

**Functional Soil Organic Carbon Pools as Affected by
Different Land Use Types in a Sub Mountainous Area of
North Kashmir**

Shamal Shasang Kumar
(MSA-2019-1256)



Division of Soil Science and Agricultural Chemistry
Faculty of Agriculture
**Sher-e-Kashmir University of Agricultural Sciences &
Technology of Kashmir**

2021

**Functional Soil Organic Carbon Pools as Affected by
Different Land Use Types in a Sub Mountainous Area of
North Kashmir**

Shamal Shasang Kumar
(MSA/2019/1256)



Thesis

Submitted to

**The Faculty of Agriculture
Sher-e-Kashmir University of Agricultural Sciences &
Technology of Kashmir
in partial fulfilment of requirement for the award of the degree of**

**Master of Science in Agriculture
(Soil Science and Agricultural Chemistry)**

2021



***Dedicated
To my
Beloved parents***

Sher-e-Kashmir
University of Agricultural Sciences & Technology of Kashmir
Faculty of Agriculture, Division of Soil Science and Agricultural
Chemistry, Wadura Campus Sopore-193201

Certificate - I

This is to certify that the thesis entitled, “**Functional Soil Organic Carbon Pools as Affected by Different Land Use Types in a Sub Mountainous Area of North Kashmir**” submitted in partial fulfilment of the requirements for the award of the degree of **Master of Science in Agriculture (Soil Science and Agricultural Chemistry)**, to the **Faculty of Agriculture, Sher-e-Kashmir University of Agricultural Sciences & Technology of Kashmir** is a record of bonafide research work carried out by **Mr. Shamal Shasang Kumar (Regd. No. MSA/2019/1256)** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

It is further certified that information received during the course of investigation has duly been acknowledged.

(Dr. Shakeel Ahmad Mir)
Chairman
Advisory Committee

Endorsed

Prof. & Head,
Division of Soil Science and Agricultural Chemistry

Sher-e-Kashmir
University of Agricultural Sciences & Technology of Kashmir
Faculty of Agriculture, Division of Soil Science and Agricultural
Chemistry, Wadura Campus Sopore-193201

Certificate - II

We, the members of the Advisory Committee of **Mr. Shamal Shasang Kumar (Regd. No. MSA/2019/1256)**, a candidate for the degree of **Master of Science in Agriculture (Soil Science and Agricultural Chemistry)**, have gone through the manuscript of the thesis entitled, **“Functional Soil Organic Carbon Pools as Affected by Different Land Use Types in a Sub Mountainous Area of North Kashmir”** and recommend that it may be submitted by the student in partial fulfilment of the requirements for the award of the degree.

Advisory Committee

Chairman

Dr. Shakeel Ahmad Mir

Assistant Professor

Division of Soil Science and Agricultural Chemistry
FoA, SKUAST-Kashmir

Members

Dr. Majeed Ul Hassan Chesti

Associate Professor

Division of Soil Science and Agricultural Chemistry
FoA, SKUAST-Kashmir

Dr. Zahoor Ahmad Baba

Associate Professor

Division of Basic Sciences and Humanities FoA,
SKUAST-Kashmir

Dr. Fehim Jeelani Wani

Assistant Professor, Division of Agriculture
Economics and Statistics. FoA, SKUAST-Kashmir

Dean's Nominee

Dr. Parvaze Ahmad Sofi

Associate Professor, Division of Genetics and Plant
Breeding

Sher-e-Kashmir
University of Agricultural Sciences & Technology of Kashmir
Faculty of Agriculture, Division of Soil Science and Agricultural
Chemistry, Wadura Campus Sopore-193201

Certificate – III

This is to certify that the thesis entitled, “**Functional Soil Organic Carbon Pools as Affected by Different Land Use Types in a Sub Mountainous Area of North Kashmir**” submitted by **Mr. Shamal Shasang Kumar (Regd. No. MSA/2019/1256)** to the **Faculty of Agriculture, Sher-e-Kashmir University of Agricultural Sciences & Technology of Kashmir** in partial fulfilment of the requirements for the award of the degree of **Master of Science in Agriculture (Soil Science and Agricultural Chemistry)** was examined and approved by the Advisory Committee and External Examiner on

Chairman
Advisory Committee

External Examiner

Prof. & Head,
Division of Soil Science & Agricultural Chemistry

Dean,
Faculty of Agriculture,
SKUAST-Kashmir, Wadura, Sopore

Sher-e-Kashmir
University of Agricultural Sciences & Technology of Kashmir
Division of Soil Science and Agricultural Chemistry Wadura,
Sopore - 193201

Name of the student : **Shamal Shasang Kumar**
Registration No. : **MSA/2019/1256**
Major subject : Soil Science and Agricultural Chemistry
Minor subject : Microbiology
Major advisor : **Dr. Shakeel Ahmad Mir,**
Assistant Professor, Division of Soil Science
and Agricultural Chemistry, FoA-Wadura,
SKUAST-Kashmir
Title of the Thesis : **“Functional Soil Organic Carbon Pools as
Affected by Different Land Use Types in a
Sub Mountainous Area of North Kashmir”**

ABSTRACT

Carbon can be seen as a fundamental unit of life on earth. The type of land use, crop species diversity and management practices have a profound impact on physical, chemical, biological properties which ultimately influences soil fertility and crop productivity. The present study entitled **“Functional Soil Organic Carbon Pools as Affected by Different Land Use Types in a Sub Mountainous Area of North Kashmir”** was undertaken during the year 2019-2021 to quantify various functional pools of soil organic carbon, carbon stocks and to evaluate carbon management indices of various land use types of the study. The study was undertaken on surface (0-20 cm) and sub-surface (20-40 cm) soils under five different land use types namely natural forests, natural grasslands, maize-fields-converted-from-forests, plantation and paddy growing soils in a sub mountainous area of North Kashmir located in Kupwara district. Soil samples were analyzed for various pools of organic carbon and it was observed that these forms were in the order; total organic carbon > walkley-black carbon > very labile carbon > labile carbon > less labile carbon > non labile carbon under all land uses. The soil pH varied from slightly acidic to mildly alkaline in the studied land uses with highest pH of 7.42 recorded in paddy soils and lowest of 6.55 in natural forests and pH increased in all the land uses with increase in soil depth. The highest bulk density (1.43 Mg m⁻³) was recorded in paddy soils and lowest (0.94 Mg m⁻³) in natural forests with increasing trend along the depth. The paddy soil recorded highest clay content 34.41 % and least (13.78 %) was observed in natural forests.

The clay content in each land use type increased with increase in depth. Among different land uses the total nitrogen was highest in natural forest (0.49 %) and lowest in paddy soils (0.18 %) which decreased with increase in soil depth. The microbial count viz., viable bacteria ($163 \text{ cfu} \times 10^{-6}$), fungi ($93 \text{ cfu} \times 10^{-5}$) and actinomycetes ($68 \text{ cfu} \times 10^{-5}$) were highest in natural forests as compared to cultivated lands and decreased with increase in depth. The highest total organic carbon (24.24 g kg^{-1}) and walkley-black carbon (18.23 g kg^{-1}) were recorded in natural forests and least (2.76 g kg^{-1} and 9.59 g kg^{-1} respectively) were recorded in paddy soils, with a decreasing trend along the depth. The highest quantities of very-labile-carbon (8.65 g kg^{-1}) and labile-carbon (3.58 g kg^{-1}) were recorded in natural forests and the lowest (4.45 g kg^{-1}) and 2.42 g kg^{-1} in paddy soils which decreased with increase in depth. Highest quantities of less-labile-carbon (2.59 g kg^{-1}) and non-labile-carbon (3.41 g kg^{-1}) were recorded in natural forests and lowest (1.25 g kg^{-1} and 1.47 g kg^{-1} , respectively) in paddy growing soils. The highest total organic carbon stock (45.88 Mg ha^{-1}), active organic carbon stock (23.14 Mg ha^{-1}), passive organic carbon stock (11.40 Mg ha^{-1}), walkley-black carbon stock (34.50 Mg ha^{-1}) were recorded in natural forests and lowest respective stocks (36.45 Mg ha^{-1} , 19.63 Mg ha^{-1} , 7.77 Mg ha^{-1} and 27.40 Mg ha^{-1}) were found in paddy soils. In all the land uses, the various organic carbon stocks decreased with depth. The highest carbon management index was recorded in natural forests (100), followed by natural grasslands (98.71) and the lowest (70.08) in paddy soils. Total organic carbon and various functional soil organic carbon pools manifested a positive correlation with clay, total nitrogen, biological properties and organic carbon stocks. Findings suggest that both the active and passive C pools in different soil layers are affected by land use and therefore dynamics of SOC turnover with land use management practices should be paid more attention to harness the C storage potential of soils in the region.

Key words: Land use, functional organic carbon pools, carbon stocks, labile carbon, carbon management index.

Signature of Student
Dated: _____

Signature of Major Advisor
Dated: _____

ACKNOWLEDGEMENT

With profound sense of gratitude I place my regards to my parents and pray to God for their health and life as they have helped me face life's challenges.

*I owe at least one appreciation to our respectable **Vice-Chancellor, Dr. J.P. Sharma**, in whom I saw a competent administrator, an esteemed scientist, and a paternal presence who truly perceives his students' attention and well-being as the best.*

*With deep privilege, I would like to express my sincere thanks to my supervisor, mentor and Chair of my advisory committee; **Dr. Shakeel Ahmad Mir**, Assistant Professor, Department of Soil Science and Agricultural Chemistry SKUAST-Kashmir for his worthy guidance, useful ideas, ever motivating inspirations and appreciation for his commitment to my work with him.*

*I am delighted to express my deepest gratitude to the co-supervisor, tutor, mentor **Dr. Majeed Ul Hassan Chesti**, Associate Professor, Department of Soil Science and Agricultural Chemistry, SKUAST-Kashmir for his wise guidance, full devotion to my job and pain staking efforts. Under the guidance of such a learned person I feel honored to be a scholar.*

*I extend my sincere gratitude and veneration to the respected members of my advisory committee **Dr. Zahoor Ahmad Baba**, **Dr. Fehim Jeelani Wani** and **Dr. Parvaze Ahmad Sofi** for their valuable guidance and encouragement during the research and for assisting in successful completion of the manuscript.*

*Without lacking in my duties, I deeply thank to the Professor and Head of Soil Science and Agricultural Chemistry, **Dr. Ayyoub Bhat** and pleasure to express my deep gratitude to the Dean Faculty of Agriculture, **Professor Abdul Hameed Hakeem**; FoA, SKUAST-K for providing me with the requisite facilities to conduct the research work smoothly.*

*I pay respect to **Dr. Shaista Nazir**, **Dr. Aamir Hassan Mir**, **Dr. Inayat**, for their wholehearted cooperation during the academic year.*

*I shall ever, remain gladly indebted to **Dr. Pramod Nair**, **Dr. Sachchida Nand Rai**, **Dr. Jahangeer Bhat**, **Dr. Kaliova Ravuiwasa**, **Dr. Hirdesh Sachan**, **Dr. Saresh Kumar**, **Mr. Esava Tabua**, **Mr. Ravneel Kumar**, **Mr. Ashmit Kumar**;*

CAFF Fiji National University, who directly inspired me to achieve my goal and enlightened me with the touch of expertise and constant encouragement.

I also thank to my seniors, Mr. Naresh, Mr. Avinash, Mr. Ananta Mahale, Mr. Salim Mir, Rajnish Yadav, Rajbeer Singh, Sushil Godara, Subham Roy, Prem Ranjan, Sandeep, Akhil, Madhu, Faheem, Manu, for their continuous help and support in my studies.

Sentences fail to express my deep gratitude and appreciation to my friends especially Yogen Reddy, Ashraf Sultan, Sanju Bamaniya, Ashad Ahmad, Shajhad, Hazar Sami Haji, Derej Allemu, Zahedullah Zahed, Mujeeburahman Ariez, Solomon Bona, Zahid Dar, Tajamul Mansoor, Tanveer Bhat, Mahrukh Mattoo, Mir Shereen, Tharun Kumar, Faisal Hayat, Vinit Vishal Singh, Shaimal Pratap, Shyneel Raj, Shivam Chand, Suraj Prasad, Alterzeem Khan, Rajnish Rishi, Pranish Chand, Ashvind Prasad, Krishneel Chand, Shamal Sumit, Avikesh Goundar, Achal Ashwini, Aadarsh Chand, Romina Kumar, Payal Andi, Dipshika Kumar, and other friends for providing continuous motivation, moral encouragement, innumerable blessing, indelible love and support without which I wouldn't have succeeded at any stage of life.

*I owe my parents more than I can tell them **Mr. Salend Kumar** and **Mrs. Roseline Lata** and my brother **Shamit Kumar** and my Beloved Grandfather **Mr. Shukh Deo**, Grandmother **Mrs Maya Wati**; and other family who gave me good wishes, love and continued support. They have always been a constant source of love and an encouragement to rely on in all times- Good and Bad. With all my heart, I dedicate the Thesis to them.*

Shamal Shasang Kumar

Place: Wadura, Sopore

Dated:

CONTENTS

Chapter	Particulars	Page No.
1.	INTRODUCTION	01
2.	REVIEW OF LITERATURE	06
2.1	Effect of different land use types on soil organic carbon and its pools	06
2.2	Effect of different land use types on basic soil properties	16
2.3	Effect of different land use types on soil microbial population	24
2.4	Effect of different land use types on organic carbon stocks	27
2.5	Effect of different land use types on carbon management index	31
3.	MATERIALS AND METHODS	33
3.1	Brief description of the study area	33
3.2	Total organic carbon and Walkley-Black carbon	35
3.3	Estimation of soil organic carbon pools	35
3.4	Estimation of basic soil properties	35
3.5	Microbial populations	36
3.6	Computation of soil organic carbon stock	37
3.7	Computation of Carbon Management Index	38
3.8	Statistical analysis	38
4.	EXPERIMENTAL FINDINGS	39
4.1	Basic soil properties	39
4.2	Soil microbial count	45

4.3	Organic carbon and lability based fractions	49
4.4	Organic carbon stocks	57
4.5	Comparison of OC stocks based on Mebius and Walkley-Black carbon method	68
4.6	Carbon Management Index	70
4.7	Correlation among various soil properties	71
5.	DISCUSSION	75
5.1	Basic soil properties under different land uses	75
5.2	Soil microbial population	78
5.3	Organic carbon and lability based fractions	80
5.4	Organic carbon stocks	83
5.5	Comparison of OC stocks based on Mebius and Walkley-Black carbon method	86
5.6	Carbon Management Index	86
5.7	Relationship between total organic carbon and functional organic carbon pools with other soil properties	87
6.	SUMMARY AND CONCLUSION	89
	LITERATURE CITED	i-xlvi

LIST OF TABLES

Table No.	Particulars	Page No.
3.1	Land uses and management practices adopted in the study area	34
4.1	Basic properties of surface (0-20 cm) and sub-surface (20-40 cm) soils under different land use types of study area	40-41
4.2	Biological properties of surface (0-20 cm) and sub-surface (20-40 cm) soils under different land use types of study area	47-48
4.3	Organic carbon and lability based fractions in surface layer (0-20 cm) of different soils in the study area	53-54
4.4	Organic carbon and lability based fractions in sub-surface layer (20-40 cm) of different soils in the study area	55-56
4.5	Total organic carbon stocks (Mg ha ⁻¹) in surface and sub-surface layers of different soils	58-59
4.6	Active organic carbon stocks (Mg ha ⁻¹) in surface and sub-surface layers of different soils	62-63
4.7	Passive organic carbon stocks (Mg ha ⁻¹) in surface and sub-surface layers of different soils	64-65
4.8	Walkley-Black carbon stocks (Mg ha ⁻¹) in surface and sub-surface layers of different soils	66-67

4.9	Comparison of TOC stocks (Mg ha^{-1}) based on Mebius and Walkley-Black carbon method in surface and sub-surface layers of different soils	69
4.10	Carbon Management Index as affected by different land uses (0-40 cm)	70
4.11	Pearson correlation coefficient (r) between functional soil organic carbon pools and total organic carbon with biological properties	73
4.12	Pearson correlation coefficient (r) between functional soil organic carbon pools and total organic carbon with organic carbon stocks	73
4.13	Pearson correlation coefficient (r) between functional soil organic carbon pools and total organic carbon with basic soil properties	74

LIST OF FIGURES

Figure No.	Particulars	After Page No.
3.1	Map of the study area	34
4.1	Soil pH of surface and sub-surface soils under different land use types	41
4.2	Electrical conductivity of surface and sub-surface soils under different land use types	41
4.3	Bulk density of surface and sub-surface soils under different land use types	44
4.4	Clay content of surface and sub-surface soils under different land use types	44
4.5	Total nitrogen of surface and sub-surface soils under different land use types	44
4.6	Viable bacteria (cfu*10 ⁻⁶ g ⁻¹) in surface and sub-surface soils under different land use types	44
4.7	Viable fungi (cfu*10 ⁻⁵ g ⁻¹) in surface and sub-surface soils under different land use types	48
4.8	Viable actinomycetes (cfu*10 ⁻⁵ g ⁻¹) in surface and sub-surface soils under different land use types	48
4.9	Organic carbon and lability based fractions in surface layer (0-20 cm) of different soils in the study area	56
4.10	Organic carbon and lability based fractions in sub-surface layer (20-40 cm) of different soils in the study area	56

4.11	Total organic carbon stocks (Mg ha ⁻¹) in surface and sub-surface layers of different soils	59
4.12	Active organic carbon stocks (Mg ha ⁻¹) in surface and sub-surface layers of different soils	59
4.13	Passive organic carbon stocks (Mg ha ⁻¹) in surface and sub-surface layers of different soils	67
4.14	Walkley-Black carbon stocks (Mg ha ⁻¹) in surface and sub-surface layers of different soils	67
4.15	Comparison of OC stocks (Mg ha ⁻¹) based on Mebius and Walkley-Black carbon method in surface and sub-surface layers of different soils	69
4.16	Carbon management index as affected by different land uses (0-40 cm)	69

ABBREVIATIONS

Above mean sea level	:	amsl
Active carbon	:	AC
Active organic carbon	:	AOC
Ammonia	:	NH ₃
Ammonium	:	NH ₄ ⁺
Bulk density	:	BD
Carbon	:	C
Carbon dioxide	:	CO ₂
Carbon management index	:	CMI
Carbon pool index	:	CPI
Cation exchange capacity	:	CEC
Centimetre	:	cm
Colony forming unit	:	cfu
Correlation coefficient	:	r
Critical difference	:	CD
Decisiemens per metre	:	dS m ⁻¹
Degree celsius	:	°C
East	:	E
Electrical conductivity	:	EC
Figure	:	Fig
Gigatons	:	Gt
Gram per gram	:	g g ⁻¹

Gram per kilogram	:	g kg^{-1}
Grams per centimetre cube	:	g cm^{-3}
Hectare	:	ha^{-1}
Hydrochloric acid	:	HCL
Labile carbon	:	LC
Lability	:	L
Lability index	:	LI
Land use change	:	LUC
Land use land cover	:	LULC
Less labile carbon	:	LLC
Mean annual temperature	:	MAT
Megagrams per cubic metre	:	Mg m^{-3}
Megagrams per hectare	:	Mg ha^{-1}
Metre	:	m
millilitre	:	ml
millimetre	:	mm
Million metric tons	:	Tg
Mineral associated organic carbon	:	MOC
Non labile carbon	:	NLC
Normality	:	N
Organic carbon	:	OC
Passive organic carbon	:	POC
Percent	:	%

Petagrams	:	Pg
Picograms per millilitre	:	pg ml ⁻¹
Potassium	:	K
Potassium dichromate	:	K ₂ Cr ₂ O ₇
Potassium permanganate	:	KMnO ₄ ⁻
Potential of hydrogen	:	pH
Sodium hydroxide	:	NaOH
Soil organic carbon	:	SOC
Soil organic matter	:	SOM
Species	:	spp.
Standard error	:	SE
Statistical package for the social science	:	SPSS
Sulfuric acid	:	H ₂ SO ₄
Tonnes per hectare	:	t ha ⁻¹
Total nitrogen	:	TN
Total organic carbon	:	TOC
Very labile carbon	:	VLC
Walkley-Black carbon	:	WBC

Chapter – 1

INTRODUCTION

Carbon can be seen as a fundamental unit of all life on the planet earth. There are five large pools in general where carbon is present; atmosphere, biosphere, lithosphere, oceans and soil. Soil plays a crucial role as a sink and in fluxes within the terrestrial system in the soil-plant-atmosphere cycle. Both inorganic and organic sources of carbon (C) are present in soils. Soil organic matter (SOM) comprises of succession of materials having different chemical composition with turnover period from days to millennia (Davidson and Janssens, 2006). The main primary element found in soil organic matter in terrestrial ecosystems is soil organic carbon (SOC) which is regarded as a core component of natural and managed soil (Manlay *et al.*, 2007). Carbon being a substantial part of SOM ultimately alters influences the basic properties (physical, chemical, biological) of soils. The quality and quantity of soil organic carbon is a critical determinant of soil quality and environmental protection (Lal, 2002). SOC is considered essential for the preservation of soil fertility and has an enormous impact on various properties and processes in soil (Pan *et al.*, 2009). It has been used to forecast planetary climate change (Kirschbaum, 2000). For understanding the dynamics of SOC which is a complex set of fractions, it is essential to know which of these fractions are active and which is passive on the basis of their physical protection or biochemical recalcitrance (Pere *et al.*, 2010).

The estimates of global SOC have extrapolated the organic carbon content of soil to up to 2500 Pg in upper one meter layer. Thus, soil is the largest terrestrial organic carbon pool and stores two-thirds of the total terrestrial organic carbon. Soils contain three times as much carbon as the global phytomass and twice as much carbon as the atmosphere (Batjes, 1996). However, owing to the anthropogenic interferences, the SOC can be one of the largest sources of carbon to the atmosphere (IPCC, 2007), depending on land use and management (Lal,

1999). Transitions in land utilization/land cover patterns are considered to be a crucial factor that affects the SOC pools. Lal (2004) has recorded that land use changes have resulted in a decrease in the cumulative SOC content by approximately 55 ± 78 Gt since 1750. The reason for this being the rate of input (e.g. plant litter) and rate of output (e.g. SOC mineralization) of SOM as a result of alterations in plant community and land management practice (Dawson and Smith, 2007). According to a study conducted in northern India, cultivated soils resulted in a loss of 21-36 % total organic carbon (TOC) as compared to uncultivated soils (Benbi *et al.* 2014) which is a little lesser than the values (30-60 %) reported in various agro-climatic regions of India (Lal R, 2004). Several studies have shown the decrease in SOC storage by changes from natural land use systems to an artificial land uses and the transition of an artificial land use pattern to a natural soil use pattern ultimately causes increment in soil organic carbon reservoirs (Guo and Gifford, 2002; Wei *et al.*, 2013; Hobley *et al.*, 2015). There are at least three factors that influence C emissions from land-use land-cover-change; these are the amount of C in the phytomass and soils (carbon stocks), the spatial distribution of carbon stocks, and the impacts of land management on phytomass and soil carbon stocks.

In order to understand how SOC losses occur or as to how it is stabilized in soil, the SOC is categorized into various functional pools which depend on residential period viz. labile and non-labile pool. The labile pool (active pool) is the most vulnerable pool that is available in small proportions since it is rapidly influenced by changes in environment. With any change in land use they quickly deteriorate and get easily oxidized (Haynes, 2005). Another SOC pool is the passive pool which known as the non-labile pool. This pool is relatively more stable and is composed of the recalcitrant fractions of SOC that form organic-mineral complexes with soil minerals is slowly broken down by microbial activity (Wiesenberg *et al.*, 2010). Therefore the labile SOC pool is critical for the immediate flow of carbon dioxide (CO₂), which is a better measure of the quality

of the soil in order to evaluate variations caused by changes in land use (Vieira *et al.* 2007), whereas the non-labile SOC pool it adds on to the TOC stock (Chan *et al.*, 2001). Rate of change in labile C is comparatively quicker as compared to SOC in whole soil (Sa Joao Carlos and Lal, 2009), and this can be considered as an early predictor for SOC changes in soil system (Franzluebbers and Arshad, 2010). Moreover, the carbon management index (CMI) originating from the total SOC pool and C lability has been widely used as a sensitive indicator of SOC heterogeneity.

Zou *et al.* (2005) has defined organic carbon lability in soils as that fraction of SOC which is easily degraded by soil microbes. They also assumed that a basic negatively exponential model oxidizes the labile organic carbon. Particular fractions obtained from different chemical and physical fractionation methods have been operationally described as soil labile organic carbon. The chemical fractionation involves the use of oxidizing agents, acids or bases for identifying slow and rapid turnover carbon. According to Alvarez and Alvarez (2000), the labile C fraction comprises mineral-free SOM carbon that consists of moderately decayed plant and animal remains, with a fast turnover density having a specific density which is comparably low than that of a mineral fraction. Various concepts and parameters have been used by soil scientists to describe the labile fraction of C in soil, consequently the terms such as dissolved organic carbon (based on solubility), light fraction organic carbon (based on density), particulate organic carbon (based on particle size), readily oxidized carbon (ease of oxidation) and soil microbial biomass carbon (carbon associated with microbial cells) [Weil *et al.*, 2003; Mirsky *et al.*, 2008; Cao *et al.*, 2013] are found in scientific literature.

Labile carbon fraction is more susceptible to management than the resistant fraction. In the international scientific studies on SOC it has been recorded that agricultural soils or intensively cultivated soils have lowest labile C (Murage *et al.* 2001; Vieira *et al.* 2007; Tan *et al.* 2007a; Gerai *et al.* 2016;

Sahoo *et al.* 2019; Mir *et al.* 2020) due to increased perturbation through tillage operations and crop residue removal. When contrasting the native land cover types for instance; forest and grasslands retain higher levels of labile carbon. This has been recorded in the temperate Kashmir Himalayas, as well (Sreekanth *et al.*, 2013; Monisa and Tahir, 2018; Mir *et al.*, 2020). As a matter of fact, the distribution of SOC into labile and non-labile or recalcitrant pools under different land uses has been found to be significantly different in majority of the studies (Murage *et al.*, 2001; Vieira *et al.*, 2007; Sainepo *et al.*, 2018; Yeasmin *et al.*, 2020; Mir *et al.*, 2020). Labile SOC fractions are known to have higher turnover rates than recalcitrant fractions and have more responsiveness to anthropogenic and management driven changes than the total SOC which is why they are given more priority as an indicator (Tan *et al.*, 2007b; Mikha *et al.*, 2013; Shao *et al.*, 2015; Yu *et al.*, 2017a; Pandher *et al.*, 2020). In undisturbed soils accumulation of more labile C occurs within aggregates that lead to enhanced protection and thus there are differences found in the chemical composition of unprotected and protected SOM (Golchin *et al.*, 1994; Six *et al.*, 2002). Since the types of land use systems influence the quantity and quality of litter inputs, decomposition and organic matter stabilization/protection processes in soils, therefore it is an essential component controlling SOM storage (Six *et al.*, 1999; Shepherd *et al.*, 2001; John *et al.*, 2005; Helfrich *et al.*, 2006).

Various studies regarding different SOC pools have been conducted in Kashmir Himalayas. The region has witnessed rampant land use changes even in the most ecologically and environmentally fragile, areas. In several studies the SOC content in forests has been reported to be in the range of 11.90-27.00 g kg⁻¹ (Dar and Sahu, 2018; Bangroo *et al.* 2020), for grasslands 17.00-24.50 g kg⁻¹ (Iqbal *et al.* 2020), in apple orchards 8.40-55.5 g kg⁻¹ (Sharma and Sood, 2020), maize fields 7.55-20.54 g kg⁻¹ and 4.27-10.40 g kg⁻¹ in paddy soils (Roheela, 2019). Decline in SOC and labile C pool due to cultivation/land use change has also been reported from southern parts of Kashmir (Monisa and Tahir, 2018).

Computation of SOC stocks for various parts of Kashmir reveals the range 6.57-54.10 Mg ha⁻¹ (Roheela, 2019; Javid and Somaiah, 2015) for different land uses types. However, meager published information is available about SOC and its different pools and stocks in the sub mountainous areas of Kupwara.

As observed by Garten and Wullschleger (1999) the overall SOM content in mineral soils can take decades to centuries to balance with changed environmental conditions caused by land use or management changes and it may also be difficult to scientifically establish those changes. Therefore, the characterization of more susceptible SOM fractions can be helpful in explaining improvements and trajectories in soil organic carbon at early stages of changes in land use and management. This study is based on a premise that soils under native vegetation covers in the area, have higher SOC concentration and stocks, as well as higher quantities of labile SOC fractions than agricultural land uses, and that these labile carbon fractions are more sensitive to changes in management and land use. Taking into account the aforementioned features and characteristics, as well as paucity of research related to these aspects, in the study area, the present investigation “**Functional Soil Organic Carbon Pools as Affected by Different Land Use Types in a Sub Mountainous Area of North Kashmir**” was carried out with the following objectives:

- To quantify various functional pools of soil organic carbon under different land use types of the study area.
- To evaluate carbon stocks and carbon management indices of various land use types.

Chapter – 2

REVIEW OF LITERATURE

Overview

Soil organic carbon, referred frequently as SOC, is known to be one of the most versatile and highly sensitive properties for land management and land-use systems. SOC is a critical soil component that enhances environmental quality, soil quality and fertility. Currently, the effect of land-use and land-cover changes on SOC and its pools has gained immense importance because of the implications on sustainability and C storage for mitigation of climate change crisis. Given the fact that land use type may have prominent influence on overall soil functioning, SOC pools and various properties (Liu *et al.* 2020; Mandal *et al.* 2020) a great deal of research has been done by various researchers on this subject, all over the world. In this chapter an effort has been made to collect and compile the relevant research highlights, under the following heads.

2.1 Effect of different land use types on soil organic carbon and its pools

Bauer and Black (1981) while conducting a study revealed that cultivated soils potentially lose 28-38 % of the SOC as compared to virgin grassland, after a 25 year of cultivation, based on the tillage practices. Bowman *et al.* (1990) also reported somewhat similar results; as such that approximately 60 % of SOC was lost in a sandy soil surface in eastern Colorado after 60 years of tillage.

Both nature and amount of organic carbon that is produced after decomposition of litter added to the soil by the aboveground vegetation, depends on the dominating tree species present aboveground and the site characteristics of the area, which regulates physio-chemical properties of soil. Vegetation is one of the major soil formers, since it creates litter forming the organic soil (Chapman and Reiss, 1992). Kushalappa (1986) recorded higher organic matter in the soils

under vegetation compared with barren soil. Raina and Gupta (2013) in the Himalayas of Garhwal noted similar results.

The conversion of natural habitats into croplands in the United States has resulted in 5,000 Tg (million metric tons) of C being released into the atmosphere. In New Zealand, in less than 20 years, conversion from grassland to forest plantation decreased OC by 9.5% in upper layers (Davis and Condron, 2002).

Abha *et al.* (2003) on the basis of 175 observations recorded that average SOC (t ha^{-1}) estimates in 0-50 cm varied between 37.5 in the tropical dry deciduous forest and 92.1 in the littoral swamp forest. In Indian forests, the total OC pools are 4.13 and 6.81 Pg C^{-1} in top 50 cm and 1 meter.

Lal (2004) reported that changes in land use, including deforestation and natural ecosystem conversion to agricultural ecosystems leads to enhanced CO_2 emissions into the atmosphere resulting in global warming.

