applied Sciences*. 3(9) : pp. 956-970.
- Harper, C. W., J. M. Blair, P. A. Fay, A. K. Knapp, and J. D. Carlisle. 2005. Increased rainfall variability and reduced rainfall amount decreases soil CO₂ flux in a grassland ecosystem. *Global Change Biology*. 11: pp. 322-334.
- Hartemink, A.E. 2008. Soil map density and a nation's wealth and income. In: A.E. Hartemink et al., editors, Digital soil mapping with limited data. Springer, New York, pp. 53–66.
- Hassink, J. 1997. The capacity of soils to preserve organic C and N by their association with clay and silt particles. *Plant Soil*. 191: pp. 77-87.
- Hassink, J. and A.P. Whitmore. 1997. A model of the physical protection of organic matter in soils. *Soil Sci. Soc. Am. J.* 61: pp. 131-139.
- Haynes, B.E., and S.T. Gower. 1995. Belowground carbon allocation in unfertilized and fertilized red pine plantations in northern Wisconsin. *Tree Physiol.* 15: pp. 317-325.
- Haynes, R.J. 2005. Labile organic matter fractions as central components of the quality of agricultural soils: An overview. *Adv. Agron.* 85: pp. 221-268.
- Helling, C.S., G. Chesters, and R.B. Corey. 1964. Contribution of organic matter and clay to soil cation-exchange capacity as affected by the pH of the saturating solution. *Soil Sci. Soc. Am. Proc.* 28: pp. 517-519.
- Högberg, P., and D.J. Read. 2006. Towards a more plant physiological perspective on soil ecology. *Trends Ecol. Evol.* 21: pp. 548-554.
- Houghton, R. A. 2003. Revised estimates of the annual net flux of carbon to the atmosphere from changes in land use and land management 1850-2000. *Tellus*. 55B: pp. 378-390.
- Howard, D. M. and P.J.A. Howard, 1993. Relationships between CO₂ evolution, moisture content and temperature for a range of soil types. *Soil Biol. Biochem.* 25: pp. 1537-1546.
- Hudson, B.D. 1994. Soil organic matter and available water capacity. *J. Soil Water Conserv.* 49: pp. 189-194.

- Hue, N.V., G.R. Craddock, and F. Adams. 1986. Effect of organic acids on aluminum toxicity in subsoils. *Soil Sci. Soc. Am. J.* 50: pp. 28-34.
- Huggins, D.R., G.A. Buyanovsky, G.H. Wagner, J.R. Brown, R.G. Darmody, T.R. Peck, G.W. Lesoing, M.B. Vanotti, and L.G. Bundy. 1998a. Soil organic C in the tallgrass prairie-derived region of the Corn Belt: Effects of long-term crop management. *Soil Tillage Res.* 47: pp. 219-234.
- Huggins, D.R., R.R. Allmaras, C.E. Clapp, J.A. Lamb, and G.W. Randall. 2007. Cornsoybean sequence and tillage effects on soil carbon dynamics and storage. *Soil Sci. Soc. Am. J.* 71 : pp. 145-154. doi:10.2136/sssaj2005.0231
- Hunt, P.G., D.L. Karlen, T.A. Matheny, and V.L. Quisenberry. 1996. Changes in carbon content of a Norfolk loamy sand after 14 years of conservation or conventional tillage. *J. Soil Water Conserv.* 51: pp. 255-258.
- Ingram, J.S.I. and E.C.M. Fernandes, 2001. Managing carbon sequestration in soils: concepts and terminology. *Agriculture, Ecosystems and Environment.* 87: pp. 111-117.
- Intergovernmental Panel on Climate Change. 1996. Climate change: 1995. The science of climate change. Cambridge Univ. Press, Cambridge, UK.
- Islam, K.R., and R.R. Weil. 2000. Soil quality indicator properties in mid Atlantic soils as influenced by conservation management. *J. Soil Water Conserv.* 55: pp. 69-78.
- Ismail, I., R.L. Blevins, and W.W. Frye. 1994. Long-term no tillage effects on soil properties and continuous corn yields. *Soil Sci. Soc. Am. J.* 58: pp. 193-198.
- Izaurrealde, R.C. 2005. Measuring and monitoring soil carbon sequestration at the project level. p. 467–500. In R. Lal et al. (ed.) Climate change and global food security. *Taylor & Francis, New York. J.* 63: pp. 1350-1358.
- Jacinthe, P.A., and R. Lal. 2005. Labile carbon and methane uptake as affected by tillage intensity in a Mollisol. *Soil Tillage Res.* 80: pp. 35-45.
- Jackson, L.E., F.J. Calderon, K.L. Stenwerth, K.M. Scow, and D.E. Rolston. 2003. Responses of soil microbial processes and community structure to tillage events and implications for soil quality. *Geoderma.* 114: pp. 305-317.

- Jackson, M. L. 1973. Soil chemical analysis, Prentice Hall of India, Pvt. Ltd., New Delhi.
- Jackson, R.B., J. Canadell, J.R. Ehleringer, H.A. Mooney, O.E. Sala, and E.D. Schulze. 1996. A global analysis of root distributions for terrestrial biomes. *Oecologia*. 108: pp. 389-411.
- Jandl, R., M. Lindner, L. Vesterdal, B. Bauwens, R. Baritz, F. Hagedorn, *et al.* 2007. How strongly can forest management influence soil carbon sequestration? *Geoderma*. 137: pp. 253-268. doi:10.1016/j.geoderma.2006.09.003.
- Janzen, H.H. 2006. The soil carbon dilemma: Shall we hoard it or use it? *Soil Biol. Biochem.* 38: pp. 419-424.
- Jastrow, J.D., J.E. Amonette, and V.L. Bailey. 2007. Mechanisms controlling soil carbon turnover and their potential application for enhancing carbon sequestration. *Clim. Change*. 80: pp. 5-23.
- Jastrow, J.D., T.W. Boutton, and R.M. Miller. 1996. Carbon dynamics of aggregate associated organic matter estimated by carbon-13 natural abundance. *Soil Sci. Soc. Am. J.* 60: pp. 801-807.
- Jenkinson, D.S. 1991. The Rothamsted long-term experiments: Are they still of use? *Agron. J.* 83: pp. 2-10.
- Jenny, H. and Raychaudhury, S.P. 1960. Effect of climate and cultivation on nitrogen and organic matter reserves in Indian soils. Indian Council of Agricultural Research. New Delhi, pp 1-125.
- Jobbagy, E.G., and R.B. Jackson. 2000. The vertical distribution of soil organic carbon and its relation to climate and vegetation. *Ecol. Appl.* 10: pp. 423-436.
- Johnson, D.W., and P.S. Curtis. 2001. Effects of forest management on soil C and N storage: Meta analysis. *For. Ecol. Manage.* 140: pp. 227-238.
- Johnson, D.W., J.D. Kloepp, W.T. Swank, J. Shan, L.A. Morris, D.H. Van Lear, and P.R. Kapeluck. 2002. Effects of forest management on soil carbon: Results of some long-term resampling studies. *Environ. Pollut.* 116: pp. S201-S208.
- Johnson, J.M.F., R.R. Allmaras, and D.C. Reicosky. 2006. Estimating source carbon from crop residues, roots and rhizodeposits using the national grain-yield database. *Agron. J.* 98: pp. 622-636. doi:10.2134/agronj2005.0179.