The decrease in soil C after the forestland/grasslands conversion into agricultural land is well-known, according to Post and Kwon (2000). Qian *et al.* (2008) found that the SOC for fallow land (FL) is more than that for other lands in steppe grasslands in Inner Mongolia. Also Chen *et al.* (2010) while studying three land-use-types (natural grassland, crop-field and abandoned old-field-10 year) in north-eastern Tibetan plateau, found that the percentage loss of SOC due to cultivation were about 45. It was also revealed that cultivation decreases OM and microbial biomass in soils.

According to Allmaras *et al.* (2000), soil function management and sustainability are primarily influenced by the quality and quantity of soil organic matter. According to the study, conversion to crop production practices results in a significant drop in SOM compared to the initial grasslands.

Zhang *et al.* (2006) carried out an investigation and reported that highest TOC and magnitudes of labile fraction of OC was found in the 0-20 cm of the

upland forest and least in cultivated land. In addition a decline in the labile OC fraction with depth was noted.

Abbasi *et al.* (2007) in their study in the mountain region of Rawalakot Kashmir revealed that the OC at 0-15 and 15-30 cm depth under forests was 24.6-14.4 g kg⁻¹, grasslands was 13.3-9.8 g kg⁻¹, whereas arable lands had 9.3-8.4 g kg⁻¹ and the OC decreased with soil depth.

Sevgi and Tecimen (2008) in an investigation found that in natural forests high OC was a result of net return of litter. Upon degradation of litter, nutrients are released which is considered as a fundamental process in biogeochemical cycles, where vegetation and soil account for 44 and 56 %, respectively.

Zhang *et al.* (2009) while examining forest type impact on soil labile OC content and seasonal changes for Huitong County, Hunan Province, China stated that forest types affect the quantity and quality of added OC.

Datta *et al.* (2010) reported that labile fraction of C in soil enhances the available soil nutrient contents. The correlation coefficients of soil pH, bulk density, cation exchange capacity, total nitrogen, and exchangeable K, according to Papini *et al.* (2011), are related to SOC concentration.

Don *et al.* (2011) stated that most of the higher levels of SOC losses have been due to the transition from primary forest into cropland and perennial crops. Secondary forests conserve fewer OC as compared to the primary forests that demonstrate importance of primary forests in C-storage.

In rice fields OC captured is fast and more apparent as compared to other arable land, due to the reduced rate at which decomposition of OM in lowland rice fields prevails (Wu, 2011).

Gupta and Sharma (2012) in their experiment on several pools of OC under different vegetation's in Uttarkashi district of Uttarakhand reported that

TOC increased in the order: forests, orchard, grassland and plantations, respectively.

Sharma *et al.* (2014) reported mean OC contents in the surface soils was highest in forests (7.22), followed by horticulture (6.47), degraded lands (6.00) and agriculture (5.89) g kg⁻¹. MBC in the same depth was maximum in forests (107.9 mg kg⁻¹), followed by horticulture (88.5) and agriculture (69.7) mg kg⁻¹, whereas degraded soils showed lowest MBC (76.7 mg kg⁻¹). In KMnO₄ oxidizable C fraction (mg kg⁻¹), highest was recorded under forests (957.9), followed by agriculture, horticulture and degraded land use.

Szopka *et al.* (2016) carried out a study in the Karkonosze Mountains of Poland and found that concentration of SOC and its pools in forest soils increased with elevations but substantially declined with profile depth. The largest portion of the SOC accumulated in 0 to 10 cm layer with the high altitude zone (> 1250 m) having larger quantities of SOC.

Geraei *et al.* (2016) reported that the TOC and labile OC pools follows the order: forest (F) > pasture (P) > forest (F) for agricultural use (A) > pasture (P) for farming (A). Nevertheless, P soils demonstrate higher and different level of OC than the other land uses.

In a study on different land use, Maqbool *et al.* (2017a) reported that SOC ranged from 0.10 to 37.4 g kg⁻¹. The SOC was found highest under forests (23.68), pasture (20.80) and lowest was recorded under waste lands (3.80) and agricultural irrigated (4.35) land use.

Meetei *et al.* (2017) reported that forests and grasslands exhibit high concentrations and higher soil organic carbon stocks than rice growing soils. Forest land exhibited higher SOC then the lands which were cultivated. Most of the forest and grassland SOC exists in easily oxidisable labile form, suggesting that accumulated C can be lost by change in land use.

Total OC and KMnO_4^- oxidizable C (KOC) contents in peat soil profiles increase with increase in depth among various land uses. Peat land converted to paddy field affects TOC content at each depth. In cultivated soils, for instance rice growing soils, KOC content is lower, thus indicating that cultivation is lowering KOC (Wang *et al.*, 2017).

A comprehensive study to evaluate the dynamics of VLC, LC, LLC, NLC and OC sequestration in fruit orchards of eastern plateau and hill region of India was conducted by Naik *et al.* (2017), revealing that orchards had highest significant increase of 20.7, 13.5 and 17.4 % in VLC, LC and NLC.

A study done by Yu *et al.* (2017b) has shown that overall SOC and SOC fractions are influenced by land use, while the C differential is far less pronounced in VLC and LLC. This suggests that land use type has a major role to play in affecting C fractions and the LC fraction makes a substantial portion of total OC.

Niaz *et al.* (2017) reported that OC, particulate OC (POC), mineral-associated OC and aggregate-associated OC (AOC) were highest in forest type of soils.

Bojko and Kabala (2017) found that at altitudes more than 1000 m asl SOC in different pools increases and then decreases in uppermost forest and subalpine zone. There are strong links between the use of land/vegetation and the type of soil and humus, reflecting their differences.

Kumar and Gupta (2017) conducted a study in the region of Garhwal Himalayas under three different forest communities i.e. Sal forest, Chir-Pine forest and Oak forest and their adjacent barren lands. They found out that SOC under natural Oak forest was 87.69 t ha^{-1} , whereas SOC pool was 44.63 t ha^{-1} in barren land near the Oak forest. Also the SOC pool under Chir Pine forest and Sal forest was higher than under barren land near Chir Pine forest and Sal forest. SOC

pool was 89.59, 58.26 and 96.48 % higher under Sal, Pine and Oak vegetation as compared to their nearby barren lands.

Ali *et al.* (2017a) found that in Bagrot valley, Northern Karakoram, Gilgit-Baltistan, Pakistan variations exists across different land uses with altitudes. Soils under forest had higher SOC as compared to pastures and arable land. Moreover, SOC increases as altitude increases and consequently decreases with depth of soil.

Oliveira *et al.* (2017) in a study, reveals that TOC in regions undergoing land use change (LUC) is a good expression of SOM change and integrated approaches such as the CMI are quite suitable for assessing LUC's effects on SOM.

Sainepo *et al.* (2018) reported that Shrub lands as compared to grasslands and bare lands have higher TOC. For soil degradation or various improvements in land uses, CMI can be used as an index. Furthermore, SOC pools and CMI are consequently affected by changes in land use.

Chatterjee *et al.* (2018) reported that TOC increases in irrigated treatments rather than rainfed treatment at soil depths of 0-5 cm. Crop residue as mulching increases TOC content at 0-5 cm of the soil in comparison to treatment with no mulch. Thus it indicates that irrigation and residue mulches (crop) enhance and increase CMI.

Grasslands have the capability of capturing and retaining approximately 34-35 % of global terrestrial C and it is essential for various ecosystem services; forage and climate. Various management practices have an impact on nearly 89 % of the C stored in grasslands (Eze *et al.*, 2018).

Thangavel *et al.* (2018) while carrying out a study on land use pattern changes concluded that land use conversion can be a useful indicator with CMI under mid-altitude subtropical ecosystems since the labile SOC fractions are very sensitive to changes with land uses.

Zhao *et al.* (2018) conducted an experiment in Qinghai-Tibetan Plateau which reveals that the O-alkyl carbon is dominant in alpine meadow, alpine steppe and cultivated grasslands.

Meena *et al.* (2018) reported that different land uses influence the soil C pools at 0-15, 15-30 and 30-45 cm, respectively. Highest non-labile C (g kg^{-1}) was found in forests (27.48), followed by grass land (23.07) and cultivated and barren lands. At 15-30 cm depth, the NLC was in the order as; FL > GL > CL > BL ecosystem. Moreover in 30-45 cm soil depth, forest land was superior to the other land uses.

Mandal *et al.* (2018) carried out a brief study and reveals that the SOC (g kg^{-1}) was higher in horticultural land (8.91), followed by cropland (5.96) and uncultivated land (3.65) in surface soils. A similar trend was found at 15-30 cm soil depth.

Hussain *et al.* (2019) reported that TOC in forest soils is higher when compared to horticultural soils whereas in degraded and agricultural systems it is comparatively less. The study exhorts that carbon-security by land-use systems must be encouraged in order to preserve high C-rich soil and encourage sustainable development in hilly ecosystems like the Himalayas.

A study by Sahoo *et al.* (2019) reveals that TOC is more in natural forest than grasslands and it decreases with increase in depth. The active carbon (AC) portion of the pool is seen greater in wet rice cultivation and is found lowest in natural forest systems. Moreover, AC in most land use systems is highly vulnerable to changes.

Kumar and Sangwan (2019) have noted that in agroforestry systems SOC is abundantly found when compared to agriculture land use systems.

In a study conducted by Sun *et al.* (2019) in China, TOC at 0-20 cm depth decreased with increase in mean annual temperature (MAT). In forests SOC

content in topsoil decreases and is more chemically recalcitrant as MAT increases without causing any change in the SOC physical fraction.

Mohamed *et al.* (2019) recorded variations of soil organic carbon pools with texture. Soil that had high clay content was reported to have higher SOC, next were clay loams and loamy soils. This highlights how soil conditions respond to land-use change and how this affects surface SOC and C sequestration.

Brito *et al.* (2019) stated that the conversions of various kinds has a negative impact on SOC dynamics especially the OC labile pools with effects that exceeds soil variability in response to land conversions.

Monisa and Tahir (2018) carried out a comprehensive study on lability based soil C fractions in South Kashmir and reported that the TOC under forest ranged between 72.37-113.69, grassland 63.43-93.71, agriculture 40.01-63.04 and in horticulture 32.30-65.85 g kg⁻¹ from 0-15 and 15-30 cm depths. Forest lands had the highest TOC, while agriculture fields had the lowest. Very labile and labile carbon was more in grasslands whereas the passive pools (less labile + non-labile) was highest in forest lands.

Hussain *et al.* (2019) reported that the TOC content ranged between 8.5 to 29.5, 17.5 to 33.0, 14.5 to 37.5 and 11.0 to 23.5 g kg⁻¹ having mean values 17.1, 24.3, 22.4 and 17.7 g kg⁻¹ in 0-15 cm under agriculture, forest, horticulture and degraded lands, respectively. Forests had the highest TOC, followed by horticulture, degraded land, and agriculture land use system, which had the lowest.

Lei and McDonald (2019) reported that land use types, depth and various interactions all have drastic influence on OC, its pools, stocks and CMI. Badole *et al.* (2020) found that converting land i.e. natural to agricultural systems, causing reduction of C stocks. It was concluded that turnover of C pools with respect to land-use transition; intensive cultivation may interrupt soil functioning causing

oxidative loss of OC. OC is primarily conserved in soil by forest/horticulture systems, which supports ecosystem function.

Babu *et al.* (2020) reported that undisturbed forest soils sequester higher OC, active C, and passive C pool. Mishra and Sarkar (2020) found that positive link exists among TOC, C pools; active and passive fractions in most land uses where highest and lowest value of TOC stock, C (active and passive) were in plantations and *degraded* lands. Similarly, both the active and passive C pools were highest under plantation crops. This reveals the importance of permanent plantations as a promising C sequestration to minimize adverse effects of climate change.

Ren *et al.* (2020) reported that in the 2000s, the total density of SOC₁ and SOC₂ has increased up 125 and 48.8 % respectively as compared with early 20th century. Via factor research it is asserted that over the past 110 years, climate change has lowered the overall SOC by about 3.2 % (or 2.166 Tg C). Cropland has immense promise for sequestration of C through better management of land use, partly compensating for climate change SOC losses.

The study conducted by Pasricha and Ghosh (2020) reveals that the labile SOC pools are the first in various management practices to be affected by grassland changes.

Srinivasarao *et al.* (2020) reported that OC is highest in agri-silviculture, followed by the silvi-pasture and agri-silvi-horti systems. Thus, suggesting that frequent addition of nutrients along with OM enhances C storage in soils.

Yu *et al.* (2020) while carrying out a comprehensive study on organic and inorganic C in soil and other properties concluded that in grasslands carbon content and stocks have no difference in comparison with forest land. The study suggests that grasslands have more potential than forest lands or crop lands for carbon fixation and soil erosion reduction.

Wehr *et al.* (2020) reported that land use along with location influences SOC. Transformation of pasture land to cropping system decreases SOC and N to a depth of 0.5 m.

The OC content decreases in regions where the land use type shifts e.g. vegetable land to grain cropland. In regions when the land use changes to either orchard or forestland; grassland to orchard and forestland its OC content increases (Shi *et al.*, 2020).

Maini *et al.* (2020) recorded various oxidisable C fractions in soils of six rainfed land use systems in north eastern part of India and regarded that the three most essential soil quality indicators for soil health are CMI, metabolic potential, and TOC.

Dar *et al.* (2020) in a study on four agroforestry systems in temperate conditions of Kashmir Himalaya revealed that the SOC in home gardens was 1.96 %, horti-agri system 1.26 %, boundary plantation 1.16 % and horti-silvipastoral system had 1.76 %. This reveals that organic carbon in home garden was high in Kashmir.

Mir *et al.* (2020) carried out a study in different land uses of temperate Himalayan and reported that highest OC (g kg^{-1}) was found under wetland (53.5), followed by forests (21.5), grassland (16.4), vegetable (15.1), apple (10.8) and lowest was recorded in rice and maize (10.30), respectively. The highest labile carbon (mg kg^{-1}) was found under wetland (10.3), followed by forests (3.64), grassland (2.32), apple (1.73), rice (1.66), maize (1.60) and lowest (1.58) under vegetable land use.

2.2 Effect of different land use types on basic soil properties

2.2.1 Soil reaction (pH)

Pal *et al.* (2013) reported that the pH of soil at 0-15 cm was 5.22, 5.69, 5.46, 5.50, 5.60 under forest, grassland, horticulture, agriculture and wasteland, where highest pH was found under grassland, followed by wasteland, agriculture and horticulture, while lowest was in forest soils.

Takoutsing *et al.* (2016) found that converting forests to other land uses has a significant impact on the distribution of SOC and supply of soil nutrients. Land use type influences nutrient availability and soil pH. These characteristics are much more prominent in secondary forest and fallow land.

Zhao *et al.* (2017) reported that the major factors influencing SOC density is mean annual temperature and soil pH. The pH of the soil being regarded as one of the most intrinsic factor that controls the soil C pools. Numerous studies have proven that pH has a strong link with soil OC storage and it influences microbial functioning that directly affects SOM matter turnover (Senechkin *et al.*, 2014; Tavakkoli *et al.*, 2015; Dlamini *et al.*, 2016).

Pham *et al.* (2018) reported in plantation forests and arable land use types; soil depth change has a relationship with soil pH. The grasslands, natural and plantation forests land uses are acidic as compared to arable land use type.

Zhou *et al.* (2019) reported that pH in topsoil with increasing depth tends and then decreases with increase in depth at the lower sub-surface layers. The soil C, N, and C/N are negatively related to pH, with low pH being advantageous to organic matter accumulation.

Alaie *et al.* (2019) carried out a study in different land use systems in district Doda: agriculture, barren lands, forests and horticulture; and reported that soil pH is moderately acidic to slightly alkaline which is thus safe for growth and

development of plants. The highest soil pH was reported in soils of barren land followed by agriculture > horticulture > forest.

Sun *et al.* (2020a) reported that pH of soil is an important soil parameter which has links to storage of carbon and nutrient cycling. Study reveals that mean pH of paddy soils reduced over two decades whereas in dry farmland area it also reduced but an increasing trend was seen in soils in woodland south

Forest conversion to agricultural and other land use systems has become a major concern. The effects of changing land use from forest to agriculture, orchard, and agroforestry on soil physico-chemical qualities have been observed in Western Iran. The pH of soil increased with land use depth except at agricultural sites (Samani *et al.*, 2020).

Namgial *et al.* (2020) in their study on estimation of nutrients in seven different land uses including agriculture, found that pH of soils followed the order as agriculture > horticulture > agrisilviculture > agrihorticulture > silvipasture > hortisilvipasture > agrihortisilviculture.

Tahir *et al.* (2021) in an investigation reported that in various land uses of sub-temperate highlands of Azad Kashmir, croplands had an alkaline soil pH 7.13, grasslands 7.0 and forestlands had 6.64 which indicate a high pH value of nearly 2-7% in croplands.

George *et al.* (2021) in their study on different land uses reported that the soil pH values had mean values of 7.24, 7.29, 7.41, 6.56, and 7.69 under paddy, maize, apple, forest and wasteland, respectively. Highest pH was recorded under wasteland, followed by apple and lowest was in forest lands.

2.2.2 Electrical conductivity (EC)

In a study Negasa *et al.* (2017) revealed that EC varied among the different land use types (agroforestry land- AG, cultivated land- CL and grazing

land- GL). The agroforestry land use type had a high EC whereas for cultivated land use types it had lower EC with slope.

Kaur *et al.* (2017) reported that the EC ranges with minimum value in grassland viz. 0.13 dS m^{-1} to a maximum in the cropland i.e. 0.22. Cropland had the greatest EC value due to the incorporation of different salts through fertilizer treatments. Grassland has the lowest value, followed by forestry. In comparison to sub-surface soils, the surface soil has a greater EC (Sondhi 1992 and Nazir 1993).

Maqbool *et al.* (2017b) carried out a study in district Ganderbal of Kashmir and revealed that selected lands were non-saline but the EC in forests were lower than agriculture soil with mean of 0.09 and 0.17 dS m^{-1} . Sharma *et al.* (2013) reported that EC values in forests and paddy soils was similar (0.10 to 0.28 dSm^{-1}), Farida (1997) reported that EC in Karewa and valley basin soils in Kashmir had a range between 0.14 to 0.15, 0.15 to 0.24 and 0.30 to 0.42 dS m^{-1} , respectively.

Wani *et al.* (2017) reported that the EC (dS m^{-1}) in pear orchards was in a normal range and at higher altitudes it ranged from 0.12-0.22 in surface and 0.19-0.29 in sub-surface soil, in mid altitude it ranged from 0.23-0.49 and 0.41-0.48 at surface and sub-surface level, while in the lower altitudes it ranged between 0.13-0.41 and 0.33-0.41, respectively, indicating that the EC increases with depth and has an increasing trend with decrease in altitude.

According to Liu *et al.* (2018a), EC is one of the best discriminating indices for land use change. The actual drivers of soil microbial traits in an area are soil physico-chemical variables, which reflect changes in land-use patterns.

Alaie *et al.* (2019) reported that in Doda district different land use systems (Agriculture, Barren lands, Forest, Horticulture) had $\text{EC} < 1 \text{ dS m}^{-1}$ that pictured non-saline conditions that are safe for growth of plants. The EC had a range

between 0.08-0.31 in forests, 0.18-0.77 under barren land, 0.11-0.45 in agricultural land and 0.10-0.35 dS m⁻¹ under horticulture, respectively.

Anindita *et al.* (2020) reported that different land use alters various properties of soil like EC, pH and cations with drastic effects on soil C dynamics.

2.2.3 Bulk density (BD)

The increase in soil BD occurs when forest land use types are converted to other land use types that lowers the water conductivity and results in higher soil erosion losses that causes degradation of soil and also causing reduction in the SOC density (Lal, 2003 and Lal *et al.*, 1997).

Celik (2005) conducted a study and revealed that cultivated lands have higher BD as compared to forests and pastures at 0-10 and 10-20 cm depth. In pasture lowest BD was seen 1.16 Mg m⁻³ at 10-20 cm depth but in cultivated lands high BD was found i.e. 1.37 Mg m⁻³.

Jiao *et al.* (2009) indicated that OC is negatively associated with BD or land use but it depends positively on TN contents. Li *et al.* (2007) revealed that enhancements in properties viz. soil aggregation, BD, particle density leads to changes in TOC fractions under long duration of annually grown pastures i.e. oats and short duration perennial pasture relative to those found in adjacent native pasture lands.

Chimdi *et al.* (2012) reported that changes in land use often decrease CEC, interchangeable bases and increase BD and Clay proportions.

Ravina (2012) found that in a particular Brazilian soil at 0-15 cm depth, BD is higher under *Eucalyptus* spp. plantation (1.24 g cm³) than in native forest (0.66 g cm³). Furthermore, according to Kolay (2000), the BD of natural productive soils ranges from 1.1 to 1.5 g cm³.

Kumar *et al.* (2018) reported that in north-western Himalayas the BD (Mg m^{-3}) at 0-15 and 15-30 cm depth in forests was 1.33 and 1.35, horticulture had 1.49 and 1.51, agriculture 1.52 and 1.54, pasture 1.32 and 1.34 and degraded land had BD values of 1.54 and 1.57, respectively. The highest BD was identified in degraded land use at both soil depths, while the lowest was found in pasture land use.

Soil BD changes with land use and altitude, according to Valentine *et al.* (2018), with substantial interactions between land use and elevation. Natural forest had the lowest BD (g cm^{-3}) among all land uses/land cover systems at all altitudes, followed by soil under *E. saligna* plantation, whereas agricultural and grazing land had high BD. Farmland had the highest BD, while those found in natural forest had least in top 0-15 cm soil layer. These findings confirm findings of Aweto and Moleele (2005) that plantations increase BD more than native forests.

2.2.4 Clay content

Abbasi and Rasool (2005) while carrying out a study reported that highest clay content (%) at 0-15 cm and 15-30 cm soil depth was found under forest (33 and 37), followed by grassland (22 and 29) and lowest under arable (18 and 22), respectively.

Wiesmeier *et al.* (2012) reported that the soil texture for croplands, grasslands and other soil was comparable, with sand proportions of 31-42 %, silt 30-46 %, and clay (%) at 23-29. The sand content significantly increased with soil depth, while the silt was slightly lower. Forest sites show 42-47 % sand content and lower (15-21 %) clay levels.

Negasa *et al.* (2017) in a study reveals that for various land use (agroforestry, cultivated land and grazing lands) each having upper, middle and

lower slope categories, the sand, clay and soil BD considerably vary among land uses, while sand, silt, clay, SOC and TN exhibits variations with slopes.

Kaur *et al.* (2017) in a study on soils of croplands and forest land use recorded higher clay and silt content in the latter; however, there was no clear pattern of clay relative to soil depth. The findings of Gilley and Doran (1997) and of Singh *et al.* (2005) on clay content are similar.

Bangroo *et al.* (2018) in a comprehensive investigation on apple orchards in district Kulgam revealed that the clay content (%) under the apple land use ranged from 22.3 to 33.9.

Abrol *et al.* (2019) reported that the clay (%) in 0-22 cm under forest land use was 28.7, in agricultural land 24.57, horticulture 26.52 and barren land had 15.37. At the sub-surface (22-45 cm) clay content under forest land use was 28.2; in agricultural land 23.44; horticulture 24.06 and barren land had 14.24. The highest clay at surface and sub-surface was recorded under forest, followed by horticulture, agriculture and least was under barren land use.

Lucas *et al.* (2019) in a study revealed that the clay content found were similar between abandoned farmland (AF) and intensive agriculture (IA). Meanwhile the texture of the forest plots (FO) varied differently with other types of lands. The soil in the AF and IA land uses (clay loam and loam, respectively) was finer, while the soil in the FO land use was coarser.

Samani *et al.* (2020) in a study on land use transitions revealed that the sand particles decreases while clay and silt particles increases in content, resulting in a finer soil texture. As a result of the decrease in OM, the quantity of N, P, OC, and EC in soil is reduced.

A large amount of C is deposited in sand aggregated fractions in agricultural land that has long-term cultivation, but is more often found in silt and clay in sites having short-term cultivation (Anindita *et al.*, 2020).

2.2.5 Soil total nitrogen (TN)

According to Dawit *et al.* (2002) and Malo *et al.* (2005), TN levels are higher in non-cultivated lands than in cultivated areas. TN content is related mainly with TOC and it decreases as depth of soils increases due to reduced humus content.

Nega (2006) reported that the average TN shows significant variation among cultivated land, grazing and forest land soils. Malo *et al.* (2005) in their study reveal that lower N levels are found in cultivated fields as opposed to other soil usage, which means that the addition of fertilizer does not replace the total loss of N in humus, which is due to harvesting, leaching and cultivation.

Rapid and injudicious cultivation practices may result in increased OC oxidation and TN losses in cultivated lands, resulting in low levels of OC and TN. In agreement with these findings, Heluf and Wakene (2006) showed that virgin land has the highest TN in the surface soil layers when compared to a research field and a farmer's field.

In a comprehensive investigation, Yimer *et al.* (2007) found that TN content is affected by both land use and soil depth. The TN in grazing lands (0.66 %) and native forest (0.72 %) at 0-20 cm was higher when compared to croplands (0.56 %).

Yifru and Taye (2011) reported that TN content varies in the order; cultivated land < fallow land < grassland < forest land. At 0-15 cm soil depth, grassland soils have higher TN than cultivated soils, although fallow lands have higher TN than cultivated soils. In cultivated soils at all depths as compared to

grasslands and forestlands lower TN is found, thus indicating that frequent cultivation reduces the TN content.

Emiru and Gebrekidan (2013) in their study reveal that soil pH, OM, TN and available P are four vital soil properties that respond to land use change. TN is influenced highly by soil depth, and TN contents under the grazing and cultivated fields are seemingly lower than in soils under natural forest.

Singh and Benbi (2018) in West Himalayas reported that the highest SOC was recorded in the forest areas, followed by silvopastoral, horticulture, agrihorticulture, agrisilviculture, agrihortisilviculture, grasslands and agriculture. TN is also higher in forest and silvopastoral land use among agroforestry systems.

Soil TN is an important measure of soil health. Bangroo *et al.* (2019) reported that Soil TN concentration decreases with depth in paddy crops (PC), apple orchards (AO) and apple intercropping (AI). It can be related that stocks of STN in PC and AO are less than AI thus apple intercropping systems can mainly cater more STN stocks relative to paddy and apple monoculture system. The highest TN was recorded under AI (0.72 kg m^{-2}), AO (0.64 kg m^{-2}) and lowest (0.55 kg m^{-2}) under PC based crop system.

Lizaga *et al.* (2019) reported higher SOC in pine afforested area and high mean TN value in the natural forest. Under agricultural lands lowest SOC and TN is found. The researchers attributed it to the effects of soil changes in Mediterranean mountain agroecosystems caused by land use changes.

Srivastava *et al.* (2020) reported that TN decreases 83-87 % in degraded lands when compared to forest land. The relation between poor indicators of soil quality in land use (degraded and agricultural land) and characteristics such as TN loss causes a loss of natural soil diversity.

In an investigation on spatial prediction of TN (g kg^{-1}) in the North Kashmir Himalayas, Bangroo *et al.* (2020) found that it ranged from 1.06 to 3.52, with a mean of 2.31 g kg^{-1} under the forest land use type.

According to Wong *et al.* (2020), TN levels are highest in forest ecosystems, followed by rubber plantations, and lastly in oil palm plantations (forest ecosystems > rubber plantations > oil palm). It was concluded that there is an associative relationship between soil physico-chemical properties and micro-habitats.

Olorunfemi *et al.* (2020) reported that TN concentration in land uses i.e. forests, plantations, woodland and croplands decreases substantially as depth increases.

2.3 Effect of different land use types on soil microbial population

Comparisons were made in four different types of lands (cultivated, pasture, pine plantation and mixed wood forest) in Georgia USA, which reveal that actinobacteria was found in high abundance in pastures and cultivated lands (Lauber *et al.*, 2009). In the study of forests, pastures and sugarcane plantations, Burck *et al.* (1989) have also stated that Actinomycetes are in higher numbers in farmland use compared to forest soils in different countries. Furthermore, as the land was converted from forest to farmland, the population of actinomycetes rose (Fierer *et al.*, 2009).

Abbasi *et al.* (2010) reveals that forest lands total count of bacteria, actinomycetes and fungi was 6.38-15.27 (10^5), 3.72-11.45 (10^5), 0.8-3.47 (10^3), respectively. In grasslands total recorded count of bacteria, actinomycetes and fungi was 5.27-8.32, 3.28-5.23, 0.78-2.02, respectively. While arable land use recorded the bacterial, actinomycetes and fungal counts of 4.52-5.67 (10^5), 2.66-3.45 (10^5), and 0.43-1.60 (10^3), respectively. When comparing grasslands and arable land, the mean values revealed that forests had 2-3 times the amount of

bacteria, actinomycetes, and fungi. Forests had the highest microbial count, followed by grasslands, while arable land had the lowest.

Rebecca *et al.* (2010) in a study reveals that the main factors which regulate microbial biomass and its composition is land use which is linked to water availability and disturbances. Higher count of gram-negative bacteria and fungi were found in dry soils and in wetter soils gram-positive, anaerobic and sulphate-reducing bacteria were seen. Disturbed soils had lower fungal and more bacterial gram-positive biomass than wild land soils.

Actinomycetes populations in irrigated cultivated land fell from 2.86×10^6 cfu g⁻¹ to 7.00×10^5 cfu g⁻¹ on pasture areas, according to Ghorbani *et al.*, (2013).

Tian *et al.* (2017) reported that soil quality had the following order; natural forest > plantation > bare land. The bacterial communities are affected more due to SOC, whereas fungal communities are more oriented to phosphorus (P).

Ahmad *et al.* (2017) in a study on rhizospheric soils of apple in Kashmir reported that viable bacterial (cfu $\times 10^6$ g⁻¹) ranged between 77.36 to 86.16 with a mean value of 82.40. The viable fungi (cfu $\times 10^4$ g⁻¹) had a range of 52.05 and 60.58 with a mean value 58.41. As for the viable actinomycetes (cfu $\times 10^5$ g⁻¹) it ranged between 32.75 to 29.60 having a mean of 31.62 in apple orchards.

Fozia *et al.* (2018) in a study on assessing microbial populations in various land uses in North western Kashmir reported that the viable bacteria under forest (cfu $\times 10^6$ g⁻¹) ranged between 92-244, fruits (91-201), agriculture (8-96), agri-horticulture (124-216) and pasture (88-236) cfu $\times 10^6$ g⁻¹. Viable fungi (cfu $\times 10^5$ g⁻¹) under forest ranged 72-120, fruits (15-52), agriculture (0-43), agri-horticulture (16-68) and pasture (0-96) cfu $\times 10^5$ g⁻¹. Viable actinomycetes (cfu $\times 10^5$ g⁻¹) under forest ranged 52-96, fruits (0-40), agriculture (0-30), agri-horticulture (8-56) and pasture (0-76) cfu $\times 10^5$ g⁻¹. The highest bacterial counts were found in forest areas, whereas the lowest were found in agriculture land. Forests had the highest

fungal count, whereas agricultural fields had the lowest. Forest land recorded highest actinomycete while lowest was found under agriculture land.

Land use changes are one of the main and most severe threats to soil biodiversity, according to Munoz *et al.*, (2020). Land use change has little effect on archaea diversity, but it does reduce bacterial diversity when forests are converted to arable land.

An experiment by Li *et al.* (2020) indicates that microbial diversity and microbial activities change drastically in permanent upland and paddy soils due to conversion in land use. Bacterial population decreased as upland fields were converted to paddy systems.

According to Mhete *et al.* (2020), bacterial diversity is determined by the degree of habitat disturbance, which is induced by differences in land use management methods, which change soil properties.

Soil microbial populations have a significant role to play in the biogeochemical cycles and land use conversion being one primary factor which has an impact on biodiversity and functioning of terrestrial ecosystem. Bacterial population is higher in forest soils as compared to agricultural land (Wu *et al.*, 2020).

Sun *et al.* (2020b) revealed that soil bacterial diversity is altered by land use changes but it does influence its alpha diversity. The beta-diversity of bacteria is reduced in younger rubber plantations and in croplands as related to forests whereas the beta-diversity of bacteria increases in older rubber plantations, thus giving indications of the effect of planting time.

Kavitha *et al.* (2020) reported that fungal population in forest areas was found to be higher than that of the other ecosystem. In forest ecosystem, fungal

population was 134×10^5 cfu g^{-1} soil, followed by Agro-ecosystem and polluted soil (125 , 116.25 and 71.5×10^5 cfu g^{-1}), respectively.

Ahmad *et al.* (2020) in a study on soil biological properties under different land uses (forest, pasture, apple, vegetable, maize and paddy) in north eastern Kashmir reported that total viable bacterial count (cfu $\times 10^6$ g^{-1}) had a range from 52-89 under different land uses. Viable fungal count (cfu $\times 10^5$ g^{-1}) ranged between 7-38. Maximum bacteria was recorded under forests (76) and followed by pastures whereas the lowest was recorded under maize (63) land. As for the viable fungi, it was higher under forests (30) and pasture (28) land in comparison to other lands, whereas paddy soils had lowest (12) viable fungal count.

2.4 Effect of different land use types on organic carbon stocks

Susmita *et al.* (2010) reported that horizontal variability of SOC content vary according to soil depth. A primary influence of SOC stock is land use and management processes. Land use and depth of soils influence OC stocks in which a successful C sink is forest systems.

Munoz *et al.* (2012) reported that scrub/vegetation's have 115.92 Tg C in an area of 22 561.98 km^2 , permanent crops (94.65 Tg C) in 17 275.66 km^2 , arable lands (84.59 Tg C) in 15 468.49 km^2 and forest contain (67.60 Tg C) in 15 911.37 km^2 . Also the soil orders having more OC stocks are Cambisols, Regosols and Vertisols.

Sharma *et al.* (2014) in their study in foothills Himalayas revealed that OC stocks ($Mg\ ha^{-1}$) in 0-50 cm was maximum in forests (47.5), followed by horticulture (42.4), degraded land (36.3) and agriculture lands (35.1). Highest fraction of TOC stock in surface layer was observed in agricultural lands as compared to the other lands while at the lower depth it was lowest. The sub-surface soils of forest and horticulture land use, contributed nearly 35 to 40 % of profile SOC stocks.

Husain (2018a) in a study on estimating soil C pools in Kashmir valley revealed that OC stocks (t ha^{-1}) were highest under grasslands (75 and 76.16) in sites A and B, as compared to agricultural land (65.17 and 63.36), vegetables (63.75 and 65.52) and wasteland/uncultivated land (30.45 and 29.31), respectively. The maximum C stock (t ha^{-1}) was under natural forest-Blue Pine land use (556.73) in site A and B.

Husain (2018b) reported that in different land use systems in district Srinagar at various sites, highest C was stored under natural forest-Blue Pine viz., $1634.56 \text{ t ha}^{-1}$, followed by plantation forest-Poplar in site A. Lowest carbon storage (t ha^{-1}) was under wastelands/uncultivated lands (2.61), followed by the Grasslands (3.58). Site B had highest above ground C in (t ha^{-1}) in natural forest-Blue Pine (1538.57), followed by plantation forest-Poplar viz., $1125.19 \text{ t ha}^{-1}$ with lowest found under wasteland/uncultivated land use (2.53 t ha^{-1})

Dad and Javaid (2019) reported that SOC stocks in Kashmir Himalaya have high variability and range. The stocks ranged between 28.85 to $94.76 \text{ Mg C ha}^{-1}$, having a mean of $54.52 \text{ Mg C ha}^{-1}$. SOC stocks of pastures and non-pasture was found to be different, averaging slightly more in pastures ($59.69 \text{ Mg C ha}^{-1}$) as compared to the non-pasture land ($56.32 \text{ Mg C ha}^{-1}$).

Singh *et al.* (2019) in a study reported that below ground biomass (t ha^{-1}) was highest under forests (47.84) and was recorded minimum in grasslands (1.09). In the agroforestry based system, highest below ground biomass (20.02) was found in agri-hortisilviculture which was higher as compared to agrihorticulture (13.18), agrisilviculture (12.47) and silvopastoral (9.01) system.

Aziz *et al.* (2019) found out that in Kashmir region average C stocks in alpine region was 372.5 t ha^{-1} with lowest of 343.5 t ha^{-1} , while the biomass C stock was recorded at 2.27 t ha^{-1} having above ground biomass value of 1.89 t ha^{-1} and below ground biomass values of 0.38 t ha^{-1} . The alpine SOC stock was

recorded as 370.6 t ha⁻¹. Average C stocks in the subalpine region were found at 340.9 t ha⁻¹ with highest recorded 352.46 t ha⁻¹ and lowest as 326.86 t ha⁻¹. Average above ground C stock and below ground carbon stocks (t ha⁻¹) was 67.9 and 13.2. The subalpine SOC stocks were measured to be 260.9 t ha⁻¹.

The distribution of SOC stock at various depths has a decreasing trend in different land use systems. Maximum stock of SOC was stored in wet rice cultivation (0-15 cm) and in agroforestry the highest SOC has been stored at 15-30 cm and 30-45 cm. The stocks had the following order: Forest > Agroforestry > Wet Rice Cultivation > Plantation > Current Jhum > Grassland > Jhum Fallow (Sahoo *et al.*, 2019).

Thakur *et al.* (2019) reported that C stocks (t ha⁻¹) for trees above-ground, below-ground, understorey and litter was 189.93, 37.99, 1.71 and 0.72 t ha⁻¹, respectively in *Cedrus deodara* (CD) forests. Total mean SOC stock at depth of 0-45 cm had 76.16 t ha⁻¹ that indicates that OC percentage follows a decreasing pattern as depth of soil is increases.

To temporarily offset climate change, SOC stocks can be raised through appropriate land management methods. In mainland France forest topsoils are saturated in SOC_{fine} thus Hassink's equation can be used in estimating SOC sequestration (Chen *et al.*, 2019).

In a comprehensive study, Badole *et al.* (2020) reveals that transforming natural lands to agricultural ecosystems cause reduction in C stocks by 25-30 %. The C pools are intimately changed as land-use changes causing loss of OC stocks in soils. Thus enhanced crop management practices have a crucial role to play in stabilizing C and its stocks.

Begum *et al.* (2020) reported that forests contain higher SOC stock as compared to agriculture and pasture in mountainous landscape of Karakoram region, Gilgit, Pakistan. Low OC stock is found in agricultural land as compared

to forests which indicates that conversion of forest land to agricultural use is one of the causes.

Girma *et al.* (2020) reported that total mean value (TMV) of SOC stocks of forest land (85.97 Mg ha⁻¹) were higher than the grazing system having 83.45 Mg ha⁻¹ and least is seen in cultivated lands (49.54 Mg ha⁻¹) in Ethiopia. This indicates that the future contribution of types of forest use increases SOC stocks and the protection of the environment.

Koga *et al.* (2020) reported that in cropland the SOC stocks that are due to forest land reduces as time elapse i.e. 2-85 years and decreases after 26-81 years.

Mandal *et al.* (2020) reported that orchards have potential of sequestering C following other patterns as; horticulture > croplands > uncultivated lands. At 90 cm depth orchards exhibit higher SOC stocks followed by croplands and uncultivated lands. C decreases along the profile under croplands.

Iqbal *et al.* (2020) carried out a detailed study on estimation of SOC stocks in various land use systems (grassland, pine forest, apple orchard and walnut orchard) in the Shopian district of Kashmir valley and found that mean SOC stocks varied from highest of 45.20 ± 12.11 Mg ha⁻¹ in Pine forest to lowest of 33.2 ± 8.36 Mg ha⁻¹ in grassland. With depth mean range of SOC stock varies from 3.25 × 1.51 in pine forest to 3.10 × 0.09 Mg C ha⁻¹ in walnut orchard at 0-30 cm depth.

In an investigation Olorunfemi *et al.* (2020) reveals that SOC varies at various depths. SOC stock total at depths of 0-30 cm follows the order; forest land use > Plantations > Woodlands > Croplands. In contrast to croplands and woodlands, forests hold greater quantity of total C Stock.

Ahirwal *et al.* (2021) conducted a study and reported that SOC stocks in the studied land uses (forests, plantation, agro-forest, and herbaceous ecosystem), highest biomass C stock was found under natural forests (138.5 Mg C ha⁻¹), while

maximum OC stock ($168.8 \text{ Mg C ha}^{-1}$) were recorded under plantation forests at 1 m top of soils.

2.5 Effect of different land use types on carbon management index

Blair *et al.* (1995) during their study revealed that CMI is a result of TOC and carbon lability index (LI) which is a very helpful tool in the evaluation of management systems in promotion of soil quality. CMI measures changes occurring as a result of management activities in total and labile C with focus on shift in labile carbon, compared with non-labile C in SOM. As a result, incorporating SOC pool and LI into the CMI may give a helpful measure for evaluating management techniques ability to promote soil quality.

Whitbread *et al.* (1998) mentioned the integrated quantity and quality calculation of SOC by CMI. CMI, rather than TOC, can be utilized as a more sensitive indicator of the rate of change in SOC in relation to soil management and land use changes.

While studying orchard systems, Tirol and Ladha (2004) reported that orchards promote high CMI values not as a result of only enhancements in formation of OM or more additions of annual C addition but is a result caused by changes that take place with OM quality viz., C/N ratio, lignin content, protein, cellulose and carbohydrate which modifies C lability making it oxidized.

Kalambukattu *et al.* (2013) reported that in Almora region Central Himalaya CMI is highest under forest land use type and lowest CMI is in barren land use ecosystems. Thus maintenance of natural land use type is needed to increase SOC pools.

Meena *et al.* (2018) found out that with depth, the CMI at 0-45 cm were 49.80, 49.62, 56.90 and 58.94 for forest, grass, cultivated and barren land. At 0-15 cm soil depth, CMI sequenced as barren > cultivated > forest > grass land,

respectively. In both 15-30 and 30-45 cm profile depth, highest CMI was found in barren and cultivated lands as compared to forest and grass lands. This suggests that long-term forest land use and cultivated land management may enhance C sequestration.

Sainepo *et al.* (2018) in a study on CMI found that CMI is a good indicator for degraded soil or LULC change improvements. Also CMI resides more in grasslands but due to overusing by grazing it decreases.

As reported by Moraes *et al.* (2018) that the SOC fractions and enzyme activity increases with increasing vegetation cover of ecological ecosystems. The SOC labile fraction and enzyme activity is sensitive to land use changes. Biological and CMI are efficient tools in characterizing impact of management systems.

Maini *et al.* (2020) reported that highest CMI are found in forests but least resides in the barren lands. Minimal influence is seen in the Middle Indian Himalayan Ecosystem in non-labile biomass, C lability, lability and C pool index (CPI).

Mir *et al.* (2020) in an intensive study on OC pools with its stocks revealed that in the different land uses found in North-eastern Kashmir, highest CMI was found under forests (162.5), followed by grassland (100) and decreased in the order of apple (87.5), maize (81.0), rice (72.8) and vegetable soils (70.7), respectively.

Kobierski *et al.* (2020) conducted a study and revealed that CMI is amply used for evaluating C transformation in soils of cultivated plots against the forest of Brunic Arenosols.

Chapter – 3

MATERIALS AND METHODS

3.1 Brief description of the study area

3.1.1 Location

The present study was conducted in a sub mountainous area of Kupwara district in North Kashmir. The district lies between longitude 74°15'19.4653" E and latitude 34°31'32.8544" N with geographical area of 2379 km². The elevation ranges between 1500 m and 3500 m above mean sea level (amsl). The valley has flat to slightly undulating topography and covering a total area of 3200 hectare (ha⁻¹). The study areas climate is mediterranean type temperate cum with minimum and maximum temperature ranging from -8°C to 35°C. The winter season starts in November, and extreme winter conditions continue until March. The annual rainfall is about 869 mm for about 60 days, in the form of rain and snow. Kupwara District is hilly and mountainous in the north, west and east regions consisting of Lesser Himalayan Pir-Panjial ranges with wide intermountain valley.

3.1.2 Design of Survey and Sampling

The five land use types chosen for this study include: Natural Forest, Natural Grassland, Maize-field-converted-from-Forest, Plantation and Paddy. Some key features of the land uses and management practices adopted in the study area are briefly presented in Table 3.1. Composite soil samples were collected from twenty five locations having five locations (Fig 3.1) in each land use. Stratified random sampling method was followed and samples were collected in autumn 2020. The samples were collected using soil auger from two depths: 0-20 and 20-40 cm. Composite soil samples were collected with three replicates and every replicate sample was composited from six subsamples randomly collected, pooled and sieved.

After removal of all stubbles, residues and undesirable substances, composite soil samples collected from each site and depth were homogenized and air dried at room temperature, ground in wooden mortar, sieved with a 2 mm sieve and 0.5 mm sieve (for SOC) and carefully preserved for further analysis in covered plastic Zip-lock bags.

Table 3.1: Land uses and management practices adopted in the study area

S.No	Land Use	Management Practice and/or other Key Features
I.	Natural Forest	Natural pine forests with some minimal felling of trees in the lower boundaries.
II.	Natural Grassland	Natural pastures affected by moderate to severe grazing.
III.	Maize-field-converted-from-Forest	Subsistence level cultivation of few maize varieties with minimum inputs and tillage on forest margins
IV.	Plantation	Mostly apple orchards. Use of moderate quantities of major fertilizers and plant protection chemicals.
V.	Paddy	Cultivation with traditional tillage practices and use of NPK chemical fertilizers.

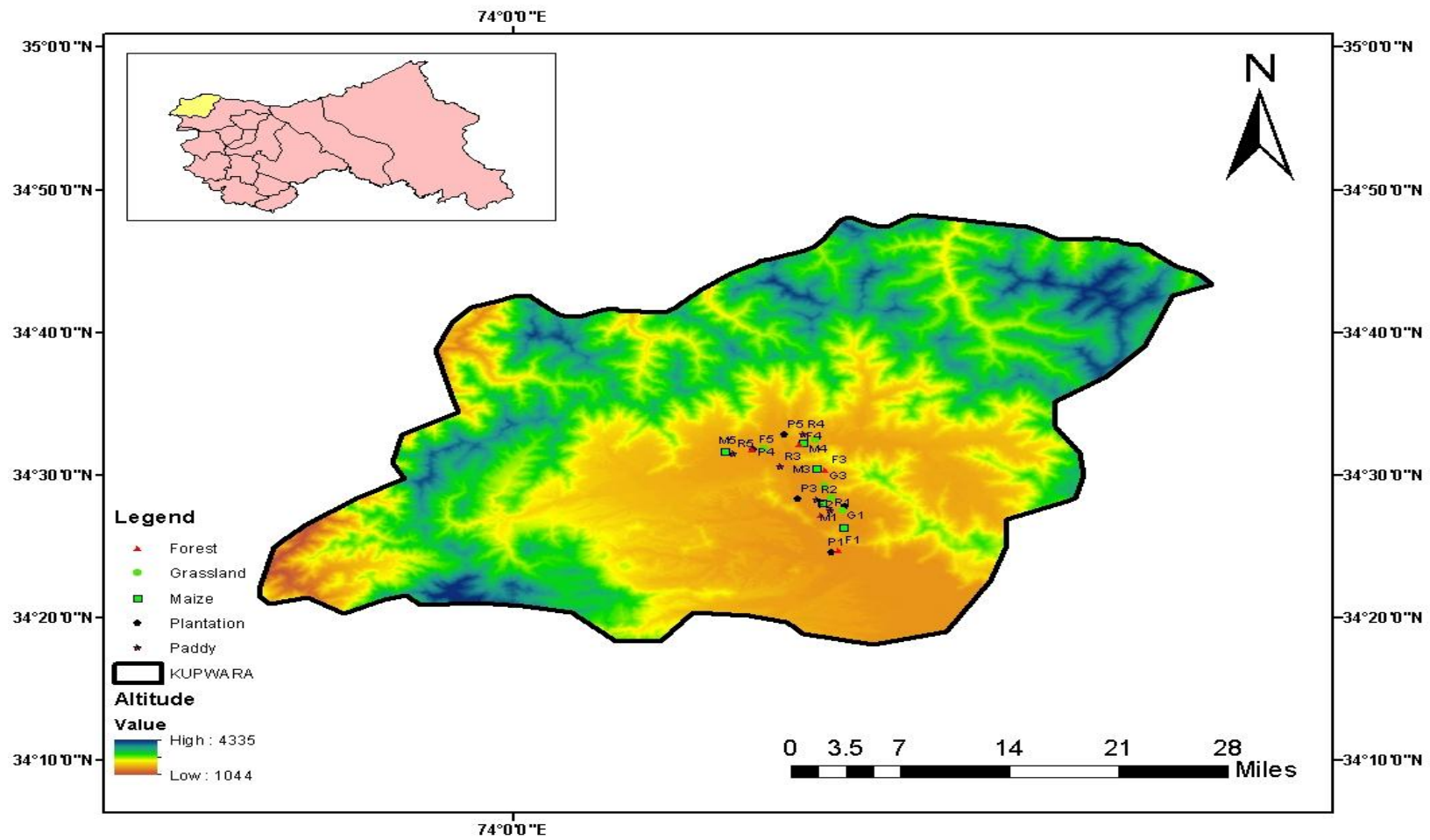


Fig 3.1 Map of the study area

3.2 Total organic carbon (TOC) and Walkley-Black carbon (WBC):

The total organic carbon under five different land use types was quantified using a modified Mebius method (Yeomans and Bremner, 1988). The soil samples were digested at 150°C for 30 minutes with $K_2Cr_2O_7$ and H_2SO_4 following titration by using 0.2 mol (Fe^{2+}) L^{-1} Mohr salt.

The method described by Walkley and Black (1934) was used to determine soil organic carbon/walkley-black carbon. Organic matter was first oxidized using chromic acid (potassium dichromate + concentrated sulphuric acid) and the unconsumed potassium dichromate was back-titrated against ferrous sulfate in this process (redox titration).

3.3 Estimation of soil organic carbon pools:

The different pools of organic carbon (OC) were estimated through a modified Walkley and Black method (1934) as described by Chan *et al.* (2001) using 12.0 N, 18.0 N and 24.0 N of H_2SO_4 , respectively. The very labile carbon was estimated using organic C oxidisable by 12.0 N H_2SO_4 . The labile carbon was estimated by the differences in SOC oxidisable by 18.0 N and that under 12.0 N H_2SO_4 . The less labile carbon was estimated by the differences in SOC oxidisable under 24.0 N and that under 18.0 N H_2SO_4 . The non-labile carbon was estimated by the differences between SOC oxidisable under 36.8 N and that under 24.0 N H_2SO_4 .

3.4 Estimation of basic soil properties

3.4.1 Soil pH (1:2.5):

Soil pH was determined with the help of glass electrode pH meter (Jackson, 1973).

3.4.2 Electrical Conductivity (EC):

The EC of the soil samples was determined using a conductivity bridge in 1:2.5 soil-water suspensions, after equilibration for 24 hours using Solu-bridge conductivity meter (Jackson, 1973).

3.4.3 Bulk Density (BD):

The bulk density of the soil samples was estimated using the core method (Blake and Hartge 1986).

3.4.4 Clay Content:

The Mechanical analysis was done by the Hydrometer method (Bouyoucos, 1962).

3.4.5 Total Nitrogen (TN):

The Modified Kjeldhal digestion method was used to estimate TN in soil. A known weight of soil sample was taken in presence of concentrated H_2SO_4 and catalyst mixture under high temperature ($420^\circ C$) and digested to break down complicated structures into simple structures, thereby releasing N in the form ammonical radicles (NH_4^+). The digested samples were then distilled by steam with concentrated NaOH (40 %), the released NH_3 is condensed and absorbed in a known volume (20 ml) of boric acid (4 %) with mixed indicator to form ammonium borate, the excess of which is titrated with 0.1N HCL (Bremner and Mulvaney, 1982).

3.5 Microbial populations:

Soil microbial populations were estimated by using serial dilution pour plate method (Aneja, 2001). In each case three replicates were kept. The following

formula was used for counting and determination of populations in the colonies growing in the plates.

Viable count (cfu / g dry soil) = (Average number of colonies x Dilution factor) / weight of the soil (g)

3.5.1 Isolation of total no. of viable bacteria

Isolation of soil bacteria (CFU/g of soil) was done on Nutrient agar using a dilution plate technique with 10^6 dilutions at $28 \pm 1^\circ\text{C}$ for 3 days.

3.5.2 Isolation of total no. of viable fungi

Potato dextrose agar (PDA) was used for the isolation of soil fungi (CFU/g of soil) using the dilution plate technique with 10^5 dilutions at $27 \pm 1^\circ\text{C}$ for 6 days. To prevent bacterial growth, the media were supplemented with 50 pg ml^{-1} of streptomycin sulphate.

3.5.3 Isolation of total no. of viable actinomycetes

The Actinomycetes populations were enumerated by growing them in an actinomycetes agar with 10^5 dilutions at $26 \pm 1^\circ\text{C}$ for 7 days incubation period. To avoid the development of fungal and bacterial contaminations, the media were treated with cycloheximide and streptomycin (1 mg ml^{-1}) respectively.

3.6 Computation of soil organic carbon stock:

The SOC stocks were calculated as follows, (Jones *et al.*, 2005). SOC stocks (Mg ha^{-1}) = SOC x ρ x d x 10,000 Where; SOC is the soil organic carbon measured in g g^{-1} ; ρ is the soil bulk density (g cm^{-3}), d is the depth of soil layer (m). The value of 10,000 indicates the stock for 1 ha^{-1} of land.

3.7 Computation of Carbon Management Index (CMI):

The CMI were calculated using the formulae; $CMI = CPI \times LI \times 100$, where CPI is the carbon pool index and LI is the lability index of the soil under a particular land use (Blair GJ *et al.*, 1995).

$CPI = \frac{\text{Total organic carbon in the treatment (g kg}^{-1}\text{)}}{\text{Total organic carbon in the reference (g kg}^{-1}\text{)}}$

$LI = \frac{L \text{ in the treatment}}{L \text{ in the reference}}$ where L is carbon lability of the soil

$L = \frac{\text{Content of labile C}}{\text{Content on non-labile C}}$

3.8 Statistical Analysis

The results on different parameters under laboratory conditions were statistically evaluated according to the procedure outlined by Gomez and Gomez (1984). The descriptive statistics-one factor analysis was done by using OPSTAT software. The coefficients of correlation between the functional OC pools and microbial population, OC stocks and basic soil properties were computed by using SPSS software version 27.0 (SPSS, 2020). Preparation of tables and graphs were done in MS Excel TM spreadsheet.

Chapter – 4

EXPERIMENTAL FINDINGS

The results pertaining to the present investigation “**Functional Soil Organic Carbon Pools as Affected by Different Land Use Types in a Sub Mountainous Area of North Kashmir**” are presented under the following headings.

4.1 Basic soil properties

4.1.1 Soil Reaction (pH)

Data pertaining to the mean values of soil pH under different land uses are presented in Table 4.1. The pH values in 0-20 cm and 20-40 cm soil depth ranged from 6.23 to 7.25, 6.44 to 7.42, 6.64 to 7.56, 6.53 to 7.34 and 7.07 to 7.74 in natural forest, natural grassland, maize-field-converted-from-forest, plantation and paddy respectively. The mean values of pH at 0-20 cm and 20-40 cm soil depth were 6.55 and 6.97 in natural forest; 6.65 and 7.12 under natural grassland; 7.05 and 7.26 in maize-field-converted-from-forest; 6.83 and 7.20 under plantation; 7.42 and 7.56 in paddy soils, respectively. The highest mean pH value viz. 7.42 at 0-20 cm and 7.56 at 20-40 cm depth were recorded in paddy land use and the lowest mean values were recorded in natural forests viz. 6.55 and 6.97 of surface and sub-surface layers (Fig 4.1). In 0-20 cm and 20-40 cm depth, the mean values under maize-field-converted-from-forest land use were higher as compared to natural forest, natural grassland and plantation. The pH values in all land use systems increased with increase soil depth, the result in respect to pH indicates that the soil varied from slightly acidic to mildly alkaline in nature. In surface soils, the pH was observed to be in the following order; paddy > maize-field-converted-from-forest > plantation > natural grassland > natural forest, respectively.

Table 4.1: Basic properties of surface (0-20 cm) and sub-surface (20-40 cm) soils under different land use types of study area

Land use type/ Location	pH		EC (dS m ⁻¹)		BD (Mg m ⁻³)		Clay (%)		TN (%)	
	(0-20 cm) Surface	(20-40 cm) Sub-surface	(0-20 cm) Surface	(20-40 cm) Sub-surface	(0-20 cm) Surface	(20-40 cm) Sub-surface	(0-20 cm) Surface	(20-40 cm) Sub-surface	(0-20 cm) Surface	(20-40 cm) Sub-surface
Natural Forest										
Kulangam	6.55	6.95	0.13	0.17	0.84	0.99	12.42	15.43	0.49	0.35
Jaggerpora	6.84	7.25	0.14	0.20	0.95	1.10	14.79	17.79	0.47	0.37
Anderhama	6.23	6.74	0.11	0.16	0.76	0.91	13.61	16.64	0.56	0.40
Kunan	6.67	7.05	0.14	0.18	1.05	1.20	12.62	15.94	0.63	0.49
Batergam	6.45	6.85	0.12	0.15	1.11	1.26	15.46	17.67	0.33	0.30
Mean	6.55	6.97	0.13	0.17	0.94	1.09	13.78	16.69	0.49	0.38
SE +/-	0.10	0.09	0.01	0.01	0.07	0.06	0.59	0.47	0.05	0.03
Natural Grassland										
Radbugha	6.44	6.75	0.09	0.12	1.11	1.22	14.26	17.35	0.28	0.21
Shalpora	6.73	7.13	0.16	0.19	1.04	1.15	17.64	20.71	0.33	0.26
Drugmulla	6.56	6.97	0.14	0.18	1.07	1.18	16.69	19.72	0.37	0.30
Kralpora	6.65	7.36	0.15	0.19	1.08	1.19	17.29	20.36	0.40	0.33
Goose	6.85	7.42	0.18	0.27	1.06	1.17	15.52	18.57	0.42	0.35
Mean	6.65	7.12	0.15	0.19	1.07	1.18	16.28	19.34	0.36	0.29
SE +/-	0.07	0.12	0.02	0.02	0.01	0.01	0.62	0.62	0.03	0.03
Maize Field converted from Forest										

Reshwari	7.38	7.56	0.23	0.26	1.19	1.26	24.67	27.51	0.23	0.16
Doni wari	6.81	7.04	0.21	0.22	1.21	1.28	26.51	29.56	0.28	0.21
Darugmul	7.25	7.45	0.24	0.26	1.24	1.31	25.64	28.59	0.30	0.23
Kunan	6.64	6.86	0.17	0.24	1.24	1.31	26.64	29.73	0.26	0.19
Herri	7.14	7.38	0.16	0.22	1.25	1.32	27.61	29.56	0.21	0.14
Mean	7.05	7.26	0.20	0.24	1.22	1.29	26.21	28.99	0.26	0.19
SE +/-	0.14	0.13	0.02	0.01	0.01	0.01	0.50	0.42	0.02	0.02
Plantation										
Braripora	6.87	7.25	0.16	0.23	1.34	1.38	30.63	33.65	0.19	0.12
Khanti pora	6.53	6.92	0.11	0.18	1.38	1.42	34.63	37.43	0.21	0.16
Nagri	6.75	7.15	0.14	0.22	1.27	1.31	32.56	35.65	0.23	0.19
Batergam	7.07	7.34	0.21	0.26	1.22	1.26	33.55	36.53	0.16	0.14
Batpora	6.94	7.32	0.19	0.24	1.36	1.40	31.72	34.58	0.19	0.16
Mean	6.83	7.20	0.16	0.23	1.32	1.36	32.62	35.57	0.20	0.15
SE +/-	0.09	0.08	0.02	0.01	0.03	0.03	0.70	0.67	0.01	0.01
Paddy										
Arampora	7.51	7.60	0.26	0.29	1.45	1.47	35.77	38.68	0.19	0.12
Cheeri koot	7.36	7.56	0.24	0.26	1.43	1.45	33.63	36.68	0.16	0.09
Mughalpora	7.07	7.25	0.22	0.25	1.41	1.43	34.51	37.65	0.21	0.16
Shatpora	7.67	7.74	0.33	0.35	1.40	1.42	32.54	35.61	0.14	0.09
Bunherri	7.46	7.64	0.25	0.27	1.45	1.47	35.61	38.61	0.21	0.14
Mean	7.42	7.56	0.26	0.29	1.43	1.45	34.41	37.45	0.18	0.12
SE +/-	0.10	0.08	0.02	0.02	0.01	0.01	0.61	0.59	0.01	0.01
CD ($p < 0.05$)	0.33	0.33	0.05	0.05	0.10	0.10	1.73	1.58	0.08	0.06

EC- Electrical conductivity, BD- Bulk density, TN- Total nitrogen

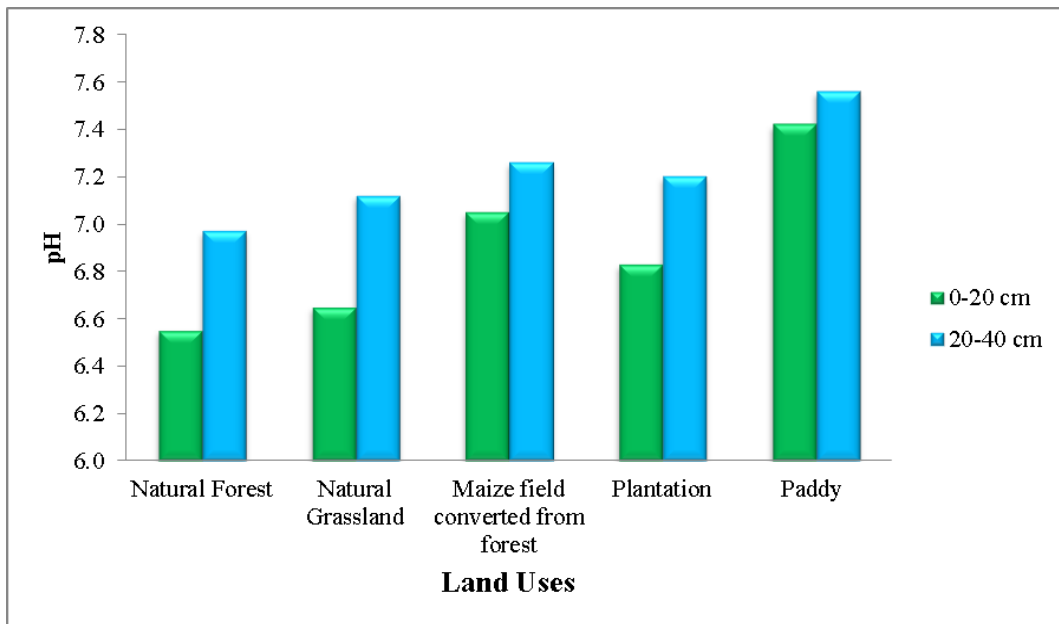


Fig. 4.1: Soil pH of surface and sub-surface soils under different land use types

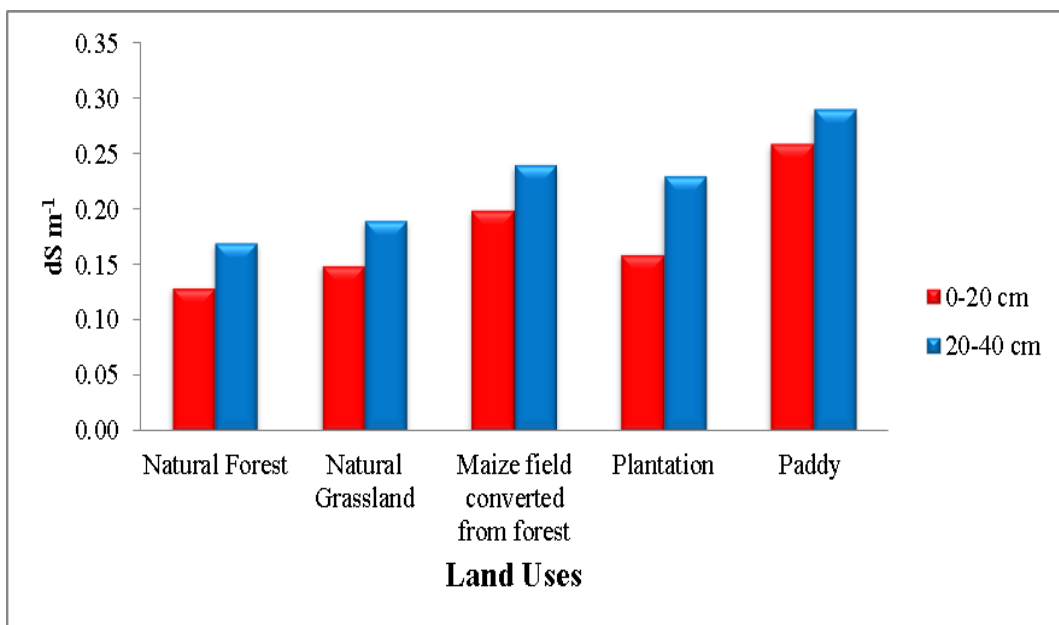


Fig. 4.2: Electrical conductivity of surface and sub-surface soils under different land use types

4.1.2 Electrical conductivity (EC)

The overall electrical conductivity (EC) ranged from 0.09-0.35 dSm⁻¹ in all land uses with lowest value in surface soils of natural grassland (Radbugha) and highest in sub-surface of paddy soils (Shatpora). The EC values of surface (0-20 cm) and sub-surface (20-40 cm) soils ranged from 0.11 to 0.20, 0.09 to 0.27, 0.16 to 0.26, 0.11 to 0.26 and 0.22 to 0.35 dS m⁻¹ in natural forest, natural grassland, maize-field-converted-from-forest, plantation and paddy soils. The mean values of EC in 0-20 cm and 20-40 cm soil depth were 0.13 and 0.17 under natural forest; 0.15 and 0.19 in natural grassland; 0.20 and 0.24 under maize-field-converted-from-forest; 0.16 and 0.23 in plantation and 0.26 and 0.29 dS m⁻¹ in paddy soils, respectively (Table 4.1). The results revealed that the highest mean EC values in surface and sub-surface soils were recorded in paddy viz., 0.26 and 0.29 dS m⁻¹ and lowest were recorded in natural forest viz., 0.13 and 0.17 dS m⁻¹ at both the soil depths (Fig 4.2). In general all the surface soils had lower values of EC as compared to sub-surface soils for all the land use systems. In both the soil depth, the EC had the following order; paddy > maize-field-converted-from-forest > plantation > natural grassland > natural forest, respectively.