- Johnston, M.H., P.S. Homann, J.K. Engstrom, and D.F. Grigal. 1996. Changes in ecosystem carbon storage over 40 years on an old-field forest landscape in east-central Minnesota. *For. Ecol. Manage.* 83: pp. 17-26.
- Jones, M.B., and A. Donnelly. 2004. Carbon sequestration in temperate grassland ecosystems and the influence of management, climate and elevated CO₂. *New Phytol.* 164: pp. 423.
- Jones, O.R., and T.W. Popham. 1997. Cropping and tillage systems for dryland grain production in the southern High Plains. *Agron. J.* 89: pp. 222-232.
Journal of Biological Sciences. 3(1): 23-29.
- Kaiser, M., R.H. Ellerbrock, and H.H. Gerke. 2007. Long-term effects of fertilization and crop rotation on soil organic matter composition. *Eur. J. Soil Sci.* 58: pp. 1460-1470.
- Kamprath, E.J., and C.D. Welch. 1962. Retention and cation-exchange properties of organic matter in coastal soils. *Soil Sci. Soc. Am. Proc.* 26: pp. 263-268.
- Karlen, D.L., M.J. Mausbach, J.W. Doran, R.G. Cline, R.F. Harris, and G.E. Schuman. 1997. Soil quality: A concept, definition, and framework for evaluation (a guest editorial). *Soil Sci. Soc. Am. J.* 61: pp. 4-10.
doi:10.2136/sssaj1997.03615995006100010001x
- Kay, B.D., and A.J. VandenBygaart. 2002. Conservation tillage and depth stratification of porosity and soil organic matter. *Soil Tillage Res.* 66: pp. 107-118.
- Keeney, D. R. and J.M. Bremner, 1964. Effect on nitrogen distribution in soil of cultivation. *Proc. Soil Sci. Soc. Am.* 28: pp. 653-656.
- Kettler, T.A., J.W. Doran, and T.L. Gilbert. 2001. Simplified method for soil particle-size determination to accompany soil-quality analyses. *Soil Sci. Soc. Am. J.* 65: pp. 849-852.
- Khanna, P.K., B. Ludwig, J. Bauhus, and C. O'Hara. 2001. Assessment and significance of labile organic C pools in forest soils. In R. Lal et al. (ed.) *Assessment methods for soil carbon*. Lewis Publ., Boca Raton, FL, p. 167–182.

- King, J.A., R.I. Bradley, R. Harrison, and A.D. Carter. 2004. Carbon sequestration and saving potential associated with changes to the management of agricultural soils in England. *Soil Use Manage.* 20: pp. 394-402.
- King, J.S., T.J. Albough, H.L. Allen, M. Buford, B.R. Strain, and P. Dougherty. 2002. Below-ground carbon input to soil is controlled by nutrient availability and fine root dynamics in loblolly pine. *New Phytol.* 154: pp. 389-398.
- Knops, J.M.H., and D. Tilman. 2000. Dynamics of soil nitrogen and carbon accumulation for 61 years after agricultural abandonment. *Ecology.* 81: pp. 88-98.
- Knorr, M., S.D. Frey, and P.S. Curtin. 2005. Nitrogen additions and litter decomposition: A meta-analysis. *Ecology.* 86: pp. 3252-3257.
- Kogel-Knabner, I. 2002. The macromolecular organic composition of plant and microbial residues as inputs to soil organic matter. *Soil Biol. Biochem.* 34: pp. 139-162.
- Kolbe, S. E., A. I. Miller, A. Townsend-Small, G. N. Cameron, T. M. Culley. 2016. Impact of Land-Use History and Forest Trees on Soil Organic Carbon and Nitrogen Stocks. *Soil Sci. Soc. Am. J.* 80: pp. 1089-1097.
- Kong, A. Y. Y., J. Six, D.C. Bryant, R.F. Denison, and van Kessel, C. 2005. The Relationship between Carbon Input, Aggregation, and Soil Organic Carbon Stabilization in Sustainable Cropping Systems. *Soil Sci. Soc. Am. J.* 69: pp. 1078-1085.
- Kool, D.M., H. Chung, K.R. Tate, D.J. Ross, P.C.D. Newton, and J. Six. 2007. Hierarchical saturation of soil carbon pools near a natural CO₂ spring. *Global Change Biol.* 13: pp. 1282-1293.
- Kristensen, E. and Holmer, M. 2001. Decomposition of plant materials in marine sediment exposed to different electron acceptors (O₂, NO³⁻, and SO₄⁻²), with emphasis on substrate origin, degradation kinetics, and the role of bioturbation. *Geochem. Cosmochim. Ac.* 65: pp. 419-433.
- Kucharik, C.J. 2007. Impact of prairie age and soil order on carbon and nitrogen sequestration. *Soil Sci. Soc. Am. J.* 71: pp. 430-441.

- Kucharik, C.J., K.R. Brye, J.M. Norman, S.T. Gower, L.G. Bundy, and J.A. Foley. 2001. Measurements and modeling of carbon and nitrogen dynamics in managed and natural ecosystems in southern Wisconsin: Potential for SOC sequestration in the next 50 years. *Ecosystems* (N. Y., Print) 4: pp. 237-258.
- Kurganova, I. N., V. O. L. de Gerenyu, T. N. Myakshina, D. V. Sapronov, V.I. Lichko, A. M. Yermolaev. 2008. Changes in carbon stocks of former croplands in Russia. *Žemės ūkio Mokslai*. 15(4): pp.10-15.
- Ladd, J.N., M. Amato, L.K. Zhou, and J.E. Schultz. 1994. Differential effects of rotation, plant residue and nitrogen fertilizer on microbial biomass and organic matter in an Australian Alfisol. *Soil Biol. Biochem.* 26: 821-831.
- Ladha, J.K., D. Dawe, H. Pathak, A.T. Padre, R.L. Yadav, B. Singh, et al. 2003. How extensive are yield declines in long-term rice–wheat experiments in Asia? *Field Crops Res.* 81:159–180.
- Ladoni, M., A. Basir and A. Kravchenko. 2015. Which Soil Carbon Fraction is the Best for Assessing Management Differences? A Statistical Power Perspective. *Soil Sci. Soc. Am. J.* 79: pp. 848-857.
- Lal, R. 1997. Residue management, conservation tillage and soil restoration for mitigating greenhouse effect by CO₂–enrichment. *Soil Tillage Res.* 43: pp. 81-107.
- Lal, R. 2000. World cropland soils as a source or sink for atmospheric C. *Adv. Agron.* 71: pp. 145-191.
- Lal, R. 2001. World cropland soils as a source or sink for atmospheric carbon. *Adv. Agron.* 71: pp. 146-191.
- Lal, R. 2001a. Soils and the greenhouse gas effect. In R. Lal (ed.) *Soil carbon sequestration and the greenhouse effect*. SSSA Spec. Publ. 57. SSSA, Madison, WI. pp. 1–8
- Lal, R. 2003a. Offsetting global CO₂ emissions by restoration of degraded soils and intensification of world agriculture and forestry. *Land Degrad. Dev.* 14: pp. 309-322.
- Lal, R. 2003b. Soil erosion and the global carbon budget. *Environ. Int.* 29: pp. 437-450.

- Lal, R. 2004. Carbon sequestration in dryland ecosystems. *Environ. Manage.* 33: pp. 528-544.
- Lal, R. 2004. Soil carbon sequestration impacts on global climate change and food security. *Science*. 304: 1623-1627. doi:10.1126/science.1097396
- Lal, R. 2008. Carbon sequestration. *Phil. Trans. R. Soc. B.* 363: pp. 815-830.
- Lal, R., and J.M. Kimble. 1997. Conservation tillage for carbon sequestration. *Nutr. Cycling Agroecosyst.* 49: pp. 243–253.
- Lal, R., and J.M. Kimble. 2000a. Pedogenic carbonate and global carbon cycle. In R. Lal et al (ed.) Global climate and pedogenic carbonates. Lewis Publ., Boca Raton, FL. pp. 1-14.
- Lal, R., and J.M. Kimble. 2000b. Inorganic carbon and global C cycle: Research and development priorities. In R. Lal et al (ed.) Global climate and pedogenic carbonates. Lewis Publ., Boca Raton, FL. pp. 291–302.
- Lal, R., J. Kimble, and R.F. Follett. 1997. Pedospheric processes and the carbon cycle. In: R. Lal, W.H. Blum, C. Valentine, and B.A. Stewart, editors, Methods for Assessment of Soil Degradation. CRC Press, Boca Raton, FL. p. 1–8.
- Lal, R., J.M. Kimble, and B.A. Stewart. 1995. World soils as a source or sink for radiatively-active gases. In R. Lal (ed.) Soil management and greenhouse effect. Adv. Soil Sci. Ser. CRC Press, Boca Raton, FL. pp. 1–8.
- Lal, R., J.M. Kimble, R.F. Follett and Cole, C. V. 1998. The Potential of US Cropland to sequester Carbon and Mitigate the Greenhouse Effect. Ann Arbor Press, Chelsea, MI.
- Landgraf, D., S. Wedig and S. Klose 2005. Medium- and short-term available organic matter, microbial biomass, and enzyme activities in soils under *Pinus sylvestris* L. and *Robinia pseudoacacia* L. in a sandy soil in NE Saxony, Germany. *J. Plant Nutr. Soil Sci. Zeitschrift Fur Pflanzenernahrung Und Bodenkunde* 168: pp. 193-201.
- Lee, J., J. Six, A.P. King, C. van Kessel, and D.E. Rolston. 2006. Tillage and field scale controls on greenhouse gas emissions. *J. Environ. Qual.* 35: pp. 714-725.