4.1.3 Bulk density (BD)

The mean values of BD (Mg m⁻³) in surface and sub-surface soil layers were 0.94 and 1.09 in natural forest; 1.07 and 1.18 in natural grassland; 1.22 and 1.29 in maize-field-converted-from-forest; 1.32 and 1.36 under plantation; 1.43 and 1.45 Mg m⁻³ in paddy, respectively (Table 4.1). The respective BD values of 0-20 cm and 20-40 cm soil depth ranged from 0.76 to 1.26, 1.04 to 1.22, 1.19 to 1.32, 1.22 to 1.42 and 1.40 to 1.47 Mg m⁻³ in natural forest, natural grassland, maize-field-converted-from-forest, plantation and paddy. From the perusal of data it is evident that paddy soils recorded higher mean BD values of 1.43 and 1.45 Mg m⁻³ at soil depths of 0-20 and 20-40 cm which were followed by plantation land use viz., 1.32 and 1.36 Mg m⁻³ and least was recorded in natural forest viz., 0.94

and 1.09 Mg m^{-3} in surface and sub-surface layers (Fig 4.3). The BD of each land use type increased with increase in depth and had the following order at both soil depths; paddy > plantation > maize-field-converted-from-forest > natural grassland > natural forest, respectively.

4.1.4 Clay content

The clay (%) content of every land use type increased with increase in depth in surface and sub-surface layers and varied in the order; paddy > plantation > maize-field-converted-from-forest > natural grassland > natural forest, respectively. The clay content in 0-20 cm and 20-40 cm soil depth ranged from 12.42 to 17.79, 14.26 to 20.71, 24.67 to 29.73, 30.63 to 37.43 and 32.54 to 38.68 in natural forest, natural grassland, maize-field-converted-from-forest, plantation and paddy soils. The mean values of clay content at 0-20 cm and 20-40 cm soil depth were 13.78 and 16.69 in natural forests; 16.28 and 19.34 in natural grasslands; 26.21 and 28.99 in maize-field-converted-from-forest; 32.62 and 35.57 in plantation sites; 34.41 and 37.45 in paddy soils, respectively (Table 4.1). Paddy soils recorded higher mean clay content values of 34.41 and 37.45 % in surface and sub-surface layers which were followed by plantation land use viz., 32.62 and 35.57 % and least was recorded in natural forests viz., 13.78 and 16.69 % (Fig 4.4).

4.1.5 Total nitrogen (TN)

Data pertaining to the mean values of soil TN under different land uses are presented in Table 4.1. The value of total nitrogen in surface and sub-surface soil layers ranged from 0.30 to 0.63, 0.21 to 0.42, 0.14 to 0.30, 0.12 to 0.23 and 0.09 to 0.21 % in natural forest, natural grassland, maize-field-converted-from-forest, plantation and paddy fields. The mean values of TN in 0-20 cm and 20-40 cm soil depth were 0.49 and 0.38 in natural forest; 0.36 and 0.29 under natural grassland; 0.26 and 0.19 in maize-field-converted-from-forest; 0.20 and 0.15 under

plantation and 0.18 and 0.12 in soils under paddy land use. Natural forest land use type recorded highest total nitrogen with mean values of 0.49 and 0.38 % at different soil depths which were followed by natural grassland viz., 0.36 and 0.29 % and least was recorded in paddy soils viz., 0.18 and 0.12 % (Fig 4.5). In general, total soil nitrogen was found in the order: natural forest > natural grassland > maize-field-converted-from-forest > plantation > paddy.

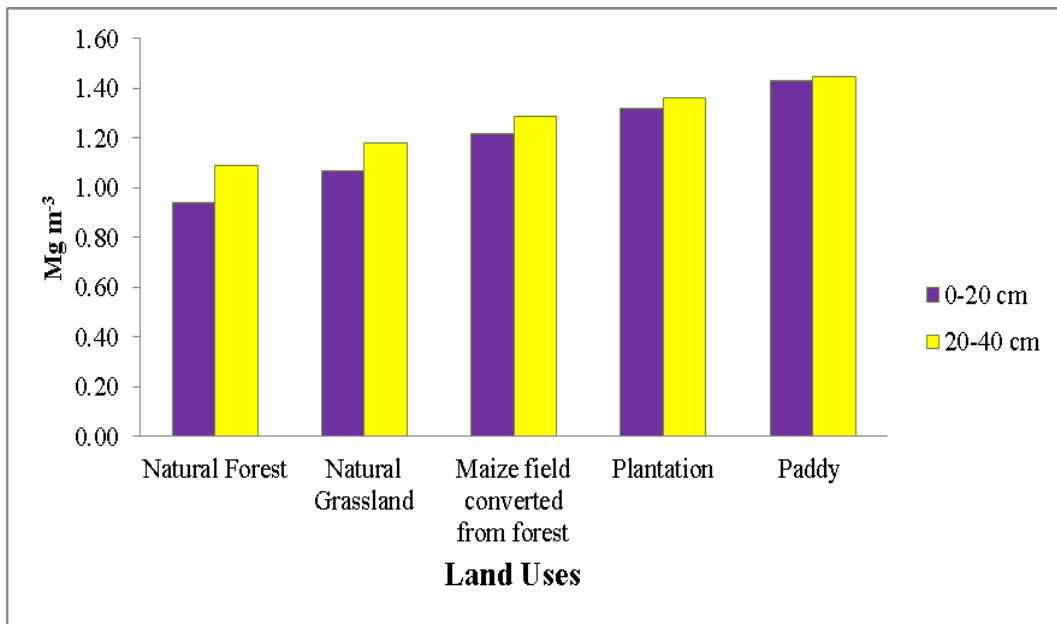


Fig. 4.3: Bulk density of surface and sub-surface soils under different land use types

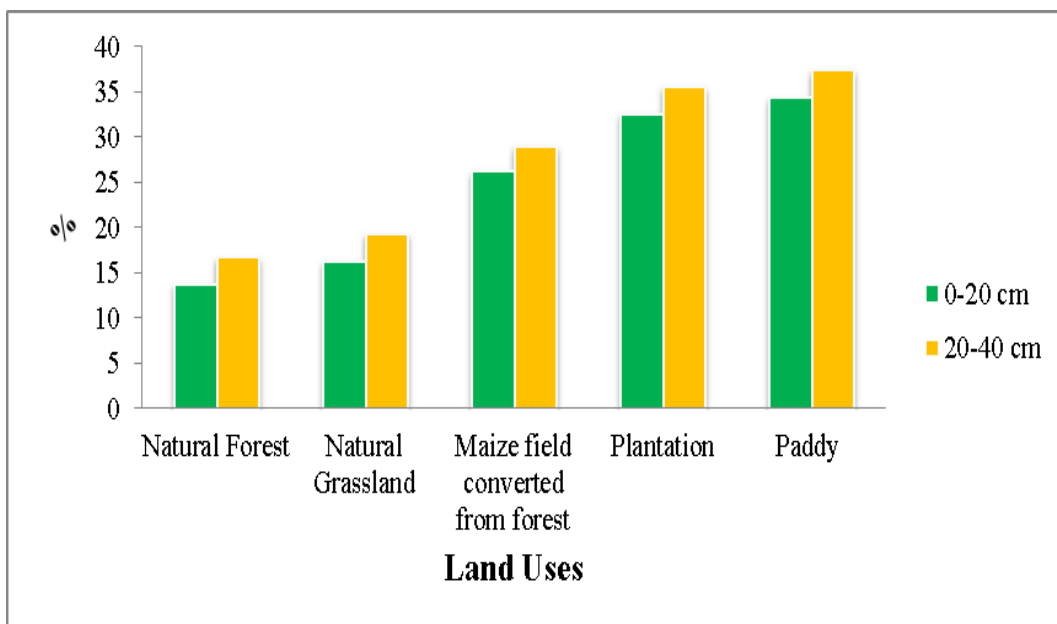


Fig. 4.4: Clay content of surface and sub-surface soils under different land use type

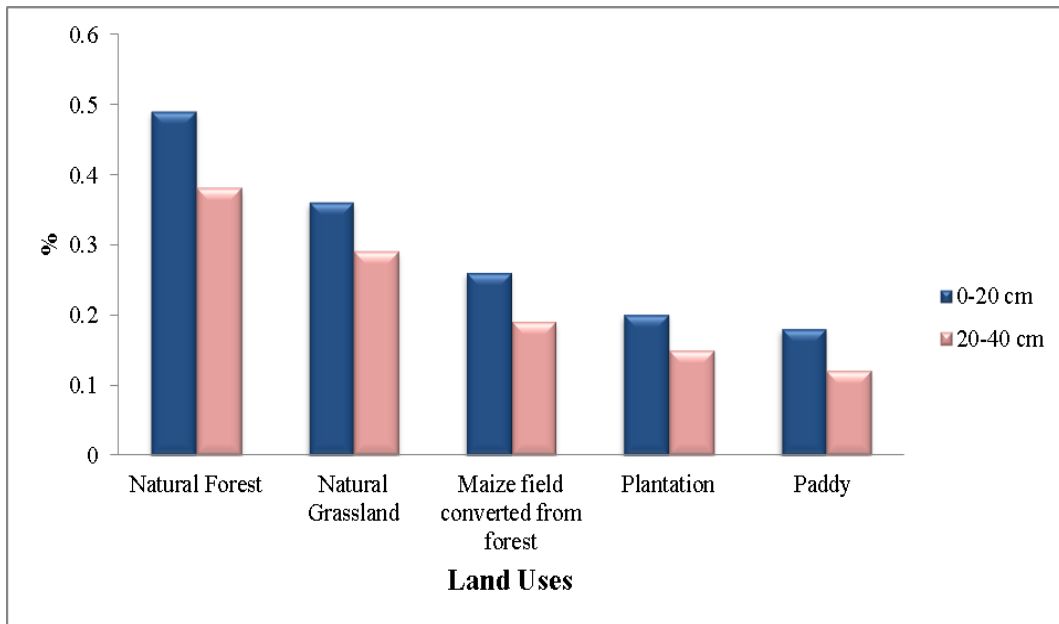


Fig. 4.5: Total nitrogen of surface and sub-surface soils under different land use types

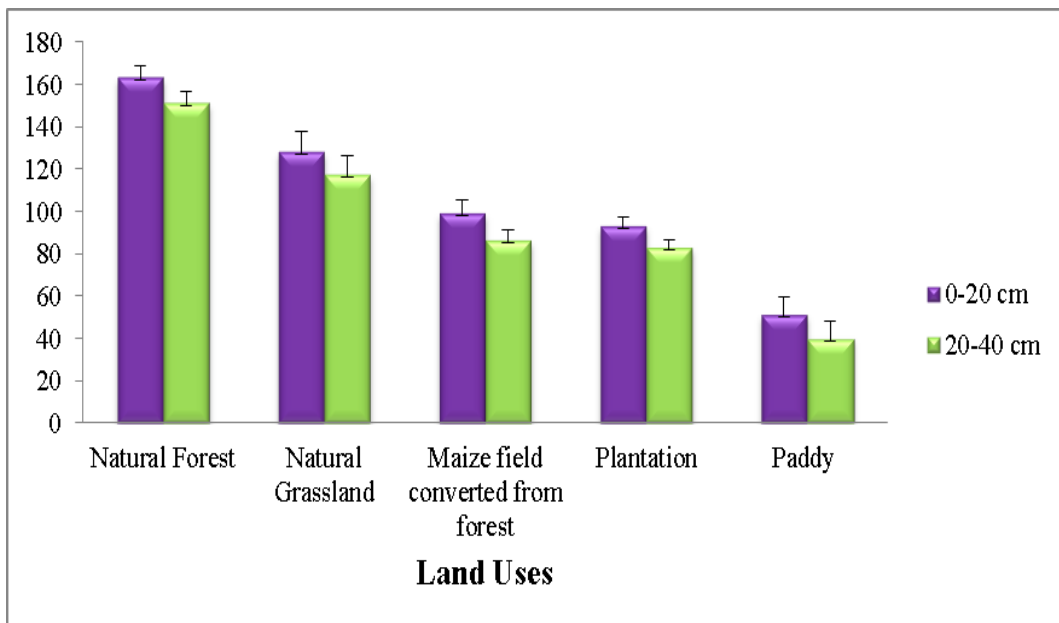


Fig. 4.6: Viable bacteria (cfu*10⁻⁶ g⁻¹) in surface and sub-surface soils under different land use types

4.2 Soil microbial count

4.2.1 Viable bacteria

Perusal of the data in Table 4.2 shows that the total number of viable bacterial counts in different land use types ranged from 14 to 183 $\text{cfu} \times 10^{-6} \text{g}^{-1}$ soil. The viable bacterial count at 0-20 cm and 20-40 cm soil depth ranged from 140 to 183, 85 to 150, 75 to 121, 70 to 104 and 14 to 74 $\text{cfu} \times 10^{-6} \text{g}^{-1}$ soil in natural forests, natural grasslands, maize-field-converted-from-forest, plantations and paddy soil (Fig. 4.6). The mean values of viable bacterial count in 0-20 cm and 20-40 cm soil depth were 163 and 151 in natural forest; 128 and 117 in natural grassland; 99 and 86 under maize-field-converted-from-forest; 93 and 83 in plantation; 51 and 40 $\text{cfu} \times 10^{-6} \text{g}^{-1}$ soil in paddy. Lowest and highest bacterial count in soil was found in paddy soils and natural forests, respectively.

4.2.2 Viable fungi

The viable fungal counts in different land use types ranged from 6 to 103 $\text{cfu} \times 10^{-5} \text{g}^{-1}$ soil with minimum and maximum values for fungal count as 72 to 103, 49 to 85, 39 to 69, 17 to 51 and 6 to 31 $\text{cfu} \times 10^{-5} \text{g}^{-1}$ of soil in natural forest, natural grassland, maize-field-converted-from-forest, plantation and paddy soils (Table 4.2). The mean values of viable bacterial count in 0-20 cm and 20-40 cm soil depth were 93 and 82 in natural forest; 71 and 59 in natural grassland; 58 and 47 under maize-field-converted-from-forest; 40 and 30 in plantation; 20 and 12 $\text{cfu} \times 10^{-5} \text{g}^{-1}$ soil in paddy soil. Lowest and highest fungal count was found in paddy soils and soils of natural forest, respectively (Fig. 4.7).

4.2.3 Viable actinomycetes

The lowest and the highest actinomycetes count was recorded for soils in paddy cultivation and natural forest, respectively. The actinomycetes population in different land use types ranged from 1 to 76 $\text{cfu} \times 10^{-5} \text{g}^{-1}$ soil with minimum and maximum values for actinomycetes count as 40 to 76, 41 to 63, 23 to 52, 10

to 35 and 1 to 14 cfu $\times 10^{-5}$ g⁻¹ soil for natural forest, natural grassland, maize-field-converted-from-forest, plantation and paddy soils, respectively (Table 4.2). The mean values of viable actinomycetes count at 0-20 cm and 20-40 cm soil depth were 68 and 57 in natural forest; 58 and 47 in natural grassland; 42 and 30 under maize-field-converted-from-forest; 29 and 18 in plantation; 9 and 4 cfu $\times 10^{-5}$ g⁻¹ soil in soils under paddy soils (Fig. 4.8).

Table 4.2: Biological properties of surface (0-20 cm) and sub-surface (20-40 cm) soils under different land use types of study area

Land use type/ Location	Viable Bacteria (cfu*10 ⁻⁶ g ⁻¹)		Viable Fungi (cfu*10 ⁻⁵ g ⁻¹)		Viable Actinomycetes (cfu*10 ⁻⁵ g ⁻¹)	
	(0-20 cm) Surface	(20-40 cm) Sub-surface	(0-20 cm) Surface	(20-40 cm) Sub-surface	(0-20 cm) Surface	(20-40 cm) Sub-surface
Natural Forest						
Kulangam	165	152	103	93	75	65
Jaggerpora	150	140	89	79	72	63
Anderhama	183	172	90	82	64	55
Kunan	160	149	101	86	76	63
Batergam	157	144	82	72	51	40
Mean	163	151	93	82	68	57
SE +/-	5.56	5.55	3.94	3.50	4.65	4.63
Natural Grassland						
Radbugha	141	127	75	63	63	53
Shalpora	150	139	85	71	62	52
Drugmulla	133	122	60	49	55	42
Kralpora	95	85	75	61	54	41
Goose	121	110	61	52	57	46
Mean	128	117	71	59	58	47
SE +/-	9.53	9.17	4.74	3.96	1.83	2.48
Maize Field						

converted from							
Forest							
Reshwari	100	87	62	52	43	31	
Doni wari	121	104	59	49	35	23	
Darugmul	104	88	69	57	37	26	
Kunan	85	75	46	39	41	31	
Herri	87	75	52	40	52	40	
Mean	99	86	58	47	42	30	
SE +/-	6.52	5.34	3.98	3.47	2.96	2.89	
Plantation							
Braripora	95	84	45	33	34	25	
Khanti pora	92	81	34	25	22	10	
Nagri	104	89	43	33	35	22	
Batergam	99	88	27	17	21	12	
Batpora	77	70	51	41	34	23	
Mean	93	83	40	30	29	18	
SE +/-	4.57	3.42	4.24	4.08	3.15	3.08	
Paddy							
Arampora	74	63	31	20	5	3	
Cheeri koot	51	41	20	11	11	6	
Mughalpora	43	32	24	14	14	7	
Shatpora	62	51	15	8	9	5	
Bunherri	25	14	11	6	4	1	
Mean	51	40	20	12	9	4	
SE +/-	8.34	8.34	3.48	2.46	1.86	1.08	

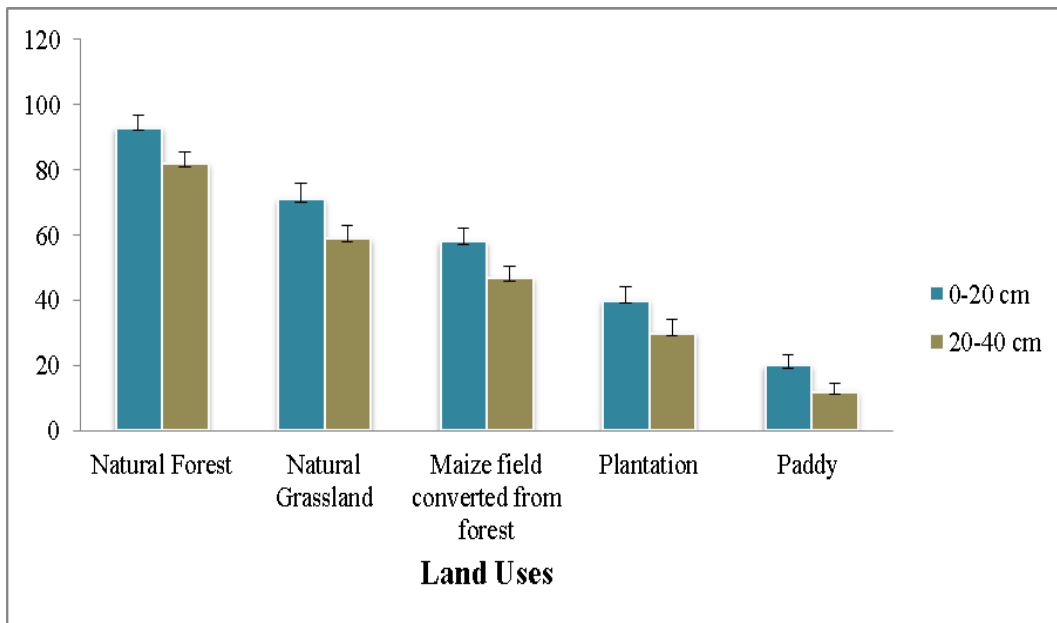


Fig. 4.7: Viable fungi ($\text{cfu} \cdot 10^{-5} \text{ g}^{-1}$) in surface and sub-surface soils under different land use types

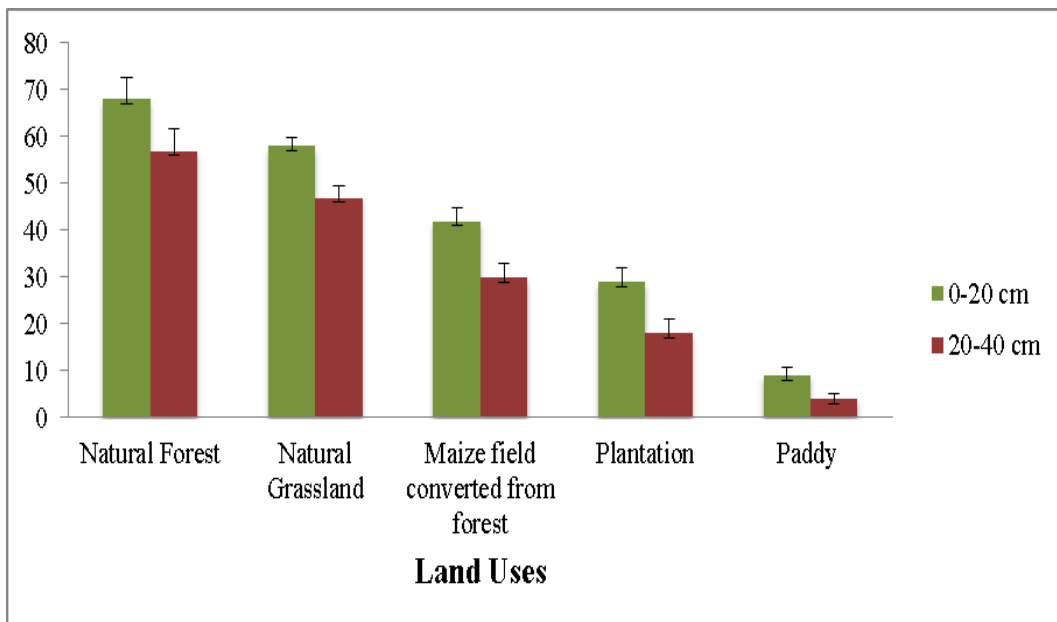


Fig. 4.8: Viable actinomycetes ($\text{cfu} \cdot 10^{-5} \text{ g}^{-1}$) in surface and sub-surface soils under different land use type

4.3 Organic carbon and lability based fractions

4.3.1 Total organic carbon (TOC)

In the present study, TOC in surface soil (0-20 cm) of various land uses had a range from 11.77 to 24.90 g kg⁻¹ and in the sub-surface (20-40 cm) layers it ranged from 9.24-19.24 g kg⁻¹ of soil (Table 4.3). The mean values of TOC in surface and sub-surface soils were 24.24 and 18.76 in natural forest; 20.52 and 15.60 in natural grassland; 16.98 and 13.44 under maize-field-converted-from-forest; 15.13 and 11.60 in plantation; 12.76 and 9.81 g kg⁻¹ in soils under paddy land use (Table 4.4). Among surface soils of different land use types the highest mean TOC was found in the natural forest (24.24 g kg⁻¹), while paddy soils showed the lowest (12.76 g kg⁻¹) (Fig. 4.9). Similar, order was recorded in the sub-surface soils also, with mean TOC content of 18.76 g kg⁻¹ in natural forest and 9.81 g kg⁻¹ in paddy soils (Fig. 4.10). The natural grassland land use system at both the soil depths also had a significantly higher amount of TOC (20.52 and 15.30 g kg⁻¹) than the maize-field-converted-from-forest system (16.98 and 13.44 g kg⁻¹) and plantation land use (15.13 and 11.60 g kg⁻¹). TOC of each land use type decreased with increase in soil depth and was observed to be in order; natural forest > natural grassland > maize-field-converted-from-forest > plantation > paddy in both surface and sub-surface soils.

4.3.2 Walkley-Black carbon (WBC)

The WBC in surface and sub-surface soils of various land uses had a range between 6.95 to 18.72 g kg⁻¹ of soil. The mean values of WBC in surface and sub-surface soils were 18.23 and 14.10 in natural forest; 15.42 and 11.73 under natural grassland; 12.77 and 10.11 in maize-field-converted-from-forest; 11.38 and 8.72 under plantation; 9.59 and 7.37 g kg⁻¹ in soils of paddy (Table 4.3). In both the soil depths of different land uses, the highest mean WBC was found in the natural forest (18.23 and 14.10 g kg⁻¹), while paddy soils showed the lowest i.e.

9.59 and 7.37 g kg⁻¹ of soil (Table 4.4). WBC of each land use type decreased with increase in soil depth and was in the order; natural forest > natural grassland > maize-field-converted-from-forest > plantation > paddy in both surface and sub-surface soils (Fig 4.9 and Fig 4.10).

4.3.3 Very labile carbon (VLC)

Data pertaining to mean values of VLC under different land uses are presented in Table 4.3. In both the surface as well as sub-surface soil depth, VLC was observed to be in the order as; natural forest > natural grassland > maize-field-converted-from-forest > plantation > paddy (Table 4.4). A decreasing trend with depth was observed for all the land use systems having highest values in the surface layer of soils. In natural forest, natural grassland, maize-field-converted-from-forest, plantation and paddy soils in surface layers, VLC ranged from 3.90 to 8.97 g kg⁻¹. In the sub-surface it had a range from 3.42 to 6.47 g kg⁻¹ of soil. Table exhibited that the highest VLC mean values of 8.65 and 6.30 g kg⁻¹ in surface and sub-surface was recorded under natural forest, followed by natural grassland (7.35 and 5.35), maize-field-converted-from-forest (5.73 and 4.54), plantation (4.98 and 4.09), whereas lowest (4.45 and 3.79) g kg⁻¹ was recorded in paddy soils (Fig. 4.9 and 4.10).

4.3.4 Labile carbon (LC)

The LC range for surface and sub-surface soil depth was 2.61 to 3.85, 2.68 to 3.70, 2.03 to 3.58, 1.68 to 3.46 and 1.30 to 2.61 g kg⁻¹ in natural forest, natural grassland, maize-field-converted-from-forest, plantation and paddy, respectively. The mean values of LC at 0-20 cm and 20-40 cm soil depth was 3.58 and 3.14 in natural forest; 3.38 and 2.91 in natural grassland; 3.07 and 2.49 under maize-field-converted-from-forest; 2.92 and 2.18 in plantation; 2.42 and 1.59 g kg⁻¹ in paddy soils (Table 4.3). Perusal of the data reveals that mean value of LC in natural forest at both the soil depths was respectively higher than the other land uses

(Table 4.4). The lowest mean value of LC i.e. 2.42 and 1.59 g kg⁻¹ in both the depths was recorded under paddy soil. A decreasing trend in LC content with depth was observed under all the land uses and it followed the order; natural forest > natural grassland > maize-field-converted-from-forest > plantation > paddy (Fig. 4.9 and 4.10).

4.3.5 Less labile carbon (LLC)

The mean values of LLC (g kg⁻¹) at 0-20 cm and 20-40 cm soil depth in natural forest was 2.59 and 2.00; natural grassland had 2.04 and 1.60; maize-field-converted-from-forest 1.90 and 1.37; 1.69 and 1.13 in plantations and 1.25 and 0.92 g kg⁻¹ in paddy soils (Table 4.3). The range for LLC in surface and sub-surface was 1.58 to 2.88, 1.38 to 2.22, 1.31 to 2.11, 0.89 to 1.91 and 0.83 to 1.50 g kg⁻¹ in natural forest, natural grassland, maize-field-converted-from-forest, plantation and paddy soils. It was found that the highest mean values of LLC viz., 2.59 g kg⁻¹ at surface layer was recorded in natural forests which was followed by natural grassland having mean value of 2.04 g kg⁻¹. At sub-surface soil layer, the highest mean value of LLC viz., 2.00 g kg⁻¹ was recorded in natural forests which were followed by natural grassland having mean value of 1.60 g kg⁻¹ of soil (Table 4.4). The lowest mean values of LLC viz., 1.25 and 0.92 g kg⁻¹ in surface and sub-surface soil depth were recorded under paddy land use. A decreasing trend in LLC content with depth was observed under all land uses with highest value observed in the surface layer. The LLC had the following order at both the soil depths; natural forest > natural grassland > maize-field-converted-from-forest > plantation > paddy, respectively (Fig. 4.9 and 4.10).

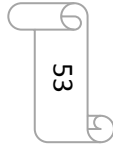
4.3.6 Non labile carbon (NLC)

A decreasing trend in NLC content with depth was observed under all land uses with highest value observed in the surface layer. The NLC followed the order; natural forest > natural grassland > maize-field-converted-from-forest >

plantation > paddy (Fig. 4.9 and 4.10). In surface and sub-surface soil depth, NLC had the range as 2.38 to 3.61, 1.29 to 2.86, 1.40 to 2.43, 1.00 to 2.03 and 0.90 to 1.69 g kg⁻¹ in natural forest, natural grassland, maize-field-converted-from-forest, plantation and paddy soils, respectively (Table 4.3). The mean values of NLC in surface and sub-surface layer was 3.41 and 2.66 in natural forest; 2.63 and 1.87 under natural grassland; 2.07 and 1.71 in maize-field-converted-from-forest; 1.79 and 1.32 in plantations and 1.47 and 1.07 g kg⁻¹ being recorded in paddy fields (Table 4.4). The mean values of NLC in natural forest (3.41 and 2.66 g kg⁻¹) land use at both soil depths were respectively higher than the other land uses, while lowest mean values of NLC (1.47 and 1.07 g kg⁻¹) was recorded in paddy soils.

Table 4.3: Organic carbon and lability based fractions in surface layer (0-20 cm) of different soils in the study area

Land use type/ Location	TOC	WBC	VLC	LC	LLC	NLC
	-----g kg ⁻¹ -----					
Natural Forest						
Kulangam	24.75	18.61	8.66	3.60	2.09	3.26
Jaggerpora	23.59	17.73	8.97	3.50	2.88	3.38
Anderhama	23.38	17.58	8.34	3.36	2.61	3.21
Kunan	24.90	18.72	8.82	3.58	2.81	3.69
Batergam	24.60	18.49	8.44	3.85	2.56	3.51
Mean	24.24	18.23	8.65	3.58	2.59	3.41
SE +/-	0.31	0.24	0.12	0.08	0.14	0.09
Natural Grassland						
Radbugha	21.31	16.02	7.12	3.38	1.99	2.71
Shalpora	20.35	15.30	7.54	3.14	2.22	2.61
Drugmulla	20.10	15.11	7.32	3.50	1.84	2.41
Kralpora	20.45	15.38	7.19	3.22	2.09	2.58
Goose	20.35	15.30	7.68	3.70	2.06	2.86
Mean	20.52	15.42	7.37	3.38	2.04	2.63
SE +/-	0.20	0.16	0.11	0.10	0.06	0.07
Maize Field converted from Forest						
Reshwari	17.32	13.02	5.83	2.89	2.11	2.24
Doni wari	16.21	12.19	5.27	2.25	1.61	1.75
Darugmul	17.37	13.06	6.35	3.10	1.74	1.88
Kunan	16.46	12.38	5.11	3.58	2.05	2.06
Herri	17.53	13.18	6.07	3.51	1.98	2.43



Mean	16.98	12.77	5.73	3.07	1.90	2.07
SE +/-	0.26	0.20	0.22	0.24	0.10	0.12
Plantation						
Braripora	15.56	11.70	4.98	2.33	1.66	1.95
Khanti pora	14.09	10.59	4.82	3.46	1.79	1.68
Nagri	15.66	11.77	4.68	2.57	1.58	2.03
Batergam	16.01	12.04	5.32	3.34	1.51	1.53
Batpora	14.34	10.78	5.11	2.91	1.91	1.75
Mean	15.13	11.38	4.98	2.92	1.69	1.79
SE +/-	0.38	0.29	0.11	0.22	0.07	0.09
Paddy						
Arampora	12.47	9.38	4.10	2.55	1.10	1.60
Cheeri koot	12.93	9.72	4.22	2.17	1.13	1.69
Mughalpora	13.08	9.84	4.92	2.61	1.23	1.53
Shatpora	11.77	8.85	3.90	2.43	1.27	1.19
Bunherri	13.54	10.18	5.11	2.36	1.50	1.34
Mean	12.76	9.59	4.45	2.42	1.25	1.47
SE +/-	0.30	0.23	0.24	0.08	0.07	0.09

TOC- Total organic carbon, WBC- Walkley-Black carbon, VLC- Very labile carbon, LC- Labile carbon, LLC- Less labile carbon, NLC- Non labile carbon.

Table 4.4: Organic carbon and lability based fractions in sub-surface layer (20-40 cm) of different soils in the study area

Land use type/ Location	TOC	WBC	VLC	LC	LLC	NLC
	----- g kg ⁻¹ -----					
Natural Forest						
Kulangam	18.64	14.01	6.31	3.30	1.58	2.80
Jaggerpora	18.99	14.28	6.47	3.37	2.02	2.59
Anderhama	18.03	13.56	6.07	3.02	1.85	2.51
Kunan	18.89	14.20	6.35	2.61	2.33	2.38
Batergam	19.24	14.47	6.27	3.38	2.21	3.01
Mean	18.76	14.10	6.30	3.14	2.00	2.66
SE +/-	0.20	0.16	0.07	0.15	0.13	0.11
Natural Grassland						
Radbugha	15.45	11.62	4.77	2.81	1.65	2.33
Shalpora	15.45	11.62	5.39	2.68	1.52	1.64
Drugmulla	15.66	11.77	5.70	3.02	1.87	1.73
Kralpora	15.76	11.85	5.00	2.85	1.38	2.37
Goose	15.66	11.77	5.87	3.17	1.58	1.29
Mean	15.60	11.73	5.35	2.91	1.60	1.87
SE +/-	0.06	0.01	0.21	0.09	0.08	0.21
Maize Field converted from Forest						
Reshwari	13.89	10.44	4.70	2.37	1.31	1.83
Doni wari	12.88	9.68	4.30	2.03	1.43	1.40
Darugmul	13.89	10.44	5.47	2.56	1.35	1.65
Kunan	12.47	9.38	4.23	2.68	1.57	1.60
Herri	14.09	10.59	3.98	2.81	1.21	2.06

Mean	13.44	10.11	4.54	2.49	1.37	1.71
SE +/-	0.32	0.24	0.26	0.14	0.06	0.11
Plantation						
Braripora	10.86	8.16	3.90	1.68	1.24	1.63
Khanti pora	11.26	8.47	3.54	2.56	1.41	1.50
Nagri	11.72	8.81	3.78	2.28	0.89	1.13
Batergam	12.73	9.57	4.42	2.65	0.98	1.35
Batpora	11.41	8.58	4.78	1.73	1.14	1.00
Mean	11.60	8.72	4.09	2.18	1.13	1.32
SE +/-	0.31	0.24	0.23	0.20	0.09	0.12
Paddy						
Arampora	9.39	7.06	3.83	1.81	0.97	1.10
Cheeri koot	10.61	7.97	3.97	1.30	0.83	1.30
Mughalpora	9.34	7.03	3.42	1.61	0.88	1.00
Shatpora	9.24	6.95	3.51	1.75	1.10	0.90
Bunherri	10.45	7.86	4.22	1.50	0.83	1.03
Mean	9.81	7.37	3.79	1.59	0.92	1.07
SE +/-	0.29	0.22	0.13	0.09	0.05	0.07

TOC- Total organic carbon, WBC- Walkley-Black carbon, VLC- Very labile carbon, LC- Labile carbon, LLC- Less labile carbon, NLC- Non labile carbon.

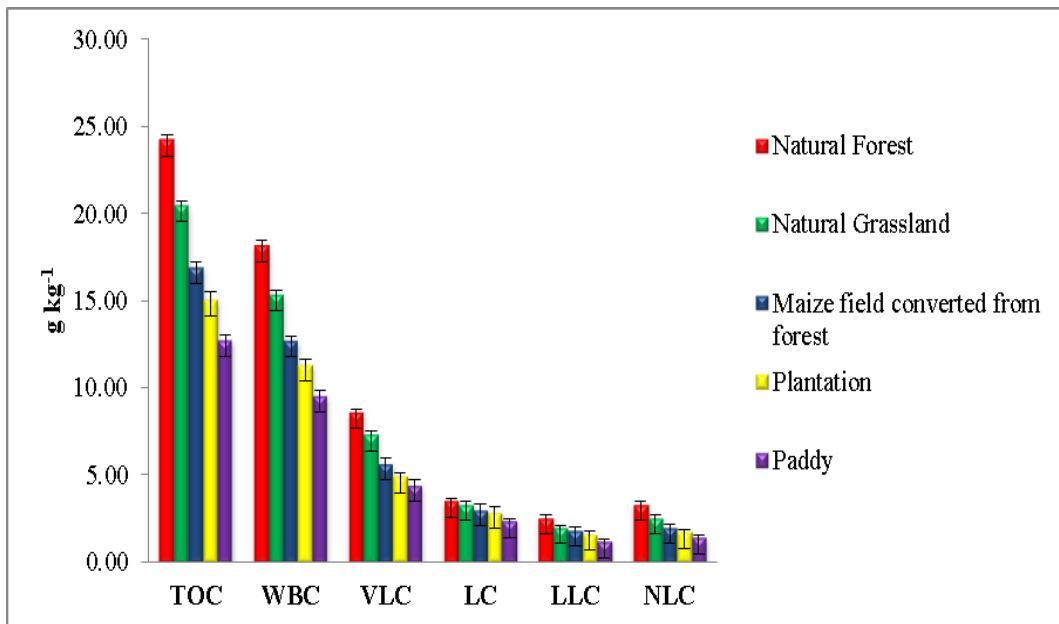


Fig. 4.9: Organic carbon and lability based fractions in surface layer (0-20 cm) of different soils in the study area

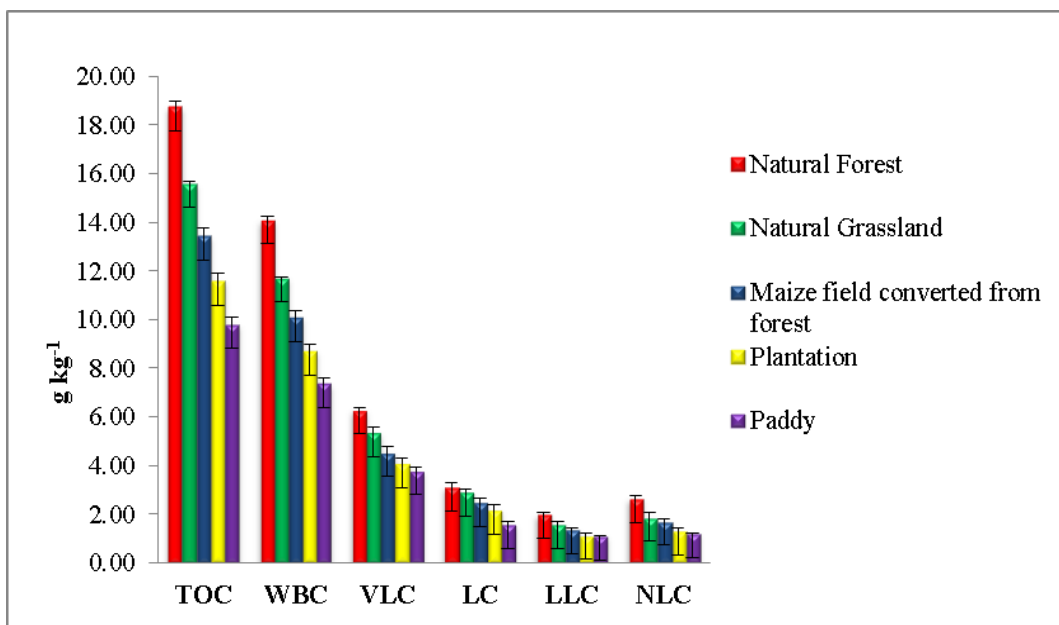


Fig. 4.10: Organic carbon and lability based fractions in sub-surface layer (20-40 cm) of different soils in the study area

4.4 Organic carbon stocks

4.4.1 Total organic carbon (TOC) stock

Data pertaining to the mean values of TOC stocks under different land uses are presented in Table 4.5. The TOC stock in natural forest land use (surface soil depth) recorded highest among the different land uses and ranged between 35.54 to 54.71 Mg ha⁻¹ with a mean of 45.88 Mg ha⁻¹, in the sub-surface it ranged between 32.82 to 48.57 Mg ha⁻¹ with a mean of 41.16 Mg ha⁻¹. In natural grassland system (surface soil depth), TOC stock ranged from 42.20 to 47.44 Mg ha⁻¹ with a mean of 43.93 Mg ha⁻¹, in sub-surface depth it ranged from 35.44 to 37.80 Mg ha⁻¹ having a mean of 36.82 Mg ha⁻¹. TOC stock in maize-field-converted-from-forest (surface soil depth) ranged from 39.13 to 43.70 Mg ha⁻¹ with a mean of 41.75 Mg ha⁻¹, in sub-surface it ranged from 32.60 to 37.11 Mg ha⁻¹ having a mean of 34.80 Mg ha⁻¹. In surface layer, the TOC stock under plantation ranged from 38.80 to 41.79 Mg ha⁻¹ with a mean of 39.73 Mg ha⁻¹, in the sub-surface depth it ranged from 30.04 to 32.16 Mg ha⁻¹ having a mean of 31.37 Mg ha⁻¹. In paddy soils, TOC stock (surface soil depth) ranged from 33.03 to 39.34 Mg ha⁻¹ with a mean of 36.45 Mg ha⁻¹, in sub-surface depth it ranged from 26.31 to 30.81 Mg ha⁻¹ having a mean of 28.42 Mg ha⁻¹. The highest TOC stock mean values in surface and sub-surface soil depth were recorded in natural forests (45.88 and 41.16 Mg ha⁻¹), followed by natural grassland (43.93 and 36.82 Mg ha⁻¹) and lowest were recorded under paddy viz., 36.45 and 28.42 Mg ha⁻¹ (Fig. 4.11). The TOC stock had the following order at both soil depths; natural forest > natural grassland > maize-field-converted-from-forest > plantation > paddy.

Table 4.5: Total organic carbon stocks (Mg ha⁻¹) in surface and sub-surface layers of different soils

Land use type/ Location	-----Surface-----				-----Sub-surface-----			
	TOC	BD	Depth	TOC stock	TOC	BD	Depth	TOC stock
Natural Forest			0.20				0.20	
Kulangam	2.47	0.84		41.74	1.86	0.99		37.02
Jaggerpora	2.36	0.95		44.97	1.90	1.10		41.90
Anderhama	2.34	0.76		35.54	1.80	0.91		32.82
Kunan	2.49	1.05		52.46	1.89	1.20		45.46
Batergam	2.46	1.11		54.71	1.92	1.26		48.57
Mean	2.42	0.94		45.88	1.88	1.09		41.16
SE +/-	0.03	0.07		3.51	0.02	0.06		2.83
Natural Grassland			0.20				0.20	
Radbugha	2.13	1.11		47.44	1.55	1.22		37.80
Shalpora	2.04	1.04		42.20	1.55	1.15		35.44
Drugmulla	2.01	1.07		42.88	1.57	1.18		36.85
Kralpora	2.05	1.08		43.99	1.58	1.19		37.36
Goose	2.04	1.06		43.15	1.57	1.17		36.64
Mean	2.05	1.07		43.93	1.56	1.18		36.82
SE +/-	0.02	0.01		0.92	0.01	0.01		0.40
Maize Field converted from Forest			0.20				0.20	
Reshwari	1.73	1.19		41.23	1.39	1.26		35.00
Doni wari	1.62	1.21		39.13	1.29	1.28		32.88
Darugmul	1.74	1.24		43.09	1.39	1.31		36.39
Kunan	1.65	1.24		40.72	1.25	1.31		32.60

Herri	1.75	1.25	43.70	1.41	1.32	37.11
Mean	1.70	1.22	41.57	1.34	1.29	34.80
SE +/-	0.03	0.01	0.83	0.03	0.01	0.91
Plantation			0.20			0.20
Braripora	1.56	1.34	41.79	1.09	1.38	30.04
Khanti pora	1.41	1.38	38.80	1.13	1.42	31.91
Nagri	1.57	1.27	39.87	1.17	1.31	30.78
Batergam	1.60	1.22	39.17	1.27	1.26	32.16
Batpora	1.43	1.36	39.01	1.14	1.40	31.96
Mean	1.51	1.32	39.73	1.16	1.36	31.37
SE +/-	0.04	0.03	0.55	0.03	0.03	0.41
Paddy			0.20			0.20
Arampora	1.25	1.45	36.09	0.94	1.47	27.56
Cheeri koot	1.29	1.43	36.98	1.06	1.45	30.76
Mughalpora	1.31	1.41	36.80	0.93	1.43	26.66
Shatpora	1.18	1.40	33.03	0.92	1.42	26.31
Bunherri	1.35	1.45	39.34	1.05	1.47	30.81
Mean	1.28	1.43	36.45	0.98	1.45	28.42
SE +/-	0.03	0.01	1.01	0.03	0.01	0.99

TOC- Total organic carbon (%), BD- Bulk density (Mg m^{-3}), Depth- m

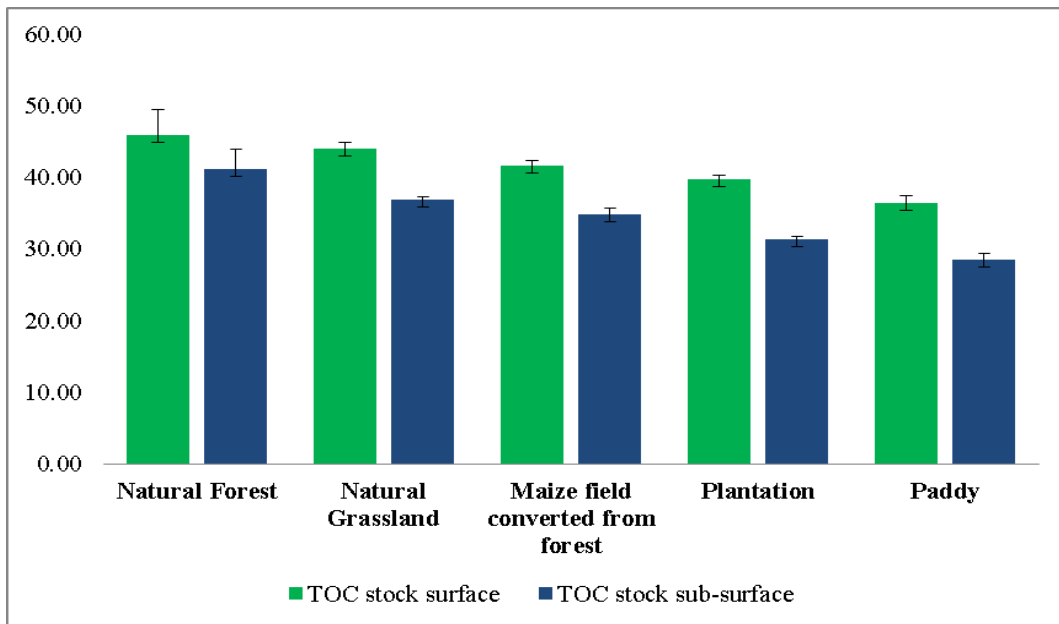


Fig. 4.11: Total organic carbon stocks (Mg ha⁻¹) in surface and sub-surface layers of different soils

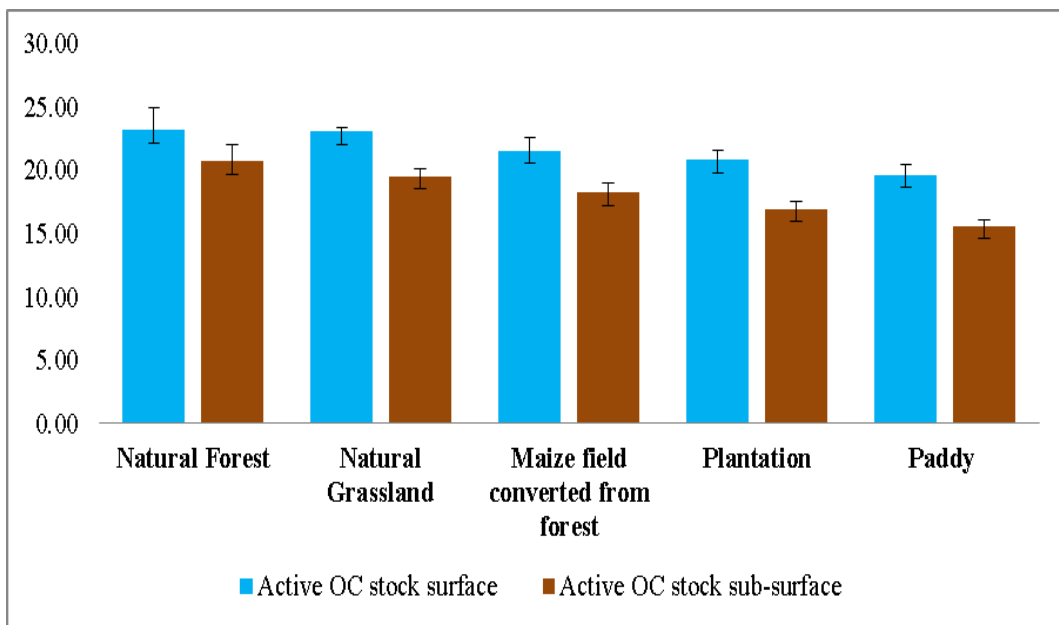


Fig. 4.12: Active organic carbon stocks (Mg ha⁻¹) in surface and sub-surface layers of different soils

4.4.2 Active organic carbon (AOC) stock

The data pertaining to the mean values of AOC stocks under different land uses are presented in Table 4.6. AOC stock had the following order at both depths i.e. surface and sub-surface as; natural forest > natural grassland > maize-field-converted-from-forest > plantation > paddy (Fig. 4.12). In surface and sub-surface soil depth, AOC stocks (Mg ha^{-1}) had the range as 16.53 to 27.35, 18.49 to 24.12, 16.17 to 23.89, 15.44 to 24.81 and 14.34 to 21.69 Mg ha^{-1} in natural forest, natural grassland, maize-field-converted-from-forest, plantation and paddy soils, respectively. The mean values of AOC stocks in surface and sub-surface layer was 23.14 and 20.66 in natural forest; 23.02 and 19.47 under natural grassland; 21.54 and 18.20 in maize-field-converted-from-forest; 20.78 and 16.95 in plantations and 19.63 and 15.60 Mg ha^{-1} found in paddy soils. The mean values of AOC stocks in natural forest (23.14 and 20.66 Mg ha^{-1}) land use at both soil depths were respectively higher than the other land uses, while lowest was recorded in paddy soils viz., 19.63 and 15.60 Mg ha^{-1} .

4.4.3 Passive organic carbon (POC) stock

The data pertaining to the mean values of POC stocks under different land uses are presented in Table 4.7. In surface and sub-surface soil depth, POC stocks (Mg ha^{-1}) ranged between 7.94 to 13.69, 6.72 to 10.46, 7.24 to 10.99, 5.30 to 9.97 and 5.36 to 8.26 Mg ha^{-1} in natural forest, natural grassland, maize-field-converted-from-forest, plantation and paddy soils, respectively. The mean values of POC stocks in surface and sub-surface layer was 11.40 and 10.26 in natural forest; 10.00 and 8.21 under natural grassland; 9.71 and 7.98 in maize-field-converted-from-forest; 9.18 and 6.68 in plantations and 7.77 and 5.76 Mg ha^{-1} found in paddy soils. The mean values of POC stocks in natural forest (11.40 and 10.26 Mg ha^{-1}) land use at both soil depths were higher than the other studied land uses, while lowest was recorded in paddy soils viz., 7.77 and 5.76 Mg ha^{-1} . POC

stock had the following order at both depths; natural forest > natural grassland > maize-field-converted-from-forest > plantation > paddy (Fig. 4.13).

4.4.4 Walkley-Black carbon (WBC) stock

Perusal of the data (Table 4.8) shows the WBC stocks in different land use types. The highest WBC stock mean values in surface and sub-surface soil depth were recorded in natural forest (34.50 and 30.94 Mg ha⁻¹) land use system, followed by natural grasslands (33.03 and 27.68 Mg ha⁻¹) and lowest were recorded in paddy soils viz., 27.40 and 21.37 Mg ha⁻¹. The WBC stock under natural forest land use system at surface ranged between 26.72 to 41.13 Mg ha⁻¹ with a mean of 34.50 Mg ha⁻¹, in the sub-surface it ranged from 24.67 to 36.52 Mg ha⁻¹ with a mean of 30.94 Mg ha⁻¹. In natural grassland system at 0-20 cm depth WBC stock ranged from 31.73 to 35.67 Mg ha⁻¹ with a mean of 33.03 Mg ha⁻¹, at 20-40 cm, it ranged from 26.65 to 28.42 Mg ha⁻¹ having a mean of 27.68 Mg ha⁻¹. WBC stock in maize-field-converted-from-forest at surface ranged from 29.42 to 32.85 Mg ha⁻¹ with a mean of 31.26 Mg ha⁻¹, at sub-surface it ranged from 24.51 to 27.90 Mg ha⁻¹ having a mean of 26.16 Mg ha⁻¹. At 0-20 cm soil depth, the WBC stock in plantations ranged between 29.17 to 31.42 Mg ha⁻¹ with a mean of 29.87 Mg ha⁻¹, at 20-40 cm soil depth it ranged from 22.59 to 24.18 Mg ha⁻¹ having a mean of 23.59 Mg ha⁻¹. Under paddy land use, the WBC stock at 0-20 cm depth ranged between 24.83 to 29.58 Mg ha⁻¹ with a mean of 27.40 Mg ha⁻¹, at 20-40 cm soil depth it ranged between 19.78 to 23.16 Mg ha⁻¹ having a mean of 21.37 Mg ha⁻¹. The WBC stock had the following order; natural forest > natural grassland > maize-field-converted-from-forest > plantation > paddy (Fig. 4.14).

Table 4.6: Active organic carbon stocks (Mg ha⁻¹) in surface and sub-surface layers of different soils

Land use type/ Location	-----Surface-----				-----Sub-surface-----			
	AOC	BD	Depth	Active OC stock	AOC	BD	Depth	Active OC stock
Natural Forest			0.20				0.20	
Kulangam	1.23	0.84		20.69	0.96	0.99		19.09
Jaggerpora	1.25	0.95		23.77	0.98	1.10		21.73
Anderhama	1.17	0.76		17.78	0.91	0.91		16.53
Kunan	1.24	1.05		26.12	0.90	1.20		21.58
Batergam	1.23	1.11		27.35	0.97	1.26		24.37
Mean	1.22	0.94		23.14	0.94	1.09		20.66
SE +/-	0.01	0.07		1.76	0.02	0.06		1.33
Natural Grassland			0.20				0.20	
Radbugha	1.05	1.11		23.36	0.76	1.22		18.55
Shalpora	1.07	1.04		22.14	0.81	1.15		18.49
Drugmulla	1.08	1.07		23.07	0.87	1.18		20.51
Kralpora	1.04	1.08		22.39	0.79	1.19		18.63
Goose	1.14	1.06		24.12	0.90	1.17		21.16
Mean	1.08	1.07		23.02	0.83	1.18		19.47
SE +/-	0.02	0.01		0.35	0.03	0.01		0.57
Maize Field converted from Forest			0.20				0.20	
Reshwari	0.87	1.19		20.77	0.71	1.26		17.82
Doni wari	0.75	1.21		18.15	0.63	1.28		16.17
Darugmul	0.94	1.24		23.43	0.80	1.31		21.04
Kunan	0.87	1.24		21.49	0.69	1.31		18.07

Herri	0.96	1.25	23.89	0.68	1.32	17.87
Mean	0.88	1.22	21.54	0.70	1.29	18.20
SE +/-	0.04	0.01	1.03	0.03	0.01	0.79
Plantation		0.20			0.20	
Braripora	0.73	1.34	19.64	0.56	1.38	15.44
Khanti pora	0.83	1.38	22.81	0.61	1.42	17.27
Nagri	0.73	1.27	18.48	0.61	1.31	15.92
Batergam	0.87	1.22	21.17	0.71	1.26	17.88
Batpora	0.80	1.36	21.81	0.65	1.40	18.24
Mean	0.79	1.32	20.78	0.63	1.36	16.95
SE +/-	0.03	0.03	0.77	0.03	0.03	0.55
Paddy		0.20			0.20	
Arampora	0.67	1.45	19.25	0.56	1.47	16.56
Cheeri koot	0.64	1.43	18.29	0.53	1.45	15.28
Mughalpora	0.75	1.41	21.18	0.50	1.43	14.34
Shatpora	0.63	1.40	17.75	0.53	1.42	14.96
Bunherri	0.75	1.45	21.69	0.57	1.47	16.86
Mean	0.69	1.43	19.63	0.54	1.45	15.60
SE +/-	0.03	0.01	0.78	0.01	0.01	0.48

AOC- Active organic carbon (%), BD- Bulk density (Mg m^{-3}), Depth- m

Table 4.7: Passive organic carbon stocks (Mg ha⁻¹) in surface and sub-surface layers of different soils

Land use type/ Location	-----Surface-----				-----Sub-surface-----			
	POC	BD	Depth	Passive OC stock	POC	BD	Depth	Passive OC stock
Natural Forest			0.20				0.20	
Kulangam	0.53	0.84		9.01	0.44	0.99		8.69
Jaggerpora	0.63	0.95		11.95	0.46	1.10		10.16
Anderhama	0.58	0.76		8.84	0.44	0.91		7.94
Kunan	0.65	1.05		13.69	0.47	1.20		11.34
Batergam	0.61	1.11		13.51	0.52	1.26		13.17
Mean	0.60	0.94		11.40	0.47	1.09		10.26
SE +/-	0.02	0.07		1.06	0.02	0.06		0.94
Natural Grassland			0.20				0.20	
Radbugha	0.47	1.11		10.46	0.40	1.22		9.74
Shalpora	0.48	1.04		10.00	0.32	1.15		7.25
Drugmulla	0.42	1.07		9.06	0.36	1.18		8.47
Kralpora	0.47	1.08		10.06	0.37	1.19		8.87
Goose	0.49	1.06		10.41	0.29	1.17		6.72
Mean	0.47	1.07		10.00	0.35	1.18		8.21
SE +/-	0.01	0.01		0.25	0.02	0.01		0.55
Maize Field converted from Forest			0.20				0.20	
Reshwari	0.43	1.19		10.34	0.31	1.26		7.91
Doni wari	0.34	1.21		8.13	0.28	1.28		7.24
Darugmul	0.36	1.24		8.96	0.30	1.31		7.88
Kunan	0.41	1.24		10.15	0.32	1.31		8.30

Herri	0.44	1.25	10.99	0.33	1.32	8.59
Mean	0.40	1.22	9.71	0.31	1.29	7.98
SE +/-	0.02	0.01	0.51	0.01	0.01	0.23
Plantation		0.20			0.20	
Braripora	0.36	1.34	9.72	0.29	1.38	7.95
Khanti pora	0.35	1.38	9.56	0.29	1.42	8.26
Nagri	0.36	1.27	9.21	0.20	1.31	5.30
Batergam	0.30	1.22	7.44	0.23	1.26	5.89
Batpora	0.37	1.36	9.97	0.21	1.40	5.99
Mean	0.35	1.32	9.18	0.25	1.36	6.68
SE +/-	0.01	0.03	0.45	0.02	0.03	0.60
Paddy		0.20			0.20	
Arampora	0.27	1.45	7.81	0.21	1.47	6.07
Cheeri koot	0.28	1.43	8.08	0.21	1.45	6.17
Mughalpora	0.28	1.41	7.79	0.19	1.43	5.36
Shatpora	0.25	1.40	6.88	0.20	1.42	5.69
Bunherri	0.28	1.45	8.26	0.19	1.47	5.50
Mean	0.27	1.43	7.77	0.20	1.45	5.76
SE +/-	0.01	0.01	0.24	0.01	0.01	0.16