- Leon, A.; K. Kohyama, Y. Takata, K. Yagi, Y. Umemiya, T. Ohkura and H. Obara. 2015. Change in soil carbon in response to organic amendments in orchards and tea gardens in Japan. *Geoderma*. Vol. 237/238 pp. 168-175.
- Lettens, S., J. Van Orshoven, B. van Wesemael, and B. Muys. 2004. Soil organic and inorganic carbon contents of landscape units in Belgium derived using data from 1950 to 1970. *Soil Use Manage.* 20: pp. 40-47. doi:10.1079/SUM2003221
- Lettens, S., J. van Orshoven, B. van Wesemael, B. Muys, and D. Perrin. 2005. Soil organic carbon changes in landscape units of Belgium between 1960 and 2000 with reference to 1990. *Global Change Biol.* 11: pp. 2128-2140.
- Li, S. G., J. Asanuma, A. Kotani, W. Eugster, G. Davaa, D. Oyunbaatar, and M. Sugita, 2005. Year-round measurement of net ecosystem CO₂ flux over a montane larch forest in Mongolia. *Journal of Geophysics Research*, 110: D09303, doi: 10. 1029/2004JD-005453.
- Liang, B.C., B.G. McConkey, C.A. Campbell, D. Curtin, G.P. Lafond, S.A. Brandt, and A.P. Moulin. 2004. Total and labile soil organic nitrogen as influenced by crop rotations and tillage in Canadian prairie soils. *Biol. Fertil. Soils*. 39: pp. 249-257. doi:10.1007/s00374-003-0712-4.
- Liebig, M. A., D.L. Tanaka and J.R. Gross. 2010. Fallow Effects on Soil Carbon and Greenhouse Gas Flux in Central North Dakota. *Soil Sci. Soc. Am. J.* 74: pp. 358-365.
- Liebig, M.A., D.L. Tanaka, and B.J. Wienhold. 2004. Tillage and cropping effects on soil quality indicators in the northern Great Plains. *Soil Tillage Res.* 78: pp. 131-141.
- Lilburne, L.R., A.E. Hewitt, and T.W. Webb. 2012. Soil and informatics science combine to develop S-map: A new generation soil information system for New Zealand. *Geoderma*. 170: 232-238. doi:10.1016/j.geoderma.2011.11.012
- Liu, X., S. Wan, B. Su, D. Hui, and Y. Luo. 2002. Response of soil CO₂ efflux to water manipulation in a tallgrass prairie ecosystem. *Plant and Soil*. 240: pp. 213-223.

- Lorenz, K., and R. Lal. 2005. The depth distribution of soil organic carbon in relation to land use and management and the potential of carbon sequestration in subsoil horizons.
- Madgoff, F. and R. Weil. 2004. Soil organic matter management strategies. *In* F. Madgoff and R. Weil (ed.) Soil organic matter in sustainable agriculture. CRC Press, Boca Raton, FL. pp. 45–65.
- Mahrer, A.; V. Hemmati and S.A. Hashemi, 2014. Effect of conversion of forest land to the tea gardens on the organic carbon nitrogen and phosphorus in the soil (case study: north of Iran). *Indian Journal of Fundamental and Applied Life Sciences*. 4(3) : pp. 432-437.
- Maier, M., H. Schack-Kirchner, E.E. Hildebrand, and Schindler, D. 2011. Soil CO₂ efflux vs. soil respiration. Implications for flux models, *Agr. Forest. Meteorol.*, 151 : pp. 1723-1730, doi:10.1016/j.agrformet.2011.07.006 .
- Majumder B., B. Mandal, P.K. Bandyopadhyay, A. Gangopadhyay, P. K. Mani, A.L. Kundu, and D. Mazumdar, 2008. Organic Amendments Influence Soil Organic Carbon Pools and Rice-Wheat Productivity. *Soil Sci. Soc. Am. J.* 72: pp. 775-785.
- Majumder, B. 2007. Soil organic carbon pools and biomass productivity under agroecosystems of subtropical India. Ph.D. diss. Jadavpur Univ., Calcutta.
- Manlay, R., C. Feller, and M.J. Swift. 2007. Historical evolution of soil organic matter concepts and their relationships with the fertility and sustainability of cropping systems. *Agric. Ecosyst. Environ.* 119: pp.217-233.
- Marriott, E.E., and M.M. Wander. 2006a. Total and labile soil organic matter in organic and conventional farming systems. *Soil Sci. Soc. Am. J.* 70: pp. 950-959. doi:10.2136/sssaj2005.024
- Matamala R., J.D. Jastrow, S.J. Kirt, and T. Vugteveen. 2006. Soil organic carbon at depth in cultivated fields is greater than in native lands on wet mollisols of the U.S. midwest region. *Eos Trans. AGU*, 87(52), Fall Meet. Suppl., Abstract B52A– 03.

- Matamala, R., M.A. Gonzales-Meler, J.D. Jastrow, R.J. Norby, and W.H. Schlesinger. 2003. Impacts of fine root turnover on forest NPP and Soil C sequestration potential *Science*. 302: pp. 1385-1387.
- Mathers, N.J., and Z.H. Xu. 2003. Solid-state ^{13}C NMR spectroscopy: Characterization of soil organic matter under two contrasting residue management regimes in a 2-year-old pine plantation of subtropical Australia. *Geoderma*. 114: pp. 19-31.
- Matthews, H.D., A.J. Weaver, and K.J. Meisner. 2005. Terrestrial carbon cycle dynamics under recent and future climate change. *J. Clim.* 18: pp. 1609-1628.
- McBratney, A.B., I.O.A. Odeh, T.F.A. Bishop, M.S. Dunabar, and T.M. Shatar. 2000. An overview of pedometrical techniques for use in soil survey. *Geoderma*. 97: pp. 293-327.
- McBratney, A.B., M.L. Mendonça Santos, and B. Minasny. 2003. On digital soil mapping. *Geoderma*. 117: pp. 3-52.
- McLauchlan, K. 2006. The nature and longevity of agricultural impacts on soil carbon and nutrients: A review. *Ecosystems* (N.Y., Print) 9: pp. 1364-1382.
- McLauchlan, K.K. and S.E. Hobbie, 2004. Comparison of labile soil organic matter fractionation techniques. *Soil Sci. Soc. Am. J.* 68: pp. 1616-25.
- McVay, K.A., J.A. Budde, K. Fabrizzi, M.M. Mikha, C.W. Rice, A.J. Schlegel, D.E. Peterson, D.W. Sweeney, and C. Thompson. 2006. Management effects on soil physical properties in long-term tillage studies in Kansas. *Soil Sci. Soc. Am. J.* 70: pp. 434-438.
- Meersmans, J., B. van Wesemael, and M. van Molle. 2009. Determining soil organic carbon for agricultural soils: A comparison between the Walkley & Black and the dry combustion methods (north Belgium). *Soil Use Manage.* 25: pp. 346-353. doi:10.1111/j.1475-2743.2009.00242.x
- Melton, F., B. Lobitz, W. Turner, E. Sheffner, and J. Haynes. 2005. Ecological modeling for applied science. *Eos Trans. AGU*. 86: pp. 319.
- Mendelssohn, I. A., B. K. Sorrell, H. Brix, H.H. Schierup, B. Lorenzen, and E. Maltby, 1999. Controls on soil cellulose decomposition along a salinity

- gradient in a phragmites australis wetland in Denmark. *Aquatic Bot.* 64: pp. 381-398.
- Mikha, M., and C.W. Rice. 2004. Tillage and manure effects on soil and aggregate associated carbon and nitrogen. *Soil Sci. Soc. Am. J.* 68: pp. 809-816.
- Mikha, M.M., M.F. Vigil, and J.G. Benjamin. 2013. Long-term tillage impacts on soil aggregation and carbon dynamics under wheat-fallow in the central Great Plains. *Soil Sci. Soc. Am. J.* 77: pp. 594-605. doi:10.2136/sssaj2012.0125.
- Mikha, M.M., M.F. Vigil, M.A. Liebig, R.A. Bowman, B. McConkey, E.J. Deibert, and J.L. Pikul, Jr. 2006. Cropping system influences on soil chemical properties and soil quality in the Great Plains. *Renewable Agric. Food Syst.* 21: pp. 26-35.
- Min, Z.; C.Y. Gen, Y.C. Ping, P.Z. Qiang, F.D. Mei, F. Z. Ping, L.Y., and W.X. Chang, 2013. Dynamic assessments of plant biomass and carbon storage during the production cycle of tea gardens. *Journal of Zhejiang University (Agriculture and Life Sciences)*. 39(6) : 687-694.
- Minasny, B.M., A.B. McBratney, M.L. Mendonca-Santos, I.O.A. Odeh, and B. Guyon. 2006. Prediction and digital mapping of soil carbon storage in the Lower Namoi Valley. *Aust. J. Soil Res.* 44: pp. 223-244.
- Mirsky, S.B., L.E. Lanyon, and B.A. Needelman. 2008. Evaluating soil management using particulate and chemically labile soil organic matter fractions. *Soil Sci. Soc. Am. J.* 72: pp. 180-185. doi:10.2136/sssaj2005.0279
- Mishra U., R. Lal, B. Slater, F. Calhoun, D. Liu, and M.V. Meirvenne. 2007. Predicting Soil Organic Carbon Stock Using Profile Depth Distribution Functions and Ordinary Kriging. *Soil Sci. Soc. Am. J.* 73: pp. 614-621.
- Mishra, P., R. Singh, P.C. Srivastava, and B. Ram, 2009. Effect of continuous cropping and fertilization on zinc fractions and their contribution to plant uptake under Rice-Wheat system. *Journal of the Indian Society of Soil Science.* 57(2) : pp. 167-171.
- Mishra, V.K., R. Saha, and R.K. Singh, 2006. Physical characterization of soils under different land use systems using non-limiting water range as a soil physical index. *Journal of the Indian Society of Soil Science.* 54(2): pp. 146-150.

- Moran, K.K., J. Six, W.R. Horwath, and C. van Kessel. 2005. Role of mineral nitrogen in residue decomposition and stable soil organic matter formation. *Soil Sci. Soc. Am. J.* 69: 1730-1736.
- Mrabet, R., N. Saber, A. El-Brahli, S. Lahlou, F. Bessam. 2001. Total Particulate Organic Matter and Structural Stability of a Calcixeroll Soil Under Different Wheat Rotation and Tillage Systems In a Semi Arid Area of Morocco. *Soil Tillage Res.*, 57: pp. 225-235.
- Murty, D., M.U.F. Kirschbaum, R.E. Mcmurtrie, and H. Mcgilvray, 2002. Does conversion of forest to agricultural land change soil carbon and nitrogen? A review of the literature. *Global Change Biology*, 8: pp. 105-123.
- Neaman, A., A. Singer, and K. Stahar. 2000. Dispersion and migration of fine particles in two palygorskite-containing soils of Jordan Valley. *J. Plant Nutr. Soil Sci.* 163: pp. 537-547.
- Needelman, B.A., M.M. Wander, G.A. Bollero, C.W. Boast, G.K. Sims, and D.G. Bullock. 1999. Interaction of tillage and soil texture: Biologically active soil organic matter in Illinois. *Soil Sci. Soc. Am. J.* 63: pp. 1326-1334.
- Neff, J.C., A.R. Townsend, G. Gleixner, S.J. Lehman, J. Turnbull, and W. Bowman. 2002. Variable effects of nitrogen on the stability and turnover of soil carbon. *Nature*. 419: pp. 915-917.
- Nelson, D.W. and L.F. Sommers, 1982. Total Carbon, Organic Carbon and Organic Matter. In: A.L. Page *et al.* (ed.) *Methods of soil analysis, part 2*. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI. pp. 539-594.
- Novak, J.M., P.J. Bauer, and P.G. Hunt. 2007. Carbon dynamics under long term conservation and disk tillage management in a Norfolk loamy sand. *Soil Sci. Soc. Am. J.* 71: pp. 453-456.
- Ogle, S.M., and K. Paustian. 2005. Soil organic carbon as an indicator of environmental quality at the national scale: Inventory monitoring methods and policy relevance. *Can. J. Soil Sci.* 85: pp. 531-540.
- Ogle, S.M., F.J. Breidt, M.D. Eve, and K. Paustian. 2003. Uncertainty in estimating land use and management impacts on soil organic carbon storage for U.S. agricultural lands between 1982 and 1997. *Global Change Biol.* 9:1521-1542.

- Olson, K.R. 2010. Impacts of conservation tillage and erosion on soil organic carbon storage, retention and loss. *Soil Sci.* 175:562–567. doi:10.1097/SS.0b013e3181fa2837.
- Orchard, V. A. and Cook, F. J. (1983) Relationship between soil respiration and soil moisture. *Soil Biol. Biochem.* 15: 447-453.
- Page, A. L., Miller, R. H. and Keeney, D. R. (1982). Methods of soil analysis, Part-2, *Soil Science Society of America*, Publishers, Madison, Wisconsin, USA.
- Page-Dumroese, D., M. Jurgensen, W. Elliott, T. Rice, J. Nesser, T. Collins, and R. Meurisse. 2000. Soil quality standards and guidelines for forest sustainability in northwestern North America. *For. Ecol. Manage.* 138:445–462.
- Pal, D., P. K. Patra, D. Mukhopadhyay. 2015. Characterizing soils under different land use patterns in Terai region of West Bengal. *Asian J. Soil Sci.* 142-148.
- Paul, E. A., Morris, S. J., Conant, R. T. and Planté, A. F. 2006. Does the acid hydrolysis incubation method measure meaningful soil organic carbon pools? *Soil Sci. Soc. Am. J.* 70:1023–35.
- Paul, E.A., D. Harris, H.P. Collins, U. Schulthess, and G.P. Robertson. 1999. Evolution of CO₂ and soil carbon dynamics in biologically managed, row-crop cultivated lands. *Appl. Soil Ecol.* 11:53–65.
- Paul, E.A., S.J. Morris, and S. Bohm. 2001. The determination of soil C pool sizes and turnover rates: Biophysical fractionation and tracers. p. 193– 206. In R. Lal et al. (ed.) *Assessment methods for soil carbon*. Lewis Publ., Boca Raton, FL.
- Paul, K.I., P.J. Polglase, J.G. Nyakuengama, and P.K. Khanna. 2002. Change in soil carbon following afforestation. *For. Ecol. Manage.* 168:241–257.
- Paustian, K., C.V. Cole, D. Sauerbeck, and N. Sampson. 1998. CO₂ mitigation by agriculture: An overview. *Clim. Change* 40:135–162.
- Paustian, K., H.P. Collins, and E.A. Paul. 1997. Management controls on soil carbon. p. 15–50. In E.A. Paul et al. (ed.) *Soil organic matter in temperate cultivated lands: Long-term experiments in North America*. CRC Press, Boca Raton, FL
- Paustian, K., J. Six, E.T. Elliot, H.W. Hunt. 2000. Management options for reducing CO₂ emissions from agricultural soils. *Biogeochemistry.* 48:147–163.