POC- Passive organic carbon (%), BD- Bulk density (Mg m^{-3}), Depth- m

Table 4.8: Walkley-Black carbon stocks (Mg ha⁻¹) in surface and sub-surface layers of different soils

Land use type/ Location	-----Surface-----				-----Sub-surface-----			
	WBC	BD	Depth	WBC stock	WBC	BD	Depth	WBC stock
Natural Forest			0.20				0.20	
Kulangam	1.86	0.84		31.38	1.40	0.99		27.84
Jaggerpora	1.77	0.95		33.81	1.43	1.10		31.51
Anderhama	1.76	0.76		26.72	1.36	0.91		24.67
Kunan	1.87	1.05		39.44	1.42	1.20		34.18
Batergam	1.85	1.11		41.13	1.45	1.26		36.52
Mean	1.82	0.94		34.50	1.41	1.09		30.94
SE +/-	0.02	0.07		2.64	0.02	0.06		2.13
Natural Grassland			0.20				0.20	
Radbugha	1.60	1.11		35.67	1.16	1.22		28.42
Shalpora	1.53	1.04		31.73	1.16	1.15		26.65
Drugmulla	1.51	1.07		32.24	1.18	1.18		27.70
Kralpora	1.54	1.08		33.08	1.18	1.19		28.09
Goose	1.53	1.06		32.44	1.18	1.17		27.55
Mean	1.54	1.07		33.03	1.17	1.18		27.68
SE +/-	0.02	0.01		0.69	0.01	0.01		0.30
Maize Field converted from Forest			0.20				0.20	
Reshwari	1.30	1.19		31.00	1.04	1.26		26.32
Doni wari	1.22	1.21		29.42	0.97	1.28		24.72
Darugmul	1.31	1.24		32.40	1.04	1.31		27.36
Kunan	1.24	1.24		30.62	0.94	1.31		24.51

Herri	1.32	1.25	32.85	1.06	1.32	27.90
Mean	1.28	1.22	31.26	1.01	1.29	26.16
SE +/-	0.02	0.01	0.62	0.02	0.01	0.68
Plantation		0.20			0.20	
Braripora	1.17	1.34	31.42	0.82	1.38	22.59
Khanti pora	1.06	1.38	29.17	0.85	1.42	23.99
Nagri	1.18	1.27	29.98	0.88	1.31	23.14
Batergam	1.20	1.22	29.45	0.96	1.26	24.18
Batpora	1.08	1.36	29.33	0.86	1.40	24.03
Mean	1.14	1.32	29.87	0.87	1.36	23.59
SE +/-	0.03	0.03	0.41	0.02	0.03	0.31
Paddy		0.20			0.20	
Arampora	0.94	1.45	27.14	0.71	1.47	20.72
Cheeri koot	0.97	1.43	27.80	0.80	1.45	23.13
Mughalpora	0.98	1.41	27.67	0.70	1.43	20.05
Shatpora	0.88	1.40	24.83	0.69	1.42	19.78
Bunherri	1.02	1.45	29.58	0.79	1.47	23.16
Mean	0.96	1.43	27.40	0.74	1.45	21.37
SE +/-	0.02	0.01	0.76	0.02	0.01	0.74

WBC- Walkley-Black carbon (%), BD- Bulk density (Mg m^{-3}), Depth- m

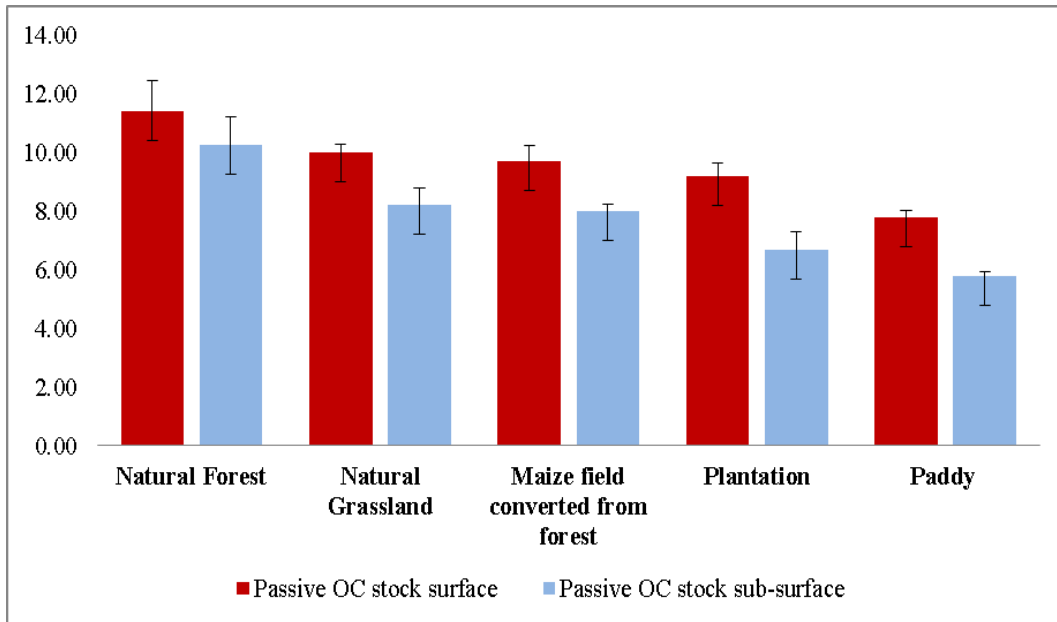


Fig. 4.13: Passive organic carbon stocks (Mg ha⁻¹) in surface and sub-surface layers of different soils

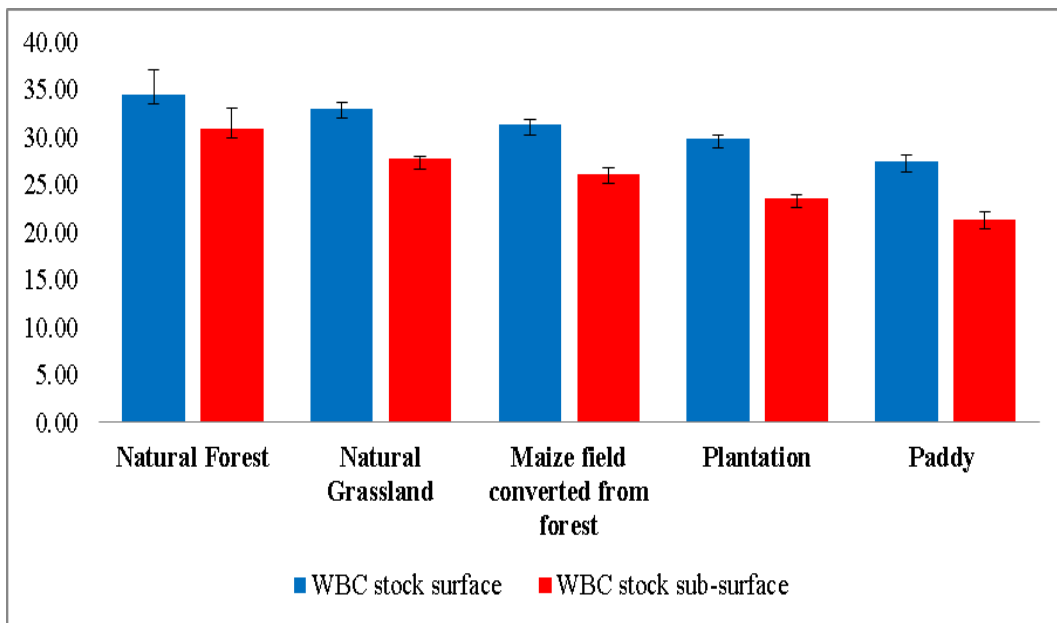


Fig. 4.14: Walkley-Black carbon stocks (Mg ha⁻¹) in surface and sub-surface layers of different soils

4.5 Comparison of OC stocks based on Mebius and Walkley-Black carbon method

The data pertaining to the comparison of OC stocks (Mg ha^{-1}) based on Mebius and Walkley-Black carbon (WBC) method in surface and sub-surface layers of different soils are presented in Table 4.9. In the surface and sub-surface layers of all land use the OC stocks based on Mebius based method were recorded to be higher as compared to the stocks based on WBC method. The mean values of TOC and WBC stock when compared at 0-20 cm soil depth were respectively; 45.88 and 34.50 in natural forest; 43.93 and 33.03 in natural grassland; 41.57 and 31.26 in maize-field-converted-from-forest; 39.73 and 29.87 under plantation; 36.45 and 27.40 Mg ha^{-1} in paddy soils. In the sub-surface, TOC and WBC stock mean values when compared were 41.16 and 30.94 in natural forest; 36.82 and 27.68 in natural grassland; 34.80 and 26.16 under maize-field-converted-from-forest; 31.37 and 23.59 in plantations; 28.42 and 21.37 Mg ha^{-1} under paddy soils, respectively. Based on both methods (TOC- Mebius and WBC) a decreasing trend in OC stocks were recorded in different land use types where natural forest land use had highest stock on both methods followed by natural grassland, least stock were found in paddy land use (Fig. 4.15). The OC stocks based on Mebius and WBC method had the following order: natural forest > natural grassland > maize-field-converted-from-forest > plantation > paddy.

Table 4.9: Comparison of OC stocks (Mg ha⁻¹) based on Mebius and Walkley-Black carbon method in surface and sub-surface layers of different soils

Land use type	Surface (0-20 cm)		Sub-surface (20-40 cm)	
	TOC stock	WBC stock	TOC stock	WBC stock
Natural Forest	45.88	34.50	41.16	30.94
Natural Grassland	43.93	33.03	36.82	27.68
Maize-Field-converted-from-Forest	41.57	31.26	34.80	26.16
Plantation	39.73	29.87	31.37	23.59
Paddy	36.45	27.40	28.42	21.37

TOC- Total organic carbon, WBC- Walkley- Black carbon

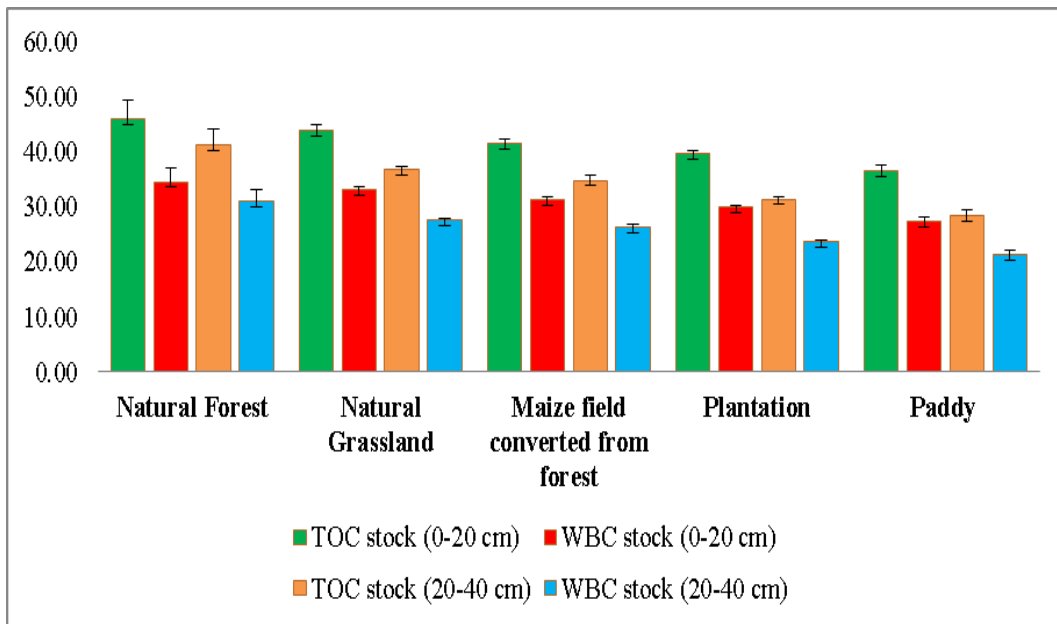


Fig. 4.15: Comparison of OC stocks (Mg ha⁻¹) based on Mebius and Walkley-Black carbon method in surface and sub-surface layers of different soils

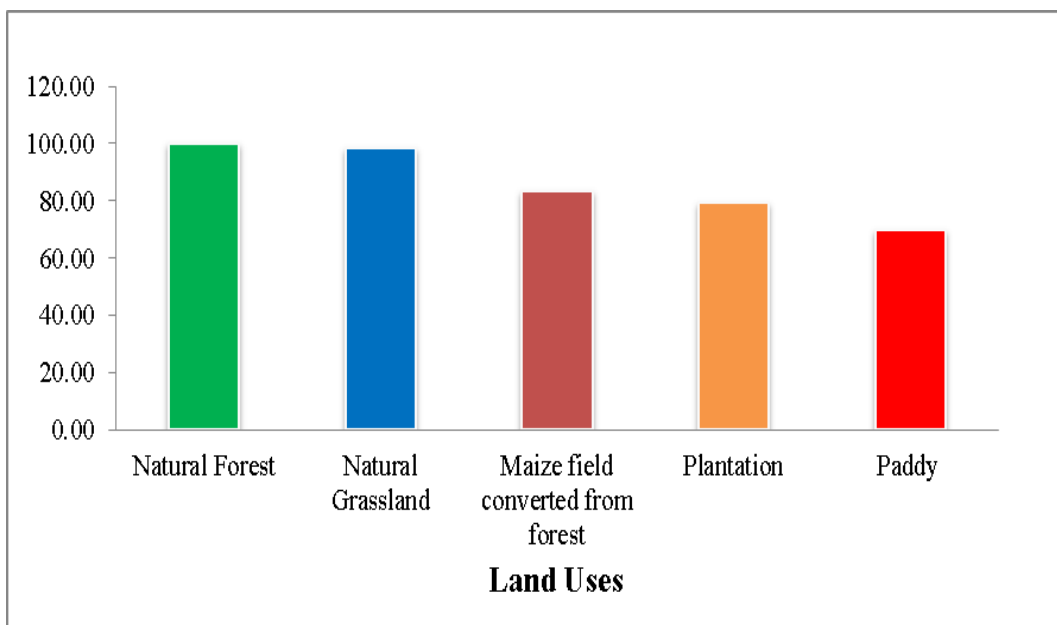


Fig. 4.16: Carbon management index as affected by different land uses (0-40 cm)

4.6 Carbon Management Index (CMI)

Table 4.10 represents the CMI of different land use types. At 0-40 cm in different land use types CMI were as follows; 100.00 in natural forest; 98.71 under natural grassland; 83.33 in maize-field-converted-from-forest; 79.39 under plantation and 70.08 in paddy soils. The highest CMI value was recorded under natural forest followed by natural grassland and lowest was in paddy land use type. The CMI values had the following order; natural forest > natural grassland > maize-field-converted-from-forest > plantation > paddy, respectively (Fig. 4.16).

Table 4.10: Carbon Management Index as affected by different land uses (0-40 cm)

Land use	CPI	CPI (g kg ⁻¹)	L	LI	CMI
Natural Forest	43.00	1.00	4.33	1.00	100
Natural Grassland	36.11	0.84	5.08	1.18	98.71
Maize Field converted from Forest	30.42	0.71	5.10	1.18	83.33
Plantation	26.73	0.62	5.52	1.28	79.39
Paddy	22.57	0.53	5.78	1.34	70.08
CD (p<0.05)					13.45

4.7 Correlation among various soil properties

4.7.1 Correlation coefficient (r) between functional soil organic carbon pools and total organic carbon with biological properties

The correlation coefficient (r) worked out between functional SOC pools (VLC, LC, LLC, NLC) and microbial count (bacteria, fungi, actinomycetes) is showed in Table 4.11. Perusal of data revealed that VLC showed positive significant correlation with all the counts: bacteria ($r= 0.851^{**}$), fungi ($r= 0.907^{**}$), actinomycetes ($r= 0.895^{**}$). The LC showed positive significant correlation with bacteria ($r= 0.751^{**}$), fungi ($r= 0.726^{**}$), actinomycetes ($r= 0.784^{**}$). Also LLC showed positive significant correlation with bacteria ($r= 0.845^{**}$), fungi ($r= 0.871^{**}$) and actinomycetes ($r= 0.873^{**}$). Similarly, NLC manifested positive significant correlation with bacteria ($r= 0.850^{**}$), fungi ($r= 0.907^{**}$) and actinomycetes ($r= 0.898^{**}$). The TOC showed positive significant correlation with bacteria ($r= 0.900^{**}$), fungi ($r= 0.935^{**}$) and actinomycetes ($r= 0.933^{**}$) count.

4.7.2 Correlation coefficient (r) between functional soil organic carbon pools and total organic carbon with carbon stocks

Correlation coefficient (r) worked out between functional soil organic carbon pools (VLC, LC, LLC, NLC) and carbon stocks (WBC stock, TOC stock, Active stock, Passive stock) is showed in Table 4.12. The data revealed that VLC showed positive significant correlation with all the carbon stocks: WBC stock ($r= 0.768^{**}$), TOC stock ($r= 0.767^{**}$), Active stock ($r= 0.713^{**}$), Passive stock ($r= 0.711^{**}$). The LC showed positive significant correlation with WBC stock ($r= 0.698^{**}$), TOC stock ($r= 0.698^{**}$), Active stock ($r= 0.747^{**}$) and Passive stock ($r= 0.684^{**}$). LLC also showed positive significant correlation with WBC stock ($r= 0.805^{**}$), TOC stock ($r= 0.805^{**}$), Active stock ($r= 0.716^{**}$) and with Passive stock ($r= 0.871^{**}$). Seemingly, NLC showed positive significant correlation with

WBC stock ($r= 0.815^{**}$), TOC stock ($r= 0.815^{**}$), Active stock ($r= 0.646^{**}$) and Passive stock ($r= 0.850^{**}$). The TOC showed positive significant correlation with WBC stock ($r= 0.815^{**}$), TOC stock ($r= 0.815^{**}$), Active stock ($r= 0.646^{**}$) and ($r= 0.850^{**}$) with Passive stock.

4.7.3 Correlation coefficient (r) between functional soil organic carbon pools and total organic carbon with Basic soil properties.

The correlation values in the Table 4.13 indicate the correlation between functional soil organic carbon pools (VLC, LC, LLC, NLC) and basic soil properties (pH, EC, BD, clay, TN). Data revealed that VLC has negative correlation with few basic soil properties as indicated by r-value: pH ($r= -0.551^{**}$), EC ($r= -0.633^{**}$), BD ($r= -0.871^{**}$) but had a positive significant correlation with clay ($r= 0.937^{**}$) and TN ($r= 0.908^{**}$). The LC showed negative correlation with pH ($r= -0.633^{**}$), EC ($r= -0.670^{**}$), BD ($r= -0.759^{**}$) but showed a positive significant correlation with clay ($r= 0.779^{**}$) and TN ($r= 0.678^{**}$). LLC also showed negative correlation with pH ($r= -0.655^{**}$), EC ($r= -0.702^{**}$), BD ($r= -0.767^{**}$) but had a positive significant correlation with clay ($r= 0.869^{**}$) and TN ($r= 0.841^{**}$). Similarly just as VLC, NLC showed a negative correlation with pH ($r= -0.640^{**}$), EC ($r= -0.765^{**}$), BD ($r= -0.819^{**}$) while exhibited a positive significant correlation with clay ($r= 0.902^{**}$) and TN ($r= 0.821^{**}$). TOC showed a negative correlation with pH ($r= -0.648^{**}$), EC ($r= -0.736^{**}$), and BD ($r= -0.893^{**}$) while it bears a positive significant correlation with clay ($r= 0.952^{**}$) and TN ($r= 0.886^{**}$).

Table 4.11: Pearson correlation coefficient (r) between functional soil organic carbon pools and total organic carbon with biological properties

Functional SOC pools	Soil biological properties		
	Bacteria	Fungi	Actinomycetes
VLC	0.851**	0.907**	0.895**
LC	0.751**	0.726**	0.784**
LLC	0.845**	0.871**	0.873**
NLC	0.850**	0.907**	0.898**
TOC	0.900**	0.935**	0.933**

*Correlation is significant at the 0.05 level

** Correlation is significant at the 0.01 level

Table 4.12: Pearson correlation coefficient (r) between functional soil organic carbon pools and total organic carbon with carbon stocks

Functional SOC pools	Soil carbon stock			
	WBC Stock	TOC Stock	Active Stock	Passive Stock
VLC	0.768**	0.767**	0.713**	0.711**
LC	0.698**	0.698**	0.747**	0.684**
LLC	0.805**	0.805**	0.716**	0.871**
NLC	0.815**	0.815**	0.646**	0.850**
TOC	0.813**	0.813**	0.686**	0.782**

*Correlation is significant at the 0.05 level

** Correlation is significant at the 0.01 level

Table 4.13: Pearson correlation coefficient (r) between functional soil organic carbon pools and total organic carbon with Basic soil properties

Functional SOC pools	Basic soil properties				
	pH	EC	BD	Clay	TN
VLC	-.551**	-.633**	-.871**	.937**	.908**
LC	-.633**	-.670**	-.759**	.779**	.678**
LLC	-.655**	-.702**	-.767**	.869**	.841**
NLC	-.640**	-.765**	-.819**	.902**	.821**
TOC	-.648**	-.736**	-.893**	.952**	.886**

*Correlation is significant at the 0.05 level

** Correlation is significant at the 0.01 level

Chapter – 5

DISCUSSION

In this chapter the results obtained under the present investigation are elaborated and discussed in light of the relevant research carried out by different researchers, under the following heads:

5.1 Basic soil properties under different land uses

5.1.1 Soil pH

The soils under study varied from slightly acidic to mildly alkaline in nature. Highest soil pH was found in paddy land use and lowest was recorded in soils of natural forests. Natural forest land use system showed lowest pH values which could be due to high organic matter content and leaching of soluble salts from the surface soil layers. Moreover, soil pH increased with soil depth in the different land uses. Similar findings were reported by Bhuyan *et al.*, (2013) and Muche *et al.*, (2015). The lower soil pH in forest soils is mostly attributed to higher soil organic matter and its decomposition products (Perie and Ouimet, 2008). The quantity of organic matter available in a particular land use system significantly influences the pH of the soil and decomposition of this organic matter releases chemicals such as organic acids that cause the lowering of soil pH (Namgial *et al.*, 2020). Since the paddy soils contain lesser amount of organic matter therefore, its pH is highest among all the land use systems. The higher value of pH in soils of paddy land may also be due to the fact that above-ground biomass is removed, decomposition of organic matter is enhanced and lesser quantities of organic matter are added.

5.1.2 Electrical conductivity (EC)

The overall EC of the soils had values ranging from 0.09-0.35 dS m⁻¹ in the different land uses, with the lowest mean value in natural grasslands and the

highest value in paddy soils. All the different land use systems have EC values below 1 dS m^{-1} which indicates that there is no prevailing salinity hazard. The EC of paddy soils was observed to be higher than the natural forest and natural grassland soils. The low EC of natural forest and natural grassland land use system can be a result of leaching of salts and base-forming cations into the sub-surface soil layer and translocation of it out of the soil profile (Abbasi and Rassol, 2005; Tufa *et al.*, 2019). Higher values of EC are seen in paddy soils and soils under maize-field-converted-from-forest land use as a result of accumulation of salts, usage of fertilizers and management practices (Kiflu and Beyene, 2013; Kaur and Bhat, 2017). In the sub-surface soil layer the EC values are higher as compared to surface layers which could be due to leaching of ions. Maqbool *et al.* (2017a), Alaie and Gupta (2019) and Wani *et al.* (2009) also reported the EC values below 1 dS m^{-1} while studying the soils of Jammu and Kashmir.

5.1.3 Bulk density (BD)

The BD has been found to be within the range of 0.76 to 1.47 Mg m^{-3} in different land uses and decreased in the order; paddy > plantation > maize-field-converted-from-forest > natural grassland > natural forest. The natural forest and natural grassland land use system recorded low BD which could be due to clay content (texture) and lesser disturbance of the soil, higher root biomass and presence of high amount of organic matter. Number of studies (Celik, 2005; Mostafa *et al.* 2008; Achalu *et al.* 2012; Bogunovic *et al.* 2020; Tumayro and Dereje, 2020), have revealed lower BD in natural forest soils. The high BD of soil in paddy lands could be due to due to intrinsic property like texture, and intensive tillage operations and practices such as ploughing and puddling that break soil aggregates, increase soil compaction, reduce the amount of organic matter in the particular land use by means of exposure in the surface soil layer to direct impact of rain drops and climatic factors (Bennett *et al.*, 2017; Amoli *et al.*, 2021). In the present study the BD of soils was found to increase with depth in all the studied land uses which is attributed to weight of the overlying soil layers and the

decrease in organic matter content with depth. This has been observed by several workers Chaudhari *et al.*, (2013), Awdenegest *et al.*, (2013) and Preetha *et al.*, (2017).

5.1.4 Clay content

The clay content of each land use type increased with increase in depth and had the following order at both soil depths; paddy > plantation > maize-field-converted-from-forest > natural grassland > natural forest. Highest clay content was observed in soils under paddy land use whereas lowest was observed in soils of natural forests. Similarly, previous authors reported higher clay content in paddy soils than the other land use systems (Raheb and Heidari, 2012; Zhao *et al.*, 2020). In this study, low clay content in natural forest land use system could be due to loss of clay particles through accelerated water erosion with elevation. Others workers have also reported the loss of the clay particles from the soil due to erosion (Sahani and Behera, 2001; Ali *et al.*, 2017b). Soils in the different land use systems followed a specific pattern in depth wise clay content i.e. it increased in the sub-surface layer (Mulat *et al.*, 2018; Zhong *et al.*, 2018). The reason for low clay in particularly surface layers of cultivated lands might be due to selective removal of clay from the surface by erosion.

5.1.5 Total Nitrogen (TN)

The present study revealed that concentrations of TN in the studied land use types varied from 0.14 to 0.63 % in the surface soils and 0.09 to 0.49 % in sub-surface soils in different land uses following a trend; natural forest > natural grassland > maize-field-converted-from-forest > plantation > paddy in both the soil layers. Nitrogen has an immense role to play in plant nutrition as it is linked with essential living processes of life. Mean values of TN in forest soils was found higher (0.49 and 0.38 %) in both depths, respectively, than the other land use types. High TN of natural forest land use is due to high organic matter content which is known as the biggest and credible source of soil total nitrogen. Several

workers (Semahugne, 2008; Nigussie and Kissi. 2012; Ufot *et al.* 2016; Chemada *et al.* 2017) have also stated that TN is higher in forest land uses as compared to cultivated land. Lowest mean values for TN were found under paddy land use (0.18 and 0.12 %) which could be due to higher decomposition rates and oxidation process being influenced by intensive cultivation practices that in turn reduces the total nitrogen content. Also low TN in this land use could be due to addition of smaller quantities of organic matter, leaching loss of nitrate-nitrogen and loss of nitrogen through denitrification process back into the atmosphere. Similarly Bahrami *et al.* (2010), Yifru and Taye (2011), Teshome *et al.* (2013) and Ufot *et al.* (2016) have reported that soils which are under cultivation tend to have lower TN concentrations as compared to uncultivated lands. A decreasing trend with increase in soil depth was observed in all the studied land uses which is usually due to decrease in soil organic matter relative to soil depth. The results are in close conformity with the findings of Yimer *et al.* (2007), Molla *et al.* (2010) and Nega and Heluf (2013) who reported that the TN decreases gradually from the surface to the sub-surface layers.

5.2 Soil microbial population

5.2.1 Total viable bacteria

The total viable bacterial count ($\text{cfu} \times 10^{-6} \text{ g}^{-1} \text{ soil}$) ranged from 25-183 in surface and 14-172 in sub-surface soils, respectively. The highest bacterial count ($\text{cfu} \times 10^{-6} \text{ g}^{-1}$) was found in natural forest soils with a mean value of (163 and 151) while lowest (51 and 40) was found in surface and sub-surface soils of paddy. The high bacterial population in natural forest land use type could be due to high carbon content which is used as a source of energy source by bacteria. Also increased bacterial count on soils in natural forest land use system is due to continuous replenishment of added tree leaves in the surface layer (Dhaliwal *et al.*, 2009). Low bacterial count in paddy land use system could be due to low above-ground and below-ground crop biomass, and subsequently increased soil

pH and other unfavorable conditions under waterlogged conditions which may have resulted in lower population (Ibekwe *et al.*, 2012). The surface soils recorded maximum count of bacteria and it decreased with soil depth. This could probably be attributed due to the presence of large carbons in forms of organic matter present in the natural forest land use. This carbon source which is required for metabolic processes may lead to increase growth and activities of bacteria in such soils. The slightly lower pH of the uncultivated land (natural forest) use type may have also encouraged the growth of bacteria that thrive in that range of soil pH. Similar results were reported by Bello *et al.*, (2013), Asadu *et al.*, (2015), Kumar *et al.*, (2017a) and Fozia *et al.*, (2018).

5.2.2 Total viable fungi

The mean values of viable fungi count in both surface and sub-surface soil layers of natural forests and grassland soils were higher than the other studied land uses. The total viable fungal count ranged from 11-103 $\text{cfu} \times 10^{-5} \text{g}^{-1}$ soil in surface and 6-93 $\text{cfu} \times 10^{-5} \text{g}^{-1}$ soil in sub-surface soil. The lowest mean value (20 and 12 $\text{cfu} \times 10^{-5} \text{g}^{-1}$) was recorded in paddy soils and highest (93 and 82 $\text{cfu} \times 10^{-5} \text{g}^{-1}$) in natural forests followed by natural grassland (71 and 59 $\text{cfu} \times 10^{-5} \text{g}^{-1}$) in both the soil depths. It might be due to low pH, higher organic matter and undisturbed soil ecosystem in the soils under native vegetation. Presence of trees and native plant species in the natural land uses could have encouraged the presence of various fungal species including mycorrhizal fungi which colonize most plant species and reduce the intensity of heavy rainfall and other climate related conditions thus favoring growth of fungi in the natural forests (Asadu *et al.*, 2015). Frequent alterations in physical properties of soils through intensive tillage operations common in paddy lands may have led to reduction of fungal populations because fungi are highly and quickly affected by drastic changes in soil conditions (Sui *et al.*, 2012). A decreasing trend of fungal population was seen under all the land use systems with increase in soil depth which may be due to decrease in soil organic matter, aeration and increase in soil pH with relative

proportions of plant biomass. The results are supported in unison with other findings by Bello *et al.*, (2013), Asadu *et al.*, (2015), Kumar *et al.*, (2017a) and James *et al.*, (2020).

5.2.3 Total viable actinomycetes

The total viable actinomycetes count ($4\text{-}76 \text{ cfu} \times 10^{-5} \text{ g}^{-1} \text{ soil}$) in surface and sub-surface soils ranged from 1-65 in various land uses of the study area. The highest mean values (68 and 57) were recorded in natural forests, followed by natural grasslands (58 and 47) and respective lowest mean values (9 and 4) were recorded in surface and sub-surface layers of paddy soils. This may be due to higher pore space as well as more organic material in natural forests and natural grasslands which is added to the soil through plant, root and leaf litter that serve as source of energy for higher actinomycetes activity in such land uses. Also, the higher activity of actinomycetes in natural forests could be due to presence of higher plant roots and decomposition resistant biomass. Less viable actinomycetes count in paddy soils could be attributed to low organic matter and use of inorganic fertilizers and more extensive tillage practices during the growth period of paddy. Similar findings have been reported by Joshi and Yadav (2005), Okonkwo *et al.*, (2010), Kumar *et al.*, (2017a) and Kumar *et al.*, (2017b).