- Petersen, C.T., H.E. Jensen, S. Hansen, and C.B. Koch. 2001. Susceptibility of a sandy loam soil to preferential flow as affected by tillage. *Soil Tillage Res.* 58:81–89.
- Phillips, D.A., H. Ferris, D.R. Cook, and D.R. Strong. 2003. Molecular control points in rhizosphere food webs. *Ecology* 84:816–826.
- Phillips, R.E., R.L. Blevins, G.W. Thomas, W.W. Frye, and S.H. Phillips. 1980. No-tillage agriculture. *Science* 208:1108–1113.
- Pikul, J. L., Osborne, Jr., Ellsbury, C. and Riedell, W. 2007. Particulate organic matter and water stable aggregation of soils under contrasting management. *Soil Sci. Soc. Am. J.* 71: 766–776.
- Pikul, J.L., Jr., J.K. Aase, and V.L. Cochran. 1997. Lentil green manure as fallow replacement in the semiarid northern Great Plains. *Agron. J.* 89:867–874.
- Post, W.M., and K.C. Kwon. 2000. Soil carbon sequestration and land-use change: Processes and potential. *Global Change Biol.* 6:317–327.
- Post, W.M., R.C. Izaurralde, J.D. Jastrow, B.A. McCarl, J.E. Amonette, V.L. Bailey, P.M. Jardine, T.O. West, and J.Z. Zhou. 2004. Enhancement of carbon sequestration in US soils. *Bioscience* 54:895–908.
- Post, W.M., R.C. Izaurralde, L.K. Mann, and N. Bliss. 2001. Monitoring and verifying changes of organic carbon in soil. *Climate Change* 51:73–99.
- Potter, K.N., O.R. Jones, H.A. Torbert, and P.W. Unger. 1997. Crop rotation and tillage effects on organic carbon sequestration in the semiarid southern Great Plains. *Soil Sci.* 62:140–147.
- Poulton, P.R., E. Pye, P.R. Hargreaves, and D.S. Jenkinson. 2003. Accumulation of carbon and nitrogen by old arable land reverting to woodland. *Global Change Biol.* 9: 942–955.
- Powlson, D. S., Whitmore, A. P. and Goulding, K. W. T. ,2011, Soil carbon sequestration to mitigate climate change: a critical re-examination to identify the true and the false. *European Journal of Soil Science*, 62: 42–55.
- Prior, S.A., D.C. Reicosky, D.W. Reeves, G.B. Runion, and R.L. Raper. 2000. Residue and tillage effects on planting implement-induced short-term CO₂ and water loss from a loamy sand soil in Alabama. *Soil Tillage Res.* 54:197–199.

- Puget, P., and L.E. Drinkwater. 2001. Short-term dynamics of root- and shoot-derived carbon from a leguminous green manure. *Soil Sci. Soc. Am. J.* 65:771–779.
- Puget, P., and R. Lal. 2005. Soil organic carbon and nitrogen in a Mollisol in central Ohio as affected by tillage and land use. *Soil Tillage Res.* 80:201–213.
- Purakayastha, T.J., Chhonkar, P.K., Bhadraray, S., Patra, A.K., Verma, V. and Khan, M.A. 2007. Long-term effects of different land use and soil management on various organic carbon fractions in an Inceptisol of subtropical India. *Australian Journal of Soil Research.* 45:33.40
- Purakayastha, T.J., D.R. Huggins, and J.L. Smith. 2008. Carbon sequestration in native prairie, perennial grass, no-till, and cultivated Palouse silt loam. *Soil Sci. Soc. Am. J.* 72:534–540. doi:10.2136/sssaj2005.0369
- Qi, Y. and M. Xu. 2001. Separating the effects of moisture and temperature on soil CO₂ efflux in a coniferous forest in the Sierra Nevada mountains. *Plant and Soil* 237:15-23.
- Qian, T. J; Yong, Z. Z.; Bin, B; Xin, S. J. 2008 Variations of soil particle size distribution with land-use types and influences on soil organic carbon and nitrogen. *Journal of Plant Ecology (Chinese Version)* Vol. 32 No. 3 pp. 601-610
- Qin, X. H.; Lin, X. R.; Qing, S. T. 2008 Effects of different fertilization on microbial biomass carbon from the red soil in tea garden. *Frontiers of Agriculture in China* Vol. 2 No. 4 pp. 418-422
- Quideau, S.A. 2006. Organic matter accumulation. p. 1172–1175. In R. Lal (ed.) *Encyclopedia of soil science*. Vol. 2. CRC Press, Boca Raton, FL.
- Raich, J. W. and Tufekcioglu, A. (2000). Vegetation and soil respiration: Correlations and controls. *Biogeochem.* 48: 71-90.
- Raison, R.J., and M.A. Rab. 2001. Guiding concepts for the application of indicators to interpret change in soil properties and processes in forests. p. 215–258. In R.J. Raison et al (ed.) *Criteria and indicators for sustainable forest management*, Vol. 7. CAB International in association with the International Union of Forestry Research Organizations, Wallington, UK.

- Rasmussen, K.J. 1999. Impacts of ploughless soil tillage on yield and soil quality: A Scandinavian review. *Soil Tillage Res.* 53:3–14.
- Rasmussen, P.E., and W.J. Parton. 1994. Long-term effects of residue management in wheat–fallow: I. Inputs, yield, and soil organic matter. *Soil Sci. Soc. Am. J.* 58:523–536.
- Raymond, P.A., and J.E. Bauer. 2001. Use of ^{14}C and ^{13}C natural abundances for evaluating riverine, estuarine, and coastal DOC and POC sources and cycling: A review and synthesis. *Org. Geochem.* 32:469–485.
- Reeves, D.W. 1997. The role of soil organic matter in maintaining soil quality in continuous cropping systems. *Soil Tillage Res.* 43:131–167.
- Reeves, D.W., and D.P. Delaney. 2002. Conservation rotations for cotton production and carbon storage. p. 344–348. In E. van Santen (ed.) *Making conservation tillage conventional: Building a future on 25 years of research*. Proc. Annu. Southern Conserv. Tillage Conf. Sustainable Agric., 25th, Auburn AL. 24–26 June 2002. Alabama Agric. Exp. Stn. and Auburn Univ., Auburn, AL.
- Rice, C.W. 2006. Organic matter and nutrient dynamics. p. 1180–1183. In R. Lal (ed.) *Encyclopedia of soil science*. Vol. 2. CRC Press, Boca Raton, FL.
- Richter, D.D., D. Markewitz, S.E. Trumbore, and C.G. Wells. 1999. Rapid accumulation and turnover of soil carbon in a re-establishing forest. *Nature* 400:56–58.
- Robertson, G.P., and S.M. Swinton. 2005. Reconciling agricultural productivity and environmental integrity: A grand challenge for agriculture. *Front. Ecol. Environ.* 3:38–46.
- Romanovskaya, A. A. 2006 Organic carbon in fallow lands of Russia. *Pochvovedenie* No. 1 pp. 52-61
- Ruddiman, W. 2005. *Plows, plagues and petroleum. How humans took control of the climate*. Princeton Univ. Press, Princeton, NJ.
- Ryan, M.G., and B.E. Law. 2005. Interpreting, measuring, and modeling soil respiration. *Biogeochemistry* 73:3–27.

- Saha, A. K. 2008. Methods of Physical and Chemical Analysis of soil. Kalyani Publishers. Pp 1-469.
- Sainju, U. M., W. B. Stevens, T. Caesar-TonThat, J. D. Jabro. 2010. Land Use and Management Practices Impact on Plant Biomass Carbon and Soil Carbon Dioxide Emission. *Soil Sci. Soc. Am. J.* 74:1613–1622.
- Sainju, U.M., A. Lenssen, T. Caesar-Tonthat, and J. Waddell. 2006. Tillage and crop rotation effects on dryland soil and residue carbon and nitrogen. *Soil Sci. Soc. Am. J.* 70:668–678.
- Sainju, U.M., J.D. Jabro, W.B. Stevens. 2008. Soil carbon dioxide emission and carbon sequestration as influenced by irrigation, tillage, cropping system, and nitrogen fertilization. *J. Environ. Qual.* 37:98–106.
- Sanderman, J., R. Faquarson, and J. Baldock. 2010. Soil carbon sequestration potential: A review for Australian agriculture. CSIRO Land and Water, A report prepared for Department of Climate Change and Energy Efficiency. CSIRO, Canberra.
- Sauerbeck, D.R. 2001. CO₂ emissions and C sequestration by agriculture-perspectives and limitations. *Nutr. Cycling Agroecosyst.* 60:253–266.
- Schimel, D.S., B.H. Braswell, E.A. Holland, R. McKeown, D.S. Ojima, T.H. Painter, W.J. Parton, and A.R. Townsend. 1994. Climatic, edaphic, and biotic controls over storage and turnover of carbon in soils. *Global Biogeochem. Cycles* 8:279–293.
- Schlesinger, W. H. and Andrews, J. A. 2000. Soil respiration and the global carbon cycle. *Biogeochem.* 48:7–20.
- Schlesinger, W.H. 1984. Soil organic matter: A source of atmospheric CO₂. p. 111–127. In G.M. Woodwell (ed.) *The role of terrestrial vegetation in the global carbon cycle*. John Wiley & Sons, New York.
- Schlesinger, W.H. 1990. Evidence from chronosequence studies for a low carbon-storage potential of soils. *Nature* 348:232–234.
- Schlesinger, W.H. 1997. The global carbon cycle. p. 358–382. In *Biogeochemistry: An analysis of global change*. Academic Press, New York.

- Schulp, C.J.E., and A. Veldkamp. 2008. Long-term landscape-land use interactions as explaining factor for soil organic matter variability in Dutch agricultural landscapes. *Geoderma* 146:457–465. doi:10.1016/j.geoderma.2008.06.016.
- Schwendenmann, L., Pendall, E. and Potvin, C. (2007). Surface soil organic carbon pools, mineralization and CO₂ efflux rates under different land-use types in Central Panama. In: Tschardtke, T., Leuschner, C., Zeller, M., Guhardja, E., and Bidin, A. (eds), *The stability of tropical rainforest margins, linking ecological, economic and social constraints of land use and conservation*, Springer Verlag Berlin. p: 109-131.
- Schwenke, G.D., W.L. Felton, D.F. Herridge, D.F. Khan, and M.B. Peoples. 2002. Relating particulate organic matter-nitrogen (POM-N) and nonPOM-N with pulse crop residues, residue management and cereal N uptake. *Agronomie* 22:777–787.
- Scott, A., B.C. Ball, I.J. Crichton, and M.N. Aitken. 2000. Nitrous oxide and carbon dioxide emissions from grassland amended with sewage sludge. *Soil Use Manage.* 16:36–41.
- Seneviratne, G. 2000. Litter quality and nitrogen release in tropical agriculture. *Biol. Fertil. Soils* 31:60–64.
- Sharifi, M., B.J. Zebarth, D.L. Burton, C.A. Grant, S. Bittman, C.F. Drury, B.G. McConkey, and N. Ziadi. 2008. Response of potentially mineralizable soil nitrogen and indices of nitrogen availability to tillage system. *Soil Sci. Soc. Am. J.* 72:1124–1131. doi:10.2136/sssaj2007.0243
- Sheikh M. A., M. Kumar, R. W. Bussman and N.P. Todaria. 2011. Forest carbon stocks and fluxes in physiographic zones of India. *Carbon Balance and Management*, 6(15) : pp. 1-10.
- Sherrod, L.A., G.A. Peterson, D.G. Westfall, and L.R. Ahuja. 2005. Soil organic carbon pools after 12 years in no-till dryland cultivated lands. *Soil Sci. Soc. Am. J.* 67:1533–1543.
- Shipitalo, M.J., W.A. Dick, and W.M. Edwards. 2000. Conservation tillage and macropore factors that affect water movement and the fate of chemicals. *Soil Tillage Res.* 53:167–183.

- Shrestha, B. M. , B. R. Singh, B. K. Sitaula, R. Lal, R. M. Bajracharya. 2006. Soil Aggregate- and Particle-Associated Organic Carbon under Different Land Uses in Nepal. *Soil Sci. Soc. Am. J.* 71:1194-1203.
- Shrestha, B.M., B.K. Sitaula, B.R. Singh, and R.M. Bajracharya. 2004. Soil organic carbon stocks in soil aggregates under different land use systems in Nepal. *Nutr. Cycling Agroecosyst.* 70:201–213.
- Silver, W. L., Kueppers, L. M., Lugo, A. E., Ostertag, R. and Matzek, V. 2004. Carbon sequestration and plant community dynamics with reforestation of tropical asture. *Ecol. Appl.* 14: 1115-1127.
- Silver, W. L., Ostertag, R. and Lugo, A. E. 2000. The potential for tropical forest restoration and reforestation for carbon accumulation and offset. *Restor. Ecol.* 8: 394-407.
- Simbahan, G.C., A. Dobermann, P. Goovaerts, J. Ping, and M.L. Haddix. 2006. Fine resolution mapping of soil organic carbon based on multivariate secondary data. *Geoderma* 132:471–489.
- Simbahan, G.C., and A. Dobermann. 2006. Sampling optimization based on secondary information and its utilization in soil carbon mapping. *Geoderma* 133:345–362.
- Singh A.K., S.V. Ngachan, G.C. Munda., K.P. Mohapatra, B.U. Choudhury, A. Das , C. S. Rao, D.P. Patel, D.J. Rajkhowa, G.I. Ramkrushna and A.S. Panwar. 2012. Carbon Management in Agriculture for Mitigating Greenhouse Effect. pp 83-101, ICAR Research Complex for NEH region, Umiam, Meghalaya, India
- Singh, B.R., and R. Lal. 2005. The potential of soil carbon sequestration through improved management practices in Norway. *Environ. Dev. Sustainability* 7:161–184.
- Singh, H., Pathak, P., Kumar, M. and Raghubanshi. 2011. Carbon sequestration potential of Indo-Gangetic agro ecosystem soils. *Tropical Ecology.* 52(2):223-228
- Six, J., and J. Jastrow. 2002. Organic matter turnover. p. 936–942. In R. Lal (ed.) *Encyclopedia of soil science.* Marcel Dekker, New York.

- Six, J., C. Feller, K. Denaf, S.M. Ogle, J.C. de M. Sa, and A. Albrecht. 2002. Soil organic matter, biota and aggregation in temperate and tropical soils: Effects of no-tillage. *Agronomie* 22:755–775.
- Six, J., E.T. Elliot, and K. Paustian. 2000. Soil macroaggregate turnover and microaggregate formation: A mechanism for C sequestration under no tillage agriculture. *Soil Biol. Biochem.* 32:2099–2103.
- Six, J., E.T. Elliott, and K. Paustian. 1998. Aggregate and soil organic matter dynamics under conventional and no-tillage systems. *Soil Sci. Soc. Am. J.* 63:1350–1358.
- Six, J., E.T. Elliott, and K. Paustian. 1999. Aggregate and soil organic matter dynamics under conventional and no-tillage systems. *Soil Sci. Soc. Am. J.* 63:1350–1358.
- Six, J., E.T. Elliott, K. Paustian, and J.W. Doran. 1998. Aggregation and soil organic matter accumulation in cultivated and native grassland soils. *Soil Sci. Soc. Am. J.* 62:1367–1377.
- Six, J., H. Bossuyt, S. Degryze, and K. Denef. 2004. A history of research on the link between (micro)aggregates, soil biota, and soil organic matter dynamics. *Soil Tillage Res.* 79:7–31.
- Six, J., K. Paustian, E.T. Elliott, and C. Combrink. 2000. Soil structure and organic matter: I. Distribution of aggregate-size classes and aggregate-associated carbon. *Soil Sci. Soc. Am. J.* 64:681–689.
- Six, J., P. S. Callewaert, S. Lenders, S.J. De Gryze, E.G. Morris Gregorich, E.A. Paul, K. Paustian. 2002. Measuring and understanding carbon storage in afforested soils by physical fractionation. *Soil Sci. Soc. Am. J.* 66 (6): 1981–1987.
- Six, J., S.D. Frey, R.K. Thiet, and K.M. Batten. 2006. Bacterial and fungal contributions to C-sequestration in cultivated lands. *Soil Sci. Soc. Am. J.* 70:555–569.
- Sleutel, S., S. De Neve, T. Nemeth, T. Toth, and G. Hofman. 2006. Effect of manure and fertilizer application on the distribution of organic carbon in different soil fractions in long-term field experiments. *Eur. J. Agron.* 25:280–288.