5.3 Organic carbon and lability based fractions

5.3.1 Total organic carbon (TOC)

Among the different land uses studied, highest mean values of TOC in surface and sub-surface layers were recorded in soils of natural forests (24.24 and 18.76 g kg^{-1}), followed by natural grassland (20.52 and 15.60 g kg^{-1}) and lowest (12.76 and 9.81 g kg^{-1}) in paddy soils. The higher TOC in natural forests, as compared to the other land uses, may be attributed to less soil disturbances such as tillage unlike in the cultivated land uses (paddy) and higher levels of C inputs i.e. leaf litter and root biomass from the natural forest trees and its recalcitrant

nature which prevents complete microbial decomposition (Nath *et al.*, 2018). Low TOC content in the other land use types other than the natural forests imply a considerable reduction of TOC in these land use systems through alterations in the plant species, loss of carbon from the soil due to crop residue removal, tillage practices and with small amount of added biomass to the soil (Yang *et al.*, 2004; Baker *et al.*, 2007; Smith, 2007; Wang *et al.*, 2014). The results are in line with the findings of Lakaria *et al.*, (2012), Meetei *et al.*, (2017), Monisa and Tahir (2018), Sahoo *et al.*, (2019) and Hussain *et al.*, (2019). There was a consistent decrease in TOC content with increase in soil depth in all the studied land uses which might be due to addition of organic matter on the surface of the soils (Jobbagy and Jackson, 2000). This is further supported by the finding of Singh *et al.*, (2011) and Sreekanth *et al.*, (2013).

5.3.2 Walkley-Black carbon (WBC)

In the present study, WBC showed a wide variation from 8.85-18.72 g kg⁻¹ and 6.95-14.47 g kg⁻¹ in both the soil depths among different land uses. The WBC of soils were in the order; natural forest > natural grassland > maize-field-converted-from-forest > plantation > paddy. The highest WBC content were found in natural forests with a mean value of (18.23 and 14.10 g kg⁻¹) and lowest were recorded in paddy (9.59 and 7.37 g kg⁻¹) soils, respectively. These results are supported by the findings of Maqbool *et al.*, (2017a). Similarly, high WBC in surface soils of natural forests have been recorded by Ghulam (2005), Yimer *et al.*, (2007), Franzluebbers and Arshad (2010), Jamala and Oke (2013), Hamkalo and Bedernichek (2014) and Selassie *et al.*, (2015). This may be attributed due to addition of high levels of inputs i.e. leaf litter and root biomass, its recalcitrant nature, high altitude, low temperature, slow rate of mineralization and role in augmentation of soil aggregates and ultimately increasing soil OC content (Bossuyt *et al.*, 2002 and Nath *et al.*, 2018). The low WBC content in paddy soils is due to rapid mineralization and loss of C from soil by soil disturbance and

management practices (Chauhan *et al.*, 2014). Also low content of WBC in paddy soils may be due to long-term cultivation under submerged conditions and application of mineral fertilizers, puddling, crop removal during harvesting, breakdown of stable aggregates and deterioration of soil organic matter resulting in degradation of overall soil quality (Yang *et al.*, 2005 and Majumdar *et al.*, 2007). The results are further supported by findings of Chemada *et al.*, (2017) as well as by Kaur *et al.*, (2017). A consistent decrease in WBC content with depth was noticed in all cultivated lands that might be due to the addition of animal wastes and plant residues to surface soils (Chibsa and Asefa, 2009). This is further supported by the findings of Chen *et al.*, (2011), Mojiri *et al.*, (2012), Sheng *et al.*, (2015) and Van *et al.*, (2015).

5.3.3 Lability based fractions of organic carbon (VLC, LC, LLC, NLC)

The very labile carbon (VLC) and labile carbon (LC) followed the trend; natural forest > natural grassland > maize-field-converted-from-forest > plantation > paddy in both the surface and sub-surface soil layers. The highest quantities (mean values) of VLC and LC in surface and sub-surface layers were found in natural forests (8.65 and 6.30 g kg⁻¹) and (3.58 and 3.14 g kg⁻¹) followed by natural grassland (7.35 and 5.35 g kg⁻¹) and (3.38 and 2.91 g kg⁻¹), and lowest (4.45 and 3.79 g kg⁻¹) and (2.42 and 1.59 g kg⁻¹) in paddy soils, respectively. High VLC and LC fractions in natural forest and natural grassland land use as compared to the other land uses could be attributed due to continuous addition (retention) of easily decomposable plant/leaf litter, high microbial biomass and mechanisms for protection of added C that substantially increases soil microbial functions with the corresponding increment in VLC and LC fractions. High concentrations of VLC and LC has been reported by Benbi *et al.* (2015) and Babu *et al.* (2020) in forests adjacent to the other land uses. The low values of VLC and LC in the other land use systems other than native vegetation could be associated with the aggregate disruption and more organic matter oxidation in conventional

farming systems, that are based on intensive management practices like ploughing and harrowing (Bayer *et al.*, 2006). The LLC fraction followed the order; natural forest > natural grassland > maize-field-converted-from-forest > plantation > paddy in both soil depths. The higher LLC in natural forests and low content in paddy soils is due to variation in the different plant/tree species found; above-ground biomass and its nature of decomposition with other variables such as climate which has intrinsic effect on its decomposition and loss. The NLC followed the order; natural forest > natural grassland > maize-field-converted-from-forest > plantation > paddy. Higher NLC content in natural forests has also been recorded by Nath *et al.*, (2018). Usually the forest litters are rich in sources of tannin and wax that are resistant to degradation, this enhances the levels of NLC in natural forests in comparison to cultivated lands (Nath *et al.*, 2018). The NLC fraction is usually resistant to field management operations and microbial decomposition due to its sorption on fine particles (Sherrod *et al.*, 2005; Sainepo *et al.*, 2018). In general, all the lability based OC fractions showed a decreasing trend with soil depth which is supported by finding obtained by Wang *et al.*, (2005), Belay *et al.*, (2009), Xia *et al.*, (2010) and Babu *et al.*, (2020).

5.4 Organic carbon stocks

5.4.1 Total organic carbon (TOC) stock

In the present study on different land use types, highest mean values of TOC stock in surface and sub-surface soil layers were recorded in natural forests (45.88 and 41.16 Mg ha⁻¹), followed by natural grasslands (43.93 and 36.82 Mg ha⁻¹) and lowest (36.45 and 28.42 Mg ha⁻¹) in paddy soils. The TOC stock had the following order; natural forest > natural grassland > maize-field-converted-from-forest > plantation > paddy soil. Higher TOC stock in natural forests due to high concentrations of OC has also been recorded by Kukal *et al.* (2012), Jafarian and Kavian (2013), Sharma *et al.* (2014) and Mir *et al.* (2020), which is attributed mainly by high leaf litter accumulation, less soil disturbance, presence of high

amount of heterogeneous plants with different root structures and less in organic matter decomposition as compared to other cultivated lands (Yang *et al.*, 2004; Baker *et al.*, 2007; Smith, 2007; Nicodemo *et al.*, 2018). Land use systems in horticultural land (plantation) had higher TOC stocks than agricultural (paddy) soils since the plantations add more amount of litter and input of animal manures, whereas in agricultural lands removal of biomass and intensive tillage practices reduce the OC (Hu *et al.*, 2013). Similar results were reported by Bayer *et al.*, (2002), Ghimire *et al.*, (2018), Hussain *et al.*, (2019), Toru and Kibret (2019).

5.4.2 Active organic carbon (AOC) stock

The active OC pool is a chief source of essential plant nutrients (Mandal *et al.* 2008) and is involved towards crop production and soil quality (Chan *et al.*, 2001). This particular pool (Active OC) of TOC is more easily and readily influenced by management practices when compared to the passive C pool (Biederbeck *et al.* 1994) and is regarded as an early indicator of soil quality (Duval *et al.*, 2013). The active C pool is composed of both the VLC as well as the LC pool (Chivane and Bhattacharyya, 2010). AOC stock followed the order; natural forest > natural grassland > maize-field-converted-from-forest > plantation > paddy. Maximum mean value of AOC stock were recorded in natural forests (23.14 and 20.66 Mg ha⁻¹) and lowest were found in paddy soils viz., 19.63 and 15.60 Mg ha⁻¹ in both the soil depths. Similar results have been reported by Meetei *et al.* (2017) and Babu *et al.* (2020) where the high content of active C pool was due to availability of readily decomposable organic matter found throughout the year in forests. Also the root systems of trees are liable as they exude labile C compounds (Contech *et al.*, 1997).

5.4.3 Passive organic carbon (POC) stock

The passive OC pool in soil is more stable and recalcitrant (Chan *et al.* 2001 and Choudhury *et al.* 2018), and is made up of the LLC and NLC pool (Wiesenberg *et al.*, 2010). The POC stocks followed the order; natural forest >

natural grassland > maize-field-converted-from-forest > plantation > paddy in both the soil depth. A higher POC stock in natural forests and natural grasslands is attributed by input of high quantity and quality of plant/leaf litter as compared to cultivated lands. Along a successional gradient, Xiang *et al.* (2015) discovered a significant increase in passive C fractions with increasing litter fall. This implies that the OC retrieved in natural grasslands and natural forests is more stable than that retrieved in other land uses. Physical and chemical conservation of C in undisturbed soils may also account for high POC storage in natural forests and grasslands.

5.4.5 Walkley-Black carbon (WBC) stock

WBC stock is mostly attributed to physiography, altitude, bulk density, organic matter additions, tree proportions and land disturbances (Turner *et al.*, 2005 and Wang *et al.*, 2013). This study revealed that highest mean value of WBC stock was present in natural forest land use (34.50 and 30.94 Mg ha⁻¹), followed by natural grasslands (33.03 and 27.68 Mg ha⁻¹) and lowest (27.40 and 21.37 Mg ha⁻¹) in surface and sub-surface of paddy soils, respectively. The WBC stocks varied with the following trend in soils; natural forest > natural grassland > maize-field-converted-from-forest > plantation > paddy. Natural forest land use recorded higher WBC stock due to reasons explained above and further supported by Dhakal *et al.*, (2010) and Homebegowda *et al.*, (2016). With increase in soil depth the WBC stock distribution showed a decreasing trend in all land use systems which have been observed in many studies (Turner *et al.*, 2005 and Sahoo *et al.*, 2019). Similar findings of higher WBC stocks in the natural forests as compared to agricultural land uses have been reported by Noordwijk *et al.*, (2002), Bewket and Stroosnijder (2003), Begum *et al.*, (2009), Begum *et al.*, (2010), Saha *et al.*, (2011), Schmitt *et al.*, (2012), Ali *et al.*, (2017a), Begum *et al.*, (2019) and Mir *et al.*, (2020).

5.5 Comparison of OC stocks based on Mebius and Walkley-Black carbon method

As indicated in Table 4.9, differences in the values for OC and consequently OC stocks were observed in soils from all the land uses, during the present study. In the surface and sub-surface soils among all land use systems, higher OC stocks were recorded in the Mebius based method as compared to the WBC based method. On the basis of Mebius and WBC method, a decreasing trend in OC stocks were recorded in different land uses where OC stocks on both methods had the following order; natural forest > natural grassland > maize-field-converted-from-forest > plantation > paddy. The same observation has been recorded and underscored by Chatterjee *et al.* (2009) and Gatto *et al.* (2009), and has been attributed to external heating that oxidizes higher amount of carbon in the soil samples.

5.6 Carbon Management Index (CMI)

CMI measures the quality and quantity of soil organic matter in a system (Reddy, 2010). Since the CMI is linked to the carbon pool index (CPI) and the lability index (LI), it may be used as a soil C rehabilitation measure to illustrate how soil C dynamics change as a result of changes in land use and management (Assis *et al.*, 2010). In reality, higher values indicate soil C rehabilitation, while lower values indicate C compound degradation (Blair *et al.*, 1995). The CMI among the different land use systems in this study was significantly different. The CMI had the following order; natural forest > natural grassland > maize-field-converted-from-forest > plantation > paddy. Forest soil with highest value (100) for CMI was used as a reference. Lowest CMI (70.08) was observed in paddy soils. The CPI is also one of the two indices that make up the CMI which is also regarded as being more susceptible to the impact of land use change on soil organic C dynamics (Geraei *et al.*, 2016). When compared to cultivated land uses, addition of organic matter on a regular basis improves the ability to boost the CMI

by increasing inputs and minimizing losses in natural forests and natural grasslands (Blair, 2000). This has also been reported by Kalambukattu *et al.* (2013) and Musinguzi *et al.* (2015) where cultivated soils had lower CMI values than uncultivated soils (forests).

5.7 Relationship between total organic carbon and functional organic carbon pools with other soil properties

In the present study, TOC had a negative correlation with soil pH, which suggests that pH may be an indicator of both quantity and stability of TOC in the studied land uses. Several workers Fey (2001), Ali *et al.*, (2017a), Liu *et al.* (2018b) have reported that TOC has a negative relationship with pH. The BD of a soil can be influenced by TOC followed by land use transitions where forests are converted to cultivated lands (Don *et al.*, 2011). BD was strongly negatively correlated with TOC. Many researchers Curtis and Post (1964), Askın and Ozdemir (2003), Gupta (2004), Ono and Kanomata (2004), Leifeld (2005), Catherine and Rock (2007), Saki *et al.* (2011), Don *et al.* (2011) and Erdal Sakin (2012) have obtained similar findings. Correlation coefficient worked out between TOC and clay content revealed that TOC was positively correlated with clay content. The findings are in line with those reported by Percival *et al.*, (2000), Pan *et al.*, (2003), Leifeld *et al.*, (2005), Zinn *et al.*, (2005) and Homann *et al.*, (2007). TOC is a significant source of nitrogen that has an impact on TN levels in the soil (Wang *et al.*, 2009). Soil TN shows positive and significant correlation with TOC. Similar results were obtained by Knops and Timal (2000), Shedayi *et al.*, (2016) and Qiao *et al.*, (2018). The most important factor influencing microbial communities is TOC (Yuan *et al.*, 2013). The microbial population i.e. bacterial, fungal and actinomycete were positively related to TOC. Bruggen and Semenov (2000) and Grayston *et al.* (2004) have shown that addition of high quality and quantity of organic matter ultimately increases microbial diversity and density which is due to C as an energy source. This has been observed by several workers Nakhro and Dkhar (2010), Hu *et al.*, (2014), Dong *et al.*, (2014), Szoboszlay *et*

al., (2017) and Soleimani *et al.*, (2019). The active OC fraction (VLC and LC) and passive OC fraction (LLC and NLC) were negatively correlated with pH, EC, BD but it showed a positive relationship with clay content and TN, as this could be due to the richness of soil with higher OC which results in higher magnitude of mineralization and higher amounts of protected C fractions, particularly, under natural land uses. These findings corroborate the result reported by Sharma *et al.*, (2014) and Monisa Raza (2015). As observed from coefficients of correlation; bacteria, fungi and actinomycetes counts were positively related to the various functional SOC pools. The VLC, LC, LLC and NLC pools all were positively correlated with microbial counts which may be due to availability of higher quantities of OC sources for microbial nutrition.

Chapter - 6

SUMMARY AND CONCLUSION

Carbon which is seen as a fundamental unit of all life forms on the planet earth is of great importance and understanding the soil C pools is intrinsic since is not only indispensably responsible for soil productivity but it form an essential part of the global C cycle. Organic matter a key component in soils is a critical component which allows assessment of soils natural fertility, stability, condition and soil health. Carbon being a substantial portion of soil organic matter ultimately alters and influences the basic properties (physical, chemical, biological) of soils. The quality and quantity of organic carbon is a critical determinant of soil quality and environmental protection. With the reduction of soil carbon content, it results in the delineation of soils fertility gradient and ultimately crop productively which is an immense problem for many of the world's agricultural production system. Relative proportions of organic carbon are crucial for the maintenance and enhancement of soil fertility, its porosity, infiltration, moisture retention, nutrient efficiency and reduction in geological erosions. An investigation entitled, **“Functional Soil Organic Carbon Pools as Affected by Different Land Use Types in a Sub Mountainous Area of North Kashmir”** was undertaken to have an appraisal of the organic carbon fractions and its stocks under different land use systems, viz. natural forest, natural grassland, maize-field-converted-from-forest, plantation and paddy and their relationship with soil properties. The present investigation was therefore undertaken with the following objectives:

1. To quantify various functional pools of soil organic carbon under different land use types of the study area.
2. To evaluate carbon stocks and carbon management indices of various land use types.

6.1 Basic soil properties

The various land uses had a significant impact on basic soil properties. The pH values increased with increasing soil depth in all land use systems, indicating that the soils ranged from slightly acidic to mildly alkaline in nature. Electrical conductivity ranged between 0.09-0.35 dS m⁻¹ in various land uses, with lowest mean value found in natural forests and highest in paddy soils. Bulk density also increased with depth and was lowest found under natural forests. The clay content of every land use type increased with increase in depth in surface and sub-surface layers and varied in the order; paddy > plantation > maize-field-converted-from-forest > natural grassland > natural forest, respectively. Total soil nitrogen decreased with increase in depth where highest was found in natural forests and lowest under paddy soils at both soil depths.

6.2 Soil microbial count

Under the different land uses studied, it had an intrinsic effect among the various soil microbes i.e. bacteria, fungi and actinomycetes. The highest bacterial count in soil was under natural forests and lowest was found in paddy soils. Lowest and highest fungal count was in paddy soils and soils of natural forest, respectively. Highest actinomycetes were found under the natural forests and lowest were seen in paddy soils. All the three types of microbe's viz., bacteria, fungi and actinomycetes decreased with increase in depth and highest being found in surface soil layers following the order as: natural forest > natural grassland > maize-field-converted-from-forest > plantation > paddy.

6.3 Land use and functional soil organic carbon pools with depth distribution

The results obtained for carbon content for the various land use types indicated that natural forests were dominant in various forms of carbon i.e. TOC, VLC, LC, LLC, NLC, and least was in paddy soils. The various functional

OC pools were significantly influenced by land use. Under all of the studied land use systems, various carbon fractions were in the following order: TOC > VLC > LC > LLC > NLC. Total organic carbon (TOC) content was high in natural forests, followed by natural grasslands and lowest was under paddy soils. As for the Active organic carbon pool (VLC, LC) and Passive organic carbon pool (LLC, NLC) it followed the order: natural forest > natural grassland > maize-field-converted-from-forest > plantation > paddy. In all of the investigated land uses, a general decrease in carbon content was seen for all forms (TOC and lability based fractions viz. VLC, LC, LLC, and NLC). Higher amounts of TOC and organic C fractions in the surface layers are generally seen because of additions of organic manures, leaf litter etc. to the surface layers.

6.4 Land use and organic carbon stocks

The various organic carbon stocks i.e. TOC stock, AOC stock, POC stock, WBC stock were influenced by different land uses. When compared to other land use systems, natural forest land use had the greatest mean value of TOC stocks at both soil depths. Similarly, highest AOC stock, POC stock and WBC were found in natural forest. The various organic carbon stocks followed the order: natural forest > natural grassland > maize-field-converted-from-forest > plantation > paddy, where highest mean values were in natural forest land use system and lowest was found under paddy soils due to variation in the quality and quantity of added organic matter in the land uses. In all of the assessed land uses, there was an overall decline in organic carbon stocks for all forms (TOC stock, AOC stock, POC stock, and WBC stock).

6.5 Land use influence on carbon management index

Under different land use types CMI followed the order; natural forest (100), natural grassland (98.71); maize-field-converted-from-forest (83.33), plantation (79.39) and paddy (70.08), respectively. The highest CMI mean value

was recorded in natural forest, followed by natural grassland and lowest was under paddy land use type. The CMI had the following trend as: natural forest > natural grassland > maize-field-converted-from-forest > plantation > paddy. In natural forests and grasslands, CMI values are high due to addition of organic matter on a regular basis improved the ability to increase the CMI by increasing inputs and lowering losses as compared to cultivated land uses (plantation and paddy).

6.6 Relationship between soil organic carbon and other soil properties

Soil pH, EC, BD, clay content and TN, were the main basic soil properties related to various functional organic carbon pools and TOC. Few basic soil properties i.e. pH, EC, BD had a negative correlation with VLC and LC pool but showed a positive relationship with clay content and TN. Seemingly, the LLC and NLC pool showed no relationship with pH, EC, BD but had a positive relationship with clay content and TN. TOC showed negative correlation with pH, EC, BD but had a positive relationship with clay content and TN. Soil bacterial, fungal and actinomycetes count were related to the various functional SOC pools viz. VLC, LC, LLC and NLC. The active organic carbon pool (VLC and LC) was positively correlated with all the biological properties: bacteria, fungi and actinomycetes that could be due to readily available forms of organic carbon sources for microbial nutrition. Seemingly the passive organic carbon pool (LLC and NLC) was positively correlated with bacteria, fungi and actinomycetes. TOC was also positively correlated with bacteria, fungi and actinomycetes. The SOC pool VLC was positively correlated with all the organic carbon stocks: WBC stock, TOC stock, AOC stock and POC stock. LC pool also showed a positive correlation with WBC, TOC, AOC and POC stock. As for the LLC pool it exhibited a positive significant relationship with WBC, TOC, AOC and POC stock. Seemingly the NLC pool had similar relation just as VLC, showing a positive correlation with

the organic carbon stocks. TOC showed a positive correlation with all the organic carbon stocks.

In general, the study reveals that the natural forest land use was rich in organic C fractions. Most of the agricultural land uses were low in organic C fractions, with management practices like tillage and crop removal in terms of produce being important reasons. It can be inferred that conversion of natural forests to agriculture land use systems has resulted in the loss of organic C fraction in the case of maize fields converted from forest where organic C were substantially lower than the natural forest system. Conservation tillage, less soil disturbance and continuous supply of good quality and quantity of organic additions can help reduce C losses in agricultural systems. Future studies need to focus on new advanced ways to enhance C sequestration potential of the agricultural systems in the region for sustaining soils natural fertility and boosting crop productivity.

CONCLUSION

- Different land uses and soil depth influenced proportions of total organic carbon and lability based organic carbon pools.
- In the different land uses the highest accumulation of various pools of organic carbon was in the surface soil layer (0-20 cm).
- High TOC, various organic carbon pools (VLC, LC, LLC, NLC) and OC stocks (WBC, TOC, AOC and POC stock) was present in natural forests than the other land uses.
- The presence of more TOC in natural forests and grassland than in maize-field-converted-from-forest shows that TOC is being depleted as a result of the land use transition.
- In all land use types, the proportion of active organic carbon stock (VLC and LC) was higher than the passive organic carbon stock (LLC and NLC), implying that stored carbon might be readily lost as a result of land use changes.
- Natural forests have the highest share of passive carbon stores (in the 0-40 cm layers); implying that stored soil organic carbon is more persistent.
- The active and passive OC pools in distinct soil layers are both affected by land use, suggesting that dynamics of SOC turnover with land use management approaches should be paid greater attention to harness the C storage capacity of soils in the region.
- Microbial populations (bacteria, fungi and actinomycetes) showed a positive and significant correlation with the various organic carbon pools.
- Soil pH, EC, BD showed a negative correlation with various functional pools but clay content and TN exhibited a significant positive correlation.

LITERATURE CITED

- Abbasi, M.K. and Rasool, G. 2005. Effects of different land-use types on soil quality in the hilly area of Rawalakot Azad Jammu and Kashmir. *Acta Agriculturae Scandinavica, Section B - Soil & Plant Science*, **55**(3): 221-228.
- Abbasi, M.K., Zafar, M. and Khan, S.R. 2007. Influence of different land-cover types on the changes of selected soil properties in the mountain region of Rawalakot Azad Jammu and Kashmir. *Nutrient Cycling in Agroecosystems*, **78**(1): 97-110.
- Abbasi, M.K., Zafar, M. and Sultan, T. 2010. Changes in Soil Properties and Microbial Indices across Various Management Sites in the Mountain Environments of Azad Jammu and Kashmir. *Communications in Soil Science and Plant Analysis*, **41**(6): 768-782.
- Abha, C., Palria, S. and Vinay, K.D. 2003. Soil organic carbon pool in Indian forests. *Forest Ecology and Management*, **173**(1): 187-199.
- Abrol, V., Sharma, R.K., Sharma, V., Sharma, P., Sharma, K.R., Kumar, A. and Sharma, M. 2019. Landuse impact on soil physical variability and erodability in North Western subtropics of India. *Journal of Environmental Biology*, **40**(4): 668-673.
- Achalu, C., Heluf G., Kibebew K. and Abi, T. 2012. Status of selected physicochemical properties of soils under different land use systems of Western Oromia, Ethiopia. *Journal of Biodiversity and Environmental Sciences*, **2**(3):57-71.
- Ahirwal, J., Nath, A., Brahma, B., Deb, S., Sahoo, U. and Nath, A.J. 2021. Patterns and driving factors of biomass carbon and soil organic carbon

stock in the Indian Himalayan region. *Science of the Total Environment*, **pp** 145292.

Ahmad, M.S., Zargar, M.Y., Kousar, S., Wani, S.A. and Akhter, F. 2017. Microbial and Chemical Indicators of Rhizospheric Soils of Apple Variety Delicious in Himalayan Kashmir. *Current Journal of Applied Science and Technology*, **pp**.1-7.

Ahmad, R., Mir, A.H., Yadav, R., Ali, T. and Baba, Z.A. 2020. Assessment of soil biological properties under different land uses in north eastern zone of Kashmir valley. *Journal of Pharmacognosy and Phytochemistry*, **9**(1): 2041-2045.

Alaie, T.A. and Gupta, R. 2019. Assessment of Soil pH, EC and OC in Different Land Use Systems of Doda District, J&K, India. *International Journal of Current Microbiology and Applied Sciences*; **8**(6): 813-818.

Ali, S., Begum, F., Hayat, R. and Bohannan, B.J. 2017a. Variation in soil organic carbon stock in different land uses and altitudes in Bagrot Valley, Northern Karakoram. *Acta Agriculturae Scandinavica, Section B-Soil & Plant Science*, **67**(6): 551-561.

Ali, S., Hayat, R., Begum, F., Bohannan, B.J.M., Inebert, L. and Meyer, K. 2017b. Variation in soil physical, chemical and microbial parameters under different land uses in Bagrot valley, Gilgit, Pakistan. *Journal of the Chemical Society of Pakistan*, **39**(1): 97-107.

Allmaras, R.R., Schomberg, H.H., Douglas, C.L. and Dao, T.H. 2000. Soil organic carbon sequestration potential of adopting conservation tillage in U.S. croplands. *Journal of Soil Water Conservation*, **55**: 365-373.

- Alvarez, R., and Alvarez, C.R. 2000. Soil Organic Matter Pools and Their Associations with Carbon Mineralization Kinetics. *Soil Science Society of America Journal*, **64**(1): 184-189.
- Amoli, F.P., Mosaddeghi, M.R., Davatgar, N., Chavoshi, E. and Golsefidi, H.T. 2021. Effects of land use and reducing conditions of paddy fields on soil quality and high energy moisture characteristic structural stability indices in North of Iran. *Paddy and Water Environment*, **pp** 1-19.
- Anija, K. R. 2001. Experiments in Microbiology, Plant Pathology Tissue Culture, and Mushroom Cultivation. New Delhi *VishwaPrakashan*, **pp**. 11-234.
- Anindita, S., Peter, F. and Steven, S. 2020. Land use effects on the geochemical soil properties and their control on organic carbon in volcanic soils, near Bandung area (Indonesia). *EGU General Assembly Conference Abstracts*, **pp** 5516.
- Asadu, C., Nwafor, I.A. and Chibuike, G.U. 2015. Contributions of microorganisms to soil fertility in Adjacent forest, fallow and cultivated land use types in Nsukka, Nigeria. *International Journal of Agriculture and Forestry*, **5**(3): 199-204.
- Askın, T. and Ozdemir, N. 2003. Soil bulk density as related to soil particle size distribution and organic matter content. *Agriculture*, **9**(2): 52-55.
- Assis, C.P., Oliveira, T.S., Dantas, J.N. and Mendonca, E.S. 2010. Organic matter and phosphorus fractions in irrigated agroecosystems in a semi-arid region of Northeastern Brazil. *Agriculture, Ecosystems & Environment*, **138**: 74-82.
- Awdenegest, M., Melku, D. and Fantaw, Y. 2013. Land Use Effects on Soil Quality Indicators: A Case Study of Abo-Wonsho Southern Ethiopia. *Applied and Environmental Soil Science*, **pp** 9.

- Aweto, A.O. and Moleele, N.M. 2005. Impact of *Eucalyptus camaldulensis* plantation on an alluvial soil in south eastern Botswana. *International Journal of Environmental Studies*, **62**(2): 163-170.
- Aziz, S., Chughtai, F.M., Shaheen, H., Khan, R.W.A. and Dar, M. 2019. Biomass and soil carbon stocks assessment in western Himalayan alpine and subalpine vegetation zones of Kashmir. *Pakistan Journal of Botany*, **51**(3): 973-978.
- Babu S, M., Yadav, G., Lal, R., Singh, R, Avasthe, R.K, Das, A., Chandra, P., Gudade, B.A. and Kumar, A. 2020. Soil carbon dynamics in diverse organic land use systems in North Eastern Himalayan ecosystem of India. *Catena*, **194**: 104785.
- Badole, S., Datta, A., Chaitanya, A.K., Majumder, S.P. and Mandal, B. 2020. Soil Carbon Dynamics Under Different Land-Use and Management Systems. *Carbon Management in Tropical and Sub-Tropical Terrestrial Systems*, pp 103-121.
- Bahrami, A., Emadodin, I., Atashi, M.R. and Bork, H.R. 2010. Land-use change and soil degradation: A case study, North of Iran". *Agriculture and Biology Journal of North America*, **1**(4): 600-605.
- Baker, J.M., Ochsner, T.E., Venterea, R.T. and Griffis, T.J. 2007. Tillage and soil carbon sequestration-what do we really know? *Agriculture, Ecosystems and Environment*, **118**: 1-5.
- Bangroo, S.A., Dar, S.B., Itoo, H., Mubarak, T. and Malik, A.R. 2018. Effect of Physico-Chemical Properties of Soil on Available Soil Nutrients in Apple Orchards of District Kulgam. *Current World Environment*, **13**(2): 61-75.
- Bangroo, S.A., Mubarak, T. and Itoo, H. 2019. Soil organic carbon and total nitrogen changes in croplands converted to apple orchard system in south

Kashmir temperate Himalayas. *International Journal of Ecology and Environmental Sciences*, **45**(2): 137-144.

Bangroo, S.A., Najar, G.R., Achin, E. and Truong, P.N. 2020. Application of predictor variables in spatial quantification of soil organic carbon and total nitrogen using regression kriging in the North Kashmir forest Himalayas. *Catena*, **193**: 104632.

Batjes, N.H. 1996. Total C and N in the soils of the world; *European Journal of Soil Science*, **47**: 151-163.

Bauer, A. and Black, A.L. 1981. Soil carbon, nitrogen, and bulk density comparisons in two cropland tillage systems after 25 years and in virgin grassland. *Soil Science Society of America Journal*, **45**: 1166-1170.

Bayer, C., Deborah, P.D., Genicelli, M.R., Klaus, K. and Scheuermann. 2002. Carbon stocks in Organic matter fractions as affected by Land use and soil management, with emphasis on No-tillage effect. *Ciencia Rural, Santa Maria*, **32**: 401-406.

Bayer, C., Martin-Neto, L., Mielniczuk, J., Pavinato, A. and Dieckow, J. 2006. Carbon sequestration in two Brazilian Cerrado soils under no-till. *Soil and Tillage Research*, **86**: 237-245.