- Song, Z. Q.; Hu, L. S.; Ying, Z. H. 2010 Study of different mulching measures on the dynamic changes of microbial biomass in the tea garden of Xinyang. *Journal of Henan Agricultural Sciences* 2010 No. 7 pp. 53-55
- Spaans, E.J.A., G.A.M. Baltissen, J. Bouma, R. Miedema, A.L.E. Lansu, D. Schoonderbeek, and W.G. Wielemaker. 1989. Changes in physical properties of young and old volcanic surface soils in Costa Rica after clearing of tropical rain forest. *Hydrol. Processes* 3:383–392.
- Srinivasarao, Ch., K.P.R. Vittal, B. Venkateswarlu, S.P. Wani, K.L. Sahrawat, S. Marimuthu, and S. Kundu. 2009. Carbon stocks in different soil types under diverse rainfed production systems in tropical India. *Commun. Soil Sci. Plant Anal.* 40:2338–2356.
- Srinivasarao, Ch., Venkateswarlu, B., Lal, R., Singh, A.K., Sumanta Kundu, Vittal, K.P.R., Patel, J.J. and Patel, M.M. 2011. Long-term manuring and fertilizer effects on depletion of soil organic carbon stocks under pearl millet-cluster bean-castor rotation in western India. *Land Degradation and Development*. DOI: 10.1002/ldr.1158
- Srinivasarao, Ch., Vittal, K.P.R., Venkateswarlu, B., Wani, SP., Sahrawat, K.L., Marimuthu, S and Kundu, S. 2009. Carbon stocks in different soil types under diverse rainfed production systems of India. *Communications in Soil Science and Plant Analysis*. 40 (15): 2338-2356
- Srinivasarao, Ch., Venkateswarlu, B., Dinesh Babu, M., Wani, S.P., Dixit, S., Sahrawat, K.L. and Sumanta Kundu. 2011. Soil health improvement with *Gliricidia* green leaf manuring in rainfed agriculture. Central Research Institute for Dryland Agriculture, Hyderabad, India. p 23
- Srinivasarao, Ch., Venkateswarlu, B., Lal, R., Singh, A.K., Vittal, K.P.R., Sumanta Kundu, Singh, S.R. and Singh, S.P. 2012. Long-term effects of soil fertility management on carbon sequestration in a rice-lentil cropping system of the Indo-Gangetic plains. *Soil Science Society of America Journal*. 76(1): 168-178
- Steenwerth, K., and K.M. Belina. 2008. Cover crops enhance soil organic matter, carbon dynamics and microbiological function in a vineyard agroecosystem. *Appl. Soil Ecol.* 40:359–369. doi:10.1016/j.apsoil.2008.06.006

- Stevenson, F.J. 1982. Humus chemistry: Genesis, composition, reactions. John Wiley Sons, New York.
- Stevenson, F.J. 1994. Humus chemistry: Genesis, composition, reactions. 2nd ed. John Wiley & Sons, New York.
- Stevenson, F.J., and M.A. Cole. 1999. Cycles of soil. Carbon, Nitrogen, Phosphorus, Sulfur, Micronutrients. 2nd ed. John Wiley & Sons, Hoboken, NJ.
- Stewart, C. E., Plante, A. F., Paustian, K., Conant, R. T. and Six, J. (2008). Soil carbon saturation: linking concept and measurable carbon pools. *Soil Sci. Soc. Am. J.* 72:379-92.
- Stoicheva, D.; Koleva, V. 2003 Influence of different land-use on the humus content of alluvial-meadow soil and organic carbon in the soil solution. Ecology and Future - Bulgarian Journal of Ecological Science Vol. 2 No. 3/4 pp. 112-114
- Subbiah, B. V. and Asija, G. L. 1956. A rapid procedure for determination of available nitrogen in soils. *Current Science*. 25 : 259-260.
- Sullivan, M.D., N.R. Fausey, and R. Lal. 1997. Long-term effects of subsurface drainage on soil organic carbon content and infiltration in the surface horizons of a lakebed soil in northwest Ohio. p. 73–82. In R. Lal et al. (ed.) Management of carbon sequestration in soil. CRC Press, Boca Raton, FL.
- Sulzman, E.W., J.B. Brant, R.D. Bowden, and K. Lajtha. 2005. Contribution of aboveground litter, belowground litter, and rhizosphere respiration to total CO₂ efflux in an old growth coniferous forest. *Biogeochemistry* 73:231–256.
- Swarup, A., M.C. Manna, and G.B. Singh. 2000. Impact of land use and management practices on organic carbon dynamics in soils of India. p. 261–281. In R. Lal et al. (ed.) Global climate change and tropical ecosystems. Adv. Soil Sci. CRC Press, Boca Raton, FL.
- Swift, R.S. 2001. Sequestration of carbon by soil. *Soil Sci.* 166:858–871.
- Templer, P.H., P.M. Groffman, A.S. Flecker, and A.G. Power. 2005. Land use change and soil nutrient transformations in the Los Haitises region of the Dominican Republic. *Soil Biol. Biochem.* 37:215–225.

- Thaysen¹, E. M., D. Jacques, S. Jessen, C. E. Andersen, E. Lalo², P. Ambus³, D. Postma, and I. Jakobsen. 2014. Inorganic carbon fluxes across the vadose zone of planted and unplanted soil mesocosms. *Biogeosciences*, 11, pp.7179–7192.
- Thiessen, S.; Gleixner, G.; Wutzler, T.; Reichstein, M., 2012, Temperature sensitivity of different soil carbon sources, *The Smithsonian/NASA Astrophysics Data System*
- Thomsen, I.K., and B.T. Christensen. 2004. Yields of wheat and soil carbon and nitrogen contents following long-term incorporation of barley straw and ryegrass catch crops. *Soil Use Manage.* 20:432–438.
- Tirol-Padre, A., Tsuchiya, K., Inubushi, K. and Ladha, J. K. (2005). Enhancing soil quality through residue management in a rice-wheat system in Fukuoka, Japan. *Soil Sci. Plant Nutr.* 51:849–60.
- Tisdall, J.M., and J.M. Oades. 1982. Organic matter and water-stable aggregates in soils. *J. Soil Sci.* 33:141–163.
- Tong, X., X. Han, W. Faqi, F. Zhao,, C. Ren, J. Li. 2016. Change in Carbon Storage in Soil Physical Fractions after Afforestation of Former Arable Land. *Soil Sci. Soc. Am. J.* 80:1098–1106.
- Tornquist, C.G., E. Giasson, J. Mielniczuk, C.E.P. Cerri, and M. Bernoux. 2009. Soil organic carbon stocks of Rio Grande do Sul, Brazil. *Soil Sci. Soc. Am. J.* 73:975–982. doi:10.2136/sssaj2008.0112
- Trettin, C.A., D.W. Johnson, and D.E. Todd, Jr. 1999. Forest nutrient and carbon pools: A 21-year assessment. *Soil Sci. Soc. Am. J.* 63:1436–1448.
- Tripathi, S.; Barua, S.; Das, B.; Chakrabarti, K. 2011 Microbial and biochemical properties of soils under different agro ecosystems in Tista valley, India. *Indian Biologist* Vol. 43 No. 1/2 pp. 33-38
- Trumbore, S. E., Davidson, E. A., Camargo, P. B., Nepstad, D. C. and Martinelli, L. A. 1995. Belowground cycling of carbon in forests and pastures of Eastern Amazonia. *Global Biogeochem. Cycles.* 9: 515-528.
- Trumbore, S.E. 1997. Potential responses of soil organic carbon to global environmental change. *Proc. Natl. Acad. Sci.* 94:8284–8291.

- Trumbore, S.E., and J.W. Harden. 1997a. Accumulation and turnover of carbon in organic and mineral soils of the BOREAS northern study area. *J. Geophys. Res.* 102:28817–28830.
- U.S. Department of Energy. 1999. Carbon sequestration: State of the science. Carbon sequestration research and development. U.S. Dep. of Energy, Office of Fossil Energy, Washington, DC.
- Uselman, S.M., R.G. Qualls, and J. Lilienfein. 2007. Fine root production across a primary successional ecosystem chronosequence at Mt. Shasta, California. *Ecosystems* (in press) doi:10.1007/s10021-007-9045-8.
- Vågen, T. G.; Lal, R.; Singh, B. R. 2005 Soil carbon sequestration in sub-Saharan Africa: a review. *Land Degradation & Development* Vol. 16 No. 1 pp. 53-71
- van Bochove, E., D. Prévost, and F. Pelletier. 2000. Effects of freeze-thaw and soil structure on nitrous oxide produced in a clay soil. *Soil Sci. Soc. Am. J.* 64:1638–1643.
- Vance, E.D. 2000. Agricultural site productivity: Principles derived from longterm experiments and their implications for intensively managed forests. *For. Ecol. Manage.* 138:369–396.
- Vanden Bygaart, A.J., E. Bremer, B.G. McConkey, B.H. Ellert, H.H. Janzen, D.A. Angers *et al.* 2011. Impact of sampling depth on differences in soil carbon stocks in long-term agroecosystem experiments. *Soil Sci. Soc. Am. J.* 75:226–234. doi:10.2136/sssaj2010.0099
- VandenBygaart, A.J., E.G. Gregorich, and D.A. Angers. 2003. Influence of agricultural management on soil organic carbon: A compendium and assessment of Canadian studies. *Can. J. Soil Sci.* 83:363–380.
- Veeranagappa, P., Prakasha, H.C., Basavaraja, M.K. and Mohamed, H. (2010). Effect of zinc enriched compost on yield and nutrient uptake of rice (*Oryza sativa* L.). *European Journal of Biological Sciences*. 3(1): 23-29.
- Veldkamp, E. (1994). Organic carbon turnover in three tropical soils under pasture after deforestation. *Soil Sci. Soc. Am. J.* 58: 175-180.
- Vieira, F. C. B., Bayer, C., Zanatta, J. A., Dieckow, J., Mielniczuk, J. and He, Z. L. (2007). Carbon management index based on physical fractionation of soil

- organic matter in an Acrisol under long-term no-till cropping systems. *Soil Till. Res.* 96:195-204.
- Vogeler, I., R. Horn, H. Wetzel, and J. Krümmelbein. 2005. Tillage effects on soil strength and solute transport. *Soil Tillage Res.* 88:193–204.
- von Lutzow, M., J. Leifeld, M. Kainz, I. Kogel-Knabner, and J.C. Munch. 2002. Indications for soil organic matter quality in soils under different management. *Geoderma* 105:243–258.
- Waldrop, M.P., and M.K. Firestone. 2004. Altered utilization patterns of young and old soil C by microorganisms caused by temperature shifts and N additions. *Biogeochemistry* 67:235–248.
- 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* 37:29-38
- Wander, M. 2004. Soil organic matter fractions and their relevance to soil function. In: Magdoff, F., Weil, R. R. (Eds.), *Soil Organic Matter in Sustainable Agriculture*. CRC Press, Boca Raton, FL, pp. 67-102.
- Wander, M.M., and X. Yang. 2000. Influence of tillage on the dynamics of loose- and occluded-particulate and humified organic matter fractions. *Soil Biol. Biochem.* 32:1151–1160.
- Wander, M.M., G. Bidart-Bouzat, and S. Aref. 1998. Tillage impacts on depth distribution of total and particulate organic matter in three Illinois soils. *Soil Sci. Soc. Am. J.* 62:1704–1711.
- Wang, W.J., R.C. Dalal, and P.W. Moody. 2004. Soil carbon sequestration and density distribution in a Vertosol under different farming practices. *Aust. J. Soil Res.* 42:875–882.
- Wang, W.J., R.C. Dalal, P.W. Moody, and C.J. Smith. 2003. Relationships of soil respiration to microbial biomass, substrate availability and clay content. *Soil Biol. Biochem.* 35:273–284. doi:10.1016/S0038-0717(02)00274-2
- Wang, Y., and Y. Hsieh. 2002. Uncertainties and novel prospects in the study of the soil carbon dynamics. *Chemosphere* 49:791–804.

- Wardle, D.A., R.D. Bardgett, J.N. Klironomos, H. Setälä, W.H. Van der Putten, and D.H. Wall. 2004. Ecological linkages between aboveground and belowground biota. *Science* 304:1629–1633.
- Watson, R.T., I.R. Noble, B. Bolin, N.H. Ravindranth, D.J. Verardo, and D.J. Doken. 2000. *Land use, land use change, and forestry*. Cambridge Univ. Press, Cambridge, UK.
- Weil, R.R., K.R. Islam, M.A. Stine, J.B. Gruver, and S.E. Samson-Liebig. 2003. Estimating active carbon for soil quality assessment: A simplified method for laboratory and field use. *Am. J. Altern. Agric.* 18:3–17.
- West, T.O., and G. Marland. 2002. A synthesis of carbon sequestration, carbon emissions, and net carbon flux in agriculture: Comparing tillage practices in the United States. *Agric. Ecosyst. Environ.* 91:217–232.
- West, T.O., and W.M. Post. 2002a. Soil organic carbon sequestration rates by tillage and crop rotation: A global data analysis. *Soil Sci. Soc. Am. J.* 66:1930–1946. doi:10.2136/sssaj2002.1930
- West, T.O., G. Marland, A.W. King, W.M. Post, A.K. Jain, and K. Andrasko. 2004. Carbon management response curves: Estimates of temporal soil carbon dynamics. *Environ. Manage.* 33:507–518.
- Wittman, H. K.; Johnson, M. S. 2008 Fallow management practices in Guatemala's Western Highlands: social drivers and biophysical impacts. *Land Degradation & Development* Vol. 19 No. 2 pp. 178-189
- Wright, A.L., and F.M. Hons. 2005. Soil carbon and nitrogen storage in aggregates from different tillage and crop regimes. *Soil Sci. Soc. Am. J.* 69:141–147.
- Wright, A.L., and F.M. Hons. 2005a. Carbon and nitrogen sequestration and soil aggregation under sorghum cropping sequences. *Biol. Fertil. Soils* 41:95–100.
- Xin, D.; Yan, L. H.; Cai, T. J.; Ling, C. H.; Hua, S. S. 2006 Comparison on community composition and activity of edaphon in organic tea garden of different planting-life. *Journal of Hunan Agricultural University* Vol. 32 No. 1 pp. 53-56

- Xu, L., D. D. Baldocchi, and J. Tang. 2004. How soil moisture, rain pulses, and growth alter the response of ecosystem respiration to temperature. *Global Biogeochemical Cycles* 18.
- Yadav, R.L., B.S. Dwivedi, and P.S. Pandey. 2000. Rice–wheat cropping system assessment of sustainability under green manuring and chemical fertilizer inputs. *Field Crops Res.* 65:15–30.
- Yan, H. W.; Kemmitt, S. J.; Brookes, P. C. 2007 Soil microbial biomass and activity in Chinese tea gardens of varying stand age and productivity. *Soil Biology & Biochemistry* Vol. 39 No. 7 pp. 1468-1478
- Yano, Y., Kk. Lajtha, P. Sollins, and B.A. Caldwell. 2005. Chemistry and dynamics of dissolved organic matter in a temperate coniferous forest on Andic soils: Effects of litter quality. *Ecosystems* 8:286–300.
- Yoo, G., and M.M. Wander. 2008. Tillage effects on aggregate turnover and sequestration of particulate and humified soil organic carbon. *Soil Sci. Soc. Am. J.* 72:670–676. doi:10.2136/sssaj2007.0110
- Young, F.J., and R.D. Hammer. 2000a. Soil landform relationships on a loessmantled landscape in Missouri. *Soil Sci. Soc. Am. J.* 64:1443–1454.
- Young, F.J., and R.D. Hammer. 2000b. Defining geographic soil bodies by landscape position, soil taxonomy, and cluster analysis. *Soil Sci. Soc. Am. J.* 64:989–998.
- Zhang, J. Y., Lin, Z. B., Zhang, R. D., and Shen, J. 2010. Effects of simulated rainfall events on soil carbon transformation, *Aust. J. Soil Res.*, 48, 404–412, doi:10.1071/Sr09182.
- Zhao, F., L. Zhang, C. Ren, J. Sun, X. Han, G. Yang, J. Wang. 2016. Effect of Microbial Carbon, Nitrogen, and Phosphorus Stoichiometry on Soil Carbon Fractions under a Black Locust Forest within the Central Loess Plateau of China. *Soil Sci. Soc. Am. J.* 80:1520–1530.
- Zibilske, L. M., J. M. Bradford. 2007. Soil Aggregation, Aggregate Carbon and Nitrogen, and Moisture Retention Induced by Conservation Tillage. *Soil Sci. Soc. Am. J.* 71: 793–802.
- Zinn, Y.L., R. Lal, J.M. Bigham, and D.V.S. Resck. 2007. Edaphic controls on soil organic carbon retention in the Brazilian Cerrado: Texture and mineralogy. *Soil Sci. Soc. Am. J.* 71:1204–1214.