Begum, F., Abbas, H., Ali, S., Ali, D., Mumtaz, S., Khan, Mz, and Mir, N. 2020. Soil quality and organic carbon stock across the different land use in a mountainous landscape of karakoram region, gilgit, pakistan. *Fresenius environmental bulletin*, **29**(1): 503-508.

Begum, F., Bajracharya, R.M., Sharma, S. and Sitaula, B.K. 2010. Influence of slope aspect on soil physicochemical and biological properties in the mid-hills of central Nepal. *International Journal of Sustainable Development and World Ecology*, **17**(5); 438-443.

- Begum, F., Bajracharya, R.M., Sharma, S. and Situala, B.K. 2009. Land use effects on soil quality Indicators in mid-hills of Central Nepal. International Conference Proceedings: Emerging Technologies in Environmental Sciences and Engineering. Aligarh Muslim University, India. **pp** 488-495.
- Begum, F., Haider, A., Shamsher, A., Danish, A., Sameena, M., Muhammad, Z. K. and Noorani, M. 2019. Soil quality and organic carbon stock across the different land use in a mountainous landscape of Karakoram region, Gilgit, Pakistan. *Fresenius Environmental Bulletin*, **29**(1): 503-508.
- Belay-Tedla, A., Zhou, X., Su, B., Wan, S. and Luo, Y. 2009. Labile, recalcitrant, and microbial carbon and nitrogen pools of a tall-grass prairie soil in the US Great Plains subjected to experimental warming and clipping. *Soil Biology and Biochemistry*, **41**(1): 110-116.
- Bello, H.S., Isa, T., Isa, M.A. and Akinmuisere, K. 2013. Effects of land use on the nature and population of microorganisms in the semi-arid region of north-eastern Nigeria. *International journal of environment*, **2**(1): 224-230.
- Benbi, D.K., Brar, K., Toor, A.S. and Singh, P. 2014. Total and labile pools of soil organic carbon in cultivated and undisturbed soils in northern India. *Geoderma*, **pp** 237-238.
- Benbi, D.K., Brar, K., Toor, A.S. and Singh, P. 2015. Total and labile pools of soil organic carbon in cultivated and undisturbed soils in northern India. *Geoderma*, **237**: 149-158.
- Bennett, J.M., Robertson, S.D., Jensen, T.A., Antille, D.L. and Hall, J. 2017. A comparative study of conventional and controlled traffic in irrigated cotton: I. Heavy machinery impact on the soil resource. *Soil Tillage Research*, **168**: 143-154.

- Bewket, W. and Stroosnijder, L. 2003. Effects of agroecological land use succession on soil properties in Chemoga watershed, Blue Nile basin, Ethiopia. *Geoderma*, **111**: 85-98.
- Bhuyan, S.I., Tripathi, O.P. and Khan, M.L. 2013. Soil nutrient status in prominent agro-ecosystems of East Siang district, Arunachal Pradesh. *International Journal of Environmental Sciences*, **3**(6): 1957-1968.
- Biederbeck, V.O., Janzen, H.H., Campbell, C.A. and Zentner, R.P. 1994. Labile soil organic matter as influenced by cropping practices in an arid environment. *Soil Biology and Biochemistry*, **26**: 1647-1656.
- Blair, G.J., Lefroy, R.D. and Lisle, L. 1995. Soil carbon fractions based on their degree of oxidation, and the development of a carbon management index for agricultural systems. *Crop Pasture Science*, **46**(7): 1459-1466.
- Blair, N. 2000. Impact of cultivation and sugar-cane green trash management on carbon fractions and aggregate stability for a Chromic Luvisol in Wueensland, Australia. *Soil Tillage Research*, **55**: 183-191.
- Blake, G.R. and Hartge, K.H. 1986. Bulk density. In methods of soil structure and migration of colloidal materials soils. In *Soil Science Society of America, Proceedings*, **26**: 297-300.
- Bogunovic, I., Viduka, A., Magdic, I., Telak, L.J., Francos, M. and Pereira, P. 2020. Agricultural and Forest Land-Use Impact on Soil Properties in Zagreb Periurban Area (Croatia). *Agronomy*, **10**(9): 1331.
- Bojko, O. and Kabala, C. 2017. Organic carbon pools in mountain soils-Sources of variability and predicted changes in relation to climate and land use changes. *Catena*, **149**: 209-220.
- Bossuyt, B., Heyn, M. and Hermy, M. 2002. Seed bank and vegetation composition of forest stands of varying age in central Belgium:

- consequences for regeneration of ancient forest vegetation. *Plant Ecology*, **162**: 33-48.
- Bowman, R.A., Reeder, J.D. and Lober, R.W. 1990. Changes in soil properties in a central Plains rangeland soil after 3, 20, and 60 years of cultivation. *Geoderma*, **13**: 16-28.
- Bremner, J.M. and Mulvaney, C.S. 1982. Nitrogen-Total. In: Page, A.L., Miller, R.H., and Keeney, D.R. Methods of soil analysis. *American Society of Agronomy*, **9**: 595-624.
- Brito, G.S., Bautista, S., Lopez-Poma, R. and Pivello, V.R. 2019. Labile soil organic carbon loss in response to land conversion in the Brazilian woodland savanna (cerradao). *Biogeochemistry*, **144**(1): 31-46.
- Bruggen-Van, A.H.C. and Semenov, A.M. 2000. In search of biological indicators for soil health and disease suppression. *Applied Soil Ecology*, **15**: 13-24.
- Buoyocous, G.J. 1962. Hydrometer method improved for making particle size analysis of soil. *Agronomy Journal*, **54**: 464-465.
- Burck, I.C., Yonker, C.M., Parton, W.J., Cole, C.V., Flach, K. and Schimel, D.S. 1989. Texture, climate, and cultivation effects on soil organic matter content in USA grassland soils. *Journal of Soil Science Society of America*, **53**: 800-805.
- Cao, J., Wang, X., Sun, X., Zhang, L. and Tian, Y. 2013. Effects of grazing intensity on soil labile organic carbon fractions in a desert steppe area in Inner Mongolia. *Springer plus*, **2**(1): S1.
- Catherine, P. and Rock, O. 2007. Organic carbon, organic matter and bulk density relationships in boreal forest soils. *Canadian journal of soil science*, **15**(5): 164-175.

- Celik, I. 2005. Land-use effects on organic matter and physical properties of soil in a southern Mediterranean highland of Turkey. *Soil and Tillage Research*, **83**(2): 270-277.
- Chan, K.Y., Bowman, A. and Oates, A. 2001. Oxidizable organic carbon fractions and soil quality changes in an oxycpaleustalf under different pasture leys. *Soil Science*, **166**: 61-67.
- Chapman, J.L. and Reiss, M.J. 1992. Ecology: Principles and applications. Cambridge, Cambridge University Press.
- Chatterjee, A., Lal, R., Wielopolski, L., Martin, M.Z. and Ebinger, M. 2009. Evaluation of different soil carbon determination methods. *Critical Reviews in Plant Science*, **28**(3): 164- 178.
- Chatterjee, S., Bandyopadhyay, K.K., Pradhan, S., Singh, R. and Datta, S.P. 2018. Effects of irrigation, crop residue mulch and nitrogen management in maize (*Zea mays* L.) on soil carbon pools in a sandy loam soil of Indo-gangetic plain region. *Catena*, **165**: 207-216.
- Chaudhari, P.R., Ahire, D.V., Ahire, V.D., Chkravarty, M. and Maity, S. 2013. Soil bulk density as related to soil texture, organic matter content and available total nutrients of Coimbatore soil. *International Journal of Scientific and Research Publications*, **3**: 2250-3153.
- Chauhan, R.P., Pande, K.R. and Thakur, S. 2014. Soil properties affected by land use systems in Western Chitwan, Nepal. *International Journal of Applied Sciences and Biotechnology*, **2**(3): 265-269.
- Chemada, M., Kibret, K. and Fite, T. 2017. Influence of different land use types and soil depths on selected soil properties related to soil fertility in Warandhab Area, Horo Guduru Wallaga Zone, Oromiya, Ethiopia.

International Journal of Environmental Sciences and Natural Resources,
4 (2): 555634.

Chen, D.D., Zhang, S.H., Dong, S.K., Wang, X.T. and Du, G.Z. 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): 446-452.

Chen, L., Qi, X., Zhang, X., Li, Q. and Zhang, Y. 2011. Effect of agricultural land use changes on soil nutrient use efficiency in an agricultural area, Beijing, China. *Chinese Geographical Science*, **21**(4): 392-402.

Chen, S., Arrouays, D., Angers, D.A., Martin, M.P. and Walter, C. 2019. Soil carbon stocks under different land uses and the applicability of the soil carbon saturation concept. *Soil and Tillage Research*, **188**: 53-58.

Chibsa, T. and Asefa, T. 2009. Assessment of soil organic matter under four land use systems in Bale Highlands, Southeast Ethiopia A. Soil organic matter contents in four land use systems: forestland, grassland, fallow land and cultivated land. *World Applied Sciences Journal*, **6**(9): 1231-1246.

Chimdi, A., Gebrekidan, H., Kibret, K. and Tadesse, A. 2012. Status of selected physicochemical properties of soils under different land use systems of Western Oromia, Ethiopia. *Journal of Biodiversity and Environmental Sciences*, **2**(3): 57-71.

Chivhane, S.P. and Bhattacharyya, T. 2010. Effect of land use and bio-climatic systems on organic carbon pool of shrink-swell soils in Vidarbha region, Maharashtra. *Agropedology*, **20**: 145-156.

Choudhury, B.U., Saha, S., Singh, S.B., Das, A., Buragohain, J., Dayal, V., Singh, A.R., Boopathi, T. and Dutta, S.K. 2018. Impact of postburn jhum

- agriculture on soil carbon pools in the north-eastern Himalayan region of India. *Soil Research*, **56**(6): 615-622.
- Contech, A., Lefroy, R.D.B. and Blair, G.J. 1997. Dynamics of organic matter in soils as determined by variation in $^{13}\text{C}/^{12}\text{C}$ isotopic ratio and fractionation by ease of oxidation. *Australian Journal of Soil Research*, **35**: 881-890.
- Curtis, R.O. and Post, W. 1964. Estimating Bulk Density from Organic Matter Content in Some Vermont Forest soils. *Soil Science Society of America Journal*, **28**: 285-286.
- Dad and Javaid, M. 2019. Organic carbon stocks in mountain grassland soils of northwestern Kashmir Himalaya: spatial distribution and effects of altitude, plant diversity and land use. *Carbon Management*, **10**(2): 149-162.
- Dar, D.A. and Sahu, P. 2018. Assessment of Soil Organic Carbon Stock in Five Forest Types of Northern Kashmir and Himalaya. *International Journal of Theoretical & Applied Sciences*, **10**(1): 86-92.
- Dar, M., Qaisar, K.N., Mughal, A.H., Khan, P.A., Masoodi, T.H., Mugloo, J.A. and Shah, I.A. 2020. Soil organic carbon content and nutrient status in temperate agroforestry systems of Kashmir Himalaya. *Range Management and Agroforestry*, **41**(2): 374-380.
- Datta, S.P., Rattan, R.K. and Chandra, S. 2010. Labile soil organic carbon, soil fertility, and crop productivity as influenced by manure and mineral fertilizers in the tropics. *Journal of Plant Nutrition and Soil Science*, **173**: 715-726.
- Davidson, E.A. and Janssens, I.A. 2006. Temperature sensitivity of soil carbon decomposition and feedbacks to climate change. *Nature*, **440**: 165-173.

- Davis, M.R. and Condron, L. M. 2002. Impact of grassland afforestation on soil carbon in New Zealand: a review of paired-site studies. *Soil Research*, **40**(4): 675-690.
- Dawit, S., Fritzsche, F., Tekalign, M., Lehmann, J. and Zech, W. 2002. Soil organic matter composition in the sub-humid Ethiopian highlands as influenced by deforestation and agricultural management. *Soil Science Society of America Journal*, **66**: 68-82.
- Dawson, J.C. and Smith, P. 2007. Carbon losses from soil and its consequences for land-use management. *Science Total Environment*, **382**: 165-190.
- Dhakal, S., Koirala, M., Sharma, E. and Subedi, N.R. 2010. Effect of Land Use Change on Soil Organic Carbon Stock in Balkhu Khola Watershed Southwestern Part of Kathmandu Valley, Central Nepal. Conference Paper: World Academy of Science, Engineering and Technology, June 2010.
- Dhaliwal, S.S., Bijay S., Sharma, B.D. and Khera, K.L. 2009. Soil quality and yield trends of different crops in low productive submontaneous tract and highly productive area in Punjab, India. *Indian Journal of Dryland Agricultural Research and Development*, **24**: 39-45.
- Dlamini, P., Chivenge, P. and Chaplot, V. 2016. Overgrazing decreases soil organic carbon stocks the most under dry climates and low soil pH: A meta-analysis shows. *Agriculture Ecosystems & Environment*, **221**: 258-269.
- Don, A., Schumacher, J. and Freibauer, A. 2011. Impact of tropical landuse change on soil organic carbon stocks - A meta-analysis. *Global Change Biology*, **17**: 1658-1670.

- Dong, W.Y., Zhang, X.Y., Dai, X.Q., Fu, X.L., Yang, F.T., Liu, X.Y., Sun, X.M., Wen, X.F. and Schaeffer, S. 2014. Changes in soil microbial community composition in response to fertilization of paddy soils in subtropical China. *Applied Soil Ecology*, **84**: 140e147
- Duval, M.E., Galantini, J.A., Iglesias, J.O., Canelo, S., Martinez, J.M. and Wall, L. 2013. Analysis of organic fractions as indicators of soil quality under natural and cultivated systems. *Soil Tillage Research*, **131**: 11-19.
- Emiru, N. and Gebrekidan, H. 2013. Effect of land use changes and soil depth on soil organic matter, total nitrogen and available phosphorus contents of soils in Senbat Watershed, Western Ethiopia. *Journal of Agricultural and Biological Science*, **8**(3): 206-2012.
- Erdal Sakin. 2012. Organic carbon organic matter and bulk density relationships in arid-semi arid soils in Southeast Anatolia region. *African Journal of Biotechnology*, **11**(6): 1373-1377.
- Eze, S., Palmer, S.M. and Chapman, P.J. 2018. Response to comments by Hoffmann on “Upland grasslands in Northern England were atmospheric carbon sinks regardless of management regime. *Agricultural and Forest Meteorology*, **264**: 366-368.
- Farida, A. 1997. Evaluation of sulphur in some paddy growing soils of Kashmir. *M. Sc. Thesis*, submitted to SKUAST-Kashmir Srinagar, **pp**. 1-102.
- Fey, M.V. 2001. Consequences of a land scape turned sour: the effect of excessive soil acidity on the natural resources, agriculture and forestry. Proc. 5th international symposium on soil plant interactions at low pH; Alpine Health, South Africa, **pp** 52-62.

- Fierer, N., Carney, K.M., Horner-Devine, M.C. and Megonigal, J.P. 2009. The biogeography of ammonia-oxidizing bacterial communities in soil. *Microbial Ecology*, **58**: 435-445.
- Fozia, S.W., Farida, A., Shakeel, M., Zahoor, A.B., Showkat, M., Mohammad, Y. Z. and Sajad, U.N. 2018. Assessment of Soil Microbial Status under Different Land Use Systems in North Western Zone of Kashmir. *International Journal of Current Microbiology and Applied Sciences*, **7**(8): 266-279.
- Franzluebbers and Arshad, J. 2010. Soil organic carbon in managed pastures of the southeastern United States of America. Grassland Carbon Sequestration: Management, Policy and Economics. *Integrated Crop Management*, **11**: 163-175.
- Garten, C.T. and Wulfschleger, S.D. 1999. Soil carbon inventories under a bioenergy crop (Switchgrass): measurement limitations. *Journal of Environmental Quality*, **28**: 1359-1365.
- Gatto, A., de Barros, N.F., Novais, R.F., Silva, I.R., Mendonca, E.D.S. and Villani, E.D.A. 2009. Comparison of methods for determination of organic carbon in soils under eucalypt plantations. *Revista Brasileira de Ciência do Solo*, **33**(3): 735-740.
- George, T.R., Bhat, J.A., Ahmad, M., Wani, D.M.M., Ramzan, S. and Yadav, R. 2021. Mapping of spatial variability of soil texture and macronutrients in Wangath watershed, Ganderbal District of Jammu and Kashmir Using GIS. *Journal of Pharmacognosy and Phytochemistry*, **10**(2): 628-642.
- Geraei, D.S., Hojati, S., Landi, A. and Cano, A.F. 2016. Total and labile forms of soil organic carbon as affected by land use change in southwestern Iran. *Geoderma regional*, **7**(1): 29-37.

- Ghimire, P., Bhatta, B., Pokhrel, B., Kafle, G. and Paudel, P. 2018. Soil organic carbon stocks under different land uses in Chure region of Makawanpur district, Nepal. *SAARC Journal of Agriculture*, **16**(2): 13-23.
- Ghorbani-Nasrabadi, R., Greiner, R., Alikhani, H. A, Hamed, J. and Yakhchali, B. 2013. Distribution of actinomycetes in different soil ecosystems and effect of media composition on extracellular phosphatase activity. *Journal of Soil Science and Plant Nutrition*, **13**(1): 223-236.
- Ghulam, R. 2005. Effects of different land-use types on soil quality in the hilly area of Rawalakot Azad Jammu and Kashmir, *Acta Agriculturae Scandinavica, Section B-Soil & Plant Science*, **55**(3): 221-228.
- Gilley, J.E. and Doran, J.W. 1997. Tillage effects on soil erosion potential and soil quality of a former conservation reserve program site. *Journal of Soil and Water Conservation*, **52**(3): 184-88.
- Girma, D., Wogi, L. and Feyissa, S. 2020. Effect of land use types on soil organic carbon stock at sire morose sub watershed, hidabu abote district of north shoa zone, central highland of Ethiopia. *Science research*, **8**(1): 1.
- Golchin, A., Oades, J.M., Skjemstad, J.O. and Clarke, P. 1994. Study of free and occluded particulate organic matter in soils by solid state ¹³C CP/MAS NMR spectroscopy and scanning electron microscopy. *Australian Journal of Soil Research*, **32**: 285-309.
- Gomez, K.A. and Gomez, A.A. 1984. Statistical procedures for Agricultural Research, *Wiley and Wiley Publications*, New York, **pp.** 680.
- Grayston, S.J., Campbell, C.D., Bardgett, R.D., Mawdsley, J.L. and Clegg, C.D. 2004. Assessing shifts in microbial community structure across a range of grasslands of differing management intensity using CLPP, PLFA and community DNA techniques. *Applied Soil Ecology*, **25**: 63-84.

- Guo, L.B. and Gifford, R.M. 2002. Soil carbon stocks and land use change: a meta-analysis. *Global Change Biology*, **8**: 345-360.
- Gupta, M.K. and Sharma, S.D. 2012. Sequestered organic carbon status in the soils supporting different tree plantations in Uttarakhand State of India. *International Journal of Research, Chemistry and Environment*, **2**(2): 32-37.
- Gupta, P.K. 2004. Plant analysis. In: Gupta PK, editor. Soil, plant, water and fertilizer analysis. Jodhpur, India: Agrobios, **pp.** 258-292.
- Hamkalo, Z. and Bedernicsek, T. 2014. Total, cold and hot water extractable organic carbon in soil profile: impact of land-use change. *Zemdirbyste-Agriculture*, **101**(2): 125-132.
- Haynes, R.J. 2005. Labile organic matter fractions as central components of the quality of agricultural soils. *Advances in Agronomy*, **85**: 221-268.
- Helfrich, M., Ludwig, B., Buurman, P. and Flessa, H. 2006. Effects of land use on the composition of soil organic matter in density and aggregate fractions as revealed by solid-state ¹³C-NMR spectroscopy. *Geoderma*, **136**: 331-341.
- Heluf, G. and Wakene, N. 2006. Impact of land use and management practices on chemical properties of some soils of Bako area, western Ethiopia. *Ethiopian Journal of Natural Resources*, **8**(2): 177-197.
- Hobley, E., Wilson, B., Wilkie, A., Gray, J. and Koen, T. 2015. Drivers of soil organic carbon storage and vertical distribution in Eastern Australia. *Plant and Soil*, **390**: 111-127.
- Homann, P.S., Kapchinske, J.S. and Boyce, A. 2007. Relations of mineral-soil C and N to climate and texture: regional differences within the conterminous USA. *Biogeochemistry*, **85**: 303-316.

- Homebegowda, H.C., Van, S.O., Kokler, M. and Holscher, D. 2016. On the Rebound: Soil Organic Carbon Stocks Can Bounce Back to near Forest Levels When Agro-Forests Replace Agriculture in Southern India. *Soil*, **2**: 13-23.
- Hu, Y., Xiang, D., Veresoglou, S.D., Chen, F., Chen, Y., Hao, Z., Zhang, X. and Chen. 2014. Soil organic carbon and soil structure are driving microbial abundance and community composition across the arid and semi-arid grasslands in northern China. *Soil Biology & Biochemistry*, **77**: 51e57.
- Hu, Y.L., Zeng, D.H., Chang, S.X. and Mao, R. 2013. Dynamics of soil and root C stocks following afforestation of croplands with poplars in a semi-arid region in northeast China. *Plant Soil*, **368**: 619-627.
- Husain, M. 2018a. Estimation of soil carbon pool under different land use systems in Kashmir valley. *Journal of Pharmacognosy and Phytochemistry*, **7**(3): 979-984.
- Husain, M. 2018b. Delineation of best land use system for carbon sequestration in Kashmir valley. *Journal of Pharmacognosy and Phytochemistry*, **7**(3): 993-997.
- Hussain, S., Sharma, V., Arya, V.M., Sharma, K.R. and Rao, C.S. 2019. Total organic and inorganic carbon in soils under different land use/land cover systems in the foothill Himalayas. *Catena*, **182**: 104104.
- Ibekwe, A.M., Poss, J.A., Grattan, S.R., Grieve, C.M. and Suarez, D. 2012. Bacterial diversity in cucumber (*Cucumis sativus*) rhizosphere in response to salinity, soil pH, and boron. *Soil Biology and Biochemistry*, **42**: 567-575.

- IPCC. Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland.
- Iqbal, K., Bhat, J.A., Pala, N.A., Hussain, A. and Negi, A.K. 2020. Variation in Soil Carbon Stock of Tree based Land Use Systems in Temperate Zone of Kashmir Himalaya. *Indian Forester*, **146**(3): 208-212.
- Jackson, M.L. 1973. Soil Chemical Analysis. Prentice-Hall of India Private Limited, *New Delhi, India*, pp. 46-47.
- Jafarian, Z. and Kaviani, A. 2013. Effects of land-use change on soil organic carbon and nitrogen. *Commun. Communications in Soil Science and Plant Analysis*, **44**: 33-346.
- Jamala, G.Y. and Oke, D.O. 2013. Soil organic carbon fractions as affected by land use in the Southern Guinea Savanna ecosystem of Adamawa State, Nigeria. *Journal of Soil Science and Environmental Management*, **4**(6): 116-122.
- James, T., Aliyu, E., Ishaku, D., Abubakar, S.Y., Mohammed, H.I. and Gideon, M.M. 2020. Soil microbial status under different land use systems in Gombe state, Nigeria. *World Journal of Advanced Research and Reviews*, **12**(1): 104-110.
- Javid, A.D. and Sundarapandian, S. 2015. Altitudinal variation of soil organic carbon stocks in temperate forests of Kashmir Himalayas, India. *Environmental Monitoring and Assessment*, **187**: 11-24.
- Jiao, Y., Xu, Z. and Zhao, J. 2009. Effects of grassland conversion to cropland and forest on soil organic carbon and dissolved organic carbon in the farming-pastoral ecotone of Inner Mongolia. *Acta Ecologica Sinica*, **29**(3): 150-154.

- Jobbagy, E.G. and Jackson, R.B. 2000. The vertical distribution of soil organic carbon and its relation to climate and vegetation. *Ecological Applications*, **10**: 423-436.
- John, B., Yamashita, T., Ludwig, B. and Flessa, H. 2005. Storage of organic carbon in aggregate and density fractions of silty soils under different types of land use. *Geoderma*, **128**: 63-79.
- Jones, R.J., Hiederer, R., Rusco, E. and Montanarella, L. 2005. Estimating organic carbon in the soils of Europe for policy support. *European Journal of Soil Science*, **56**(5): 655-671.
- Joshi, P.K. and Yadav, R.K. 2005. Effect of sewage on microbiological and chemical properties and crop growth in reclaimed alkali soil. Proceeding of the International Conference on Soil, Water and Environment Quality, Issues and Strategies, New Delhi.
- Kalambukattu, J.G., Singh, R., Patra, A.K. and Arunkumar, K. 2013. Soil carbon pools and carbon management index under different land use systems in the Central Himalayan region. *Acta Agriculturae Scandinavica, Section B-Soil & Plant Science*, **63**(3): 200-205.
- Kaur., Rajwinder. and Bhat, Z.A. 2017. Effect of different agricultural land use systems on physico-chemical properties of soil in sub-mountainous districts of Punjab, North-West India. *Journal of Pharmacognosy and Phytochemistry*, **6**(3): 226-233.
- Kavitha, P.G.A., Sudha, P., Ahila, D. and Kumaran, K. 2020. A Comparative Study on Forest Soil Microbial Diversity and Biomass in Nilgiri Biosphere of Southern India. *International Journal of Current Microbiology and Applied Sciences*, **9**(9): 3701-3715.

- Kiflu, A. and Beyene, S. 2013. Effects of different land use systems on selected soil properties in south Ethiopia. *Journal of Soil Science and Environmental Management*, **4**: 100-107.
- Kirschbaum, M.U. 2000. Will changes in soil organic carbon act as a positive or negative feedback on global warming. *Biogeochemistry*, **48**(1): 21-51.
- Knops, J.M.H. and Tilman, D. 2000. Dynamics of soil nitrogen and carbon accumulation for 61 years after agricultural abandonment. *Ecology*, **81**(1): 88-98.
- Kobierski, M., Ciescinska, B., Ciescinski, J. and Kondratowicz-Maciejewska, K. 2020. Effect of Soil Management Practices on the Mineralization of Organic Matter and Quality of Sandy Soils. *Journal of Ecological Engineering*, **21**(4): 219-225.
- Koga, N., Shimoda, S., Shirato, Y., Kusaba, T., Shima, T., Niimi, H. and Atsumi, K. 2020. Assessing changes in soil carbon stocks after land use conversion from forest land to agricultural land in Japan. *Geoderma*, **377**: 114487.
- Kolay, A.K. 2000. Basic concepts of soil science. *New Age International Publishers, New Delhi*. pp. 78-138.
- Kukul, Debasish-Saha., S.S. and Bawa, S.S. 2012. Soil organic carbon stock and fractions in relation to land use and soil depth in the degraded shivaliks hills of lower Himalayas. *Land Degradation & Development*, **25**(5): 407-416.
- Kumar, D., Upadhyay, G.P. and Anildutt, B.K. 2017b. Assessment of soil biological properties under different land uses in Barog-Dhillon watershed in Solan district of Himachal Pradesh. *International Journal of Chemical Studies*, **5**(4): 221-224.

- Kumar, P. and Gupta, M.K. 2017. Sequestered organic carbon in the soils under three different natural Forest communities and barren lands in the region of Garhwal Himalayas, Uttarakhand, India. *eJournal of Applied Forest Ecology*, **5**(1): 8-12.
- Kumar, R. and Sangwan, P.S. 2019. Soil Organic Carbon Dynamics in relation to different land uses. *Journal of Plant Development Sciences*, **11**(10): 551-558.
- Kumar, U., Shahid, M., Tripathi, R., Mohanty, S., Kumar, A., Bhattacharyya, P., Banwari, B.G., Priyanka, R., Rajagounder, P., Bipin, J., Nitiprasad, S. and Arvind, N. 2017a. Variation of functional diversity of soil microbial community in sub-humid tropical rice-rice cropping system under long – term organic and inorganic fertilization. *Ecological Indicators*, **73**: 536–543.
- Kumar, V., Sharma, K.R., Arya, V.M. and Sharma, V. 2018. Landuse effects on structural stability and soil organic carbon in the sub-montane areas of north-western Himalayas, India. *Journal of Soil and Water Conservation*, **17**(2): 117-122.
- Kushalappa, K.A. 1986. Nutrient status in eucalyptus hybrid mono-culture. In: Proc. National Seminar on Eucalyptus in India: Past, Present and Future” held at Kerala Forest Research Institute, India, **pp** 120-125.
- Lakaria, B.L., Patne, M.K., Jha, P. and Biswas, A.K. 2012. Soil organic carbon pools and indices under different land use systems in vertisols of central India. *Journal of the Indian Society of Soil Science*, **60**(2): 125-131.
- Lal, R. 1999. Soil management and restoration for C sequestration to mitigate the accelerated greenhouse effect. *Progress in Environmental Science*, **1**(4): 307-326.

- Lal, R. 2002. Soil carbon dynamics in cropland and rangeland. *Environmental Pollution*, **116**(3): 353-362.
- Lal, R. 2003. Soil erosion and the global carbon budget. *Environment International*, **29**: 437-450.
- Lal, R. 2004. Soil carbon sequestration to mitigate climate change. *Geoderma*, **123**: 1-22.
- Lal, R., Kimble, J. and Follett, R.F. 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, pp 1-8.
- Lauber, C.L., Hamady, M., Knight, R. and Fierer, N. 2009. Pyrosequencing-based assessment of soil pH as a predictor of soil bacterial community structure at the continental scale. *Applied and Environmental Microbiology*, **75**: 5111-5120.
- Lei, L. and McDonald, L.M. 2019. Comparison of Soil Organic Carbon, Its Fractions and Carbon Management Index among Cropland, Grassland and Forest Soils in Northern West Virginia. *In Soil Science Society of America (SSSA) International Soils Meeting*. pp 1431.
- Leifeld, J., Bassin, S. and Fuhrer, J. 2005. Carbon stocks in Swiss agricultural soils predicted by land-use, soil characteristics, and altitude. *Agriculture, Ecosystem & Environment*, **105**: 255-266.
- Li, X., Zhang, H., Sun, M., Xu, N., Sun, G. and Zhao, M. 2020. Land use change from upland to paddy field in Mollisols drives soil aggregation and associated microbial communities. *Applied Soil Ecology*, **146**: 103351.

- Li, X.G., Li, F.M., Zed, R., Zhan, Z.Y. and Singh, B. 2007. Soil physical properties and their relations to organic carbon pools as affected by land use in an alpine pastureland. *Geoderma*, **139**(1-2): 98-105.
- Liu, D., Huang, Y., An, S., Sun, H., Bhople, P. and Chen, Z. 2018a. Soil physico-chemical and microbial characteristics of contrasting land-use types along soil depth gradients. *Catena*, **162**: 345-353.
- Liu, X., Chen, D., Yang, T., Huang, F., Fu, S. and Li, L. 2020. Changes in soil labile and recalcitrant carbon pools after land-use change in a semi-arid agro-pastoral ecotone in Central Asia. *Ecological Indicators*, **110**: 105925.
- Liu, X., Li, L., Wang, Q. and Mu, S. 2018b. Land-use change affects stocks and stoichiometric ratios of soil carbon, nitrogen, and phosphorus in a typical agro-pastoral region of northwest China. *Journal of Soils and Sediments*, **18**: 3167-3176.
- Lizaga, I., Quijano, L., Gaspar, L., Ramos, M. C. and Navas, A. 2019. Linking land use changes to variation in soil properties in a Mediterranean mountain agroecosystem. *Catena*, **172**: 516-527.
- Lucas-Borja, M.E., Zema, D.A., Plaza-Alvarez, P.A., Zupanc, V., Baartman, J., Sagra, J. and delasHeras, J. 2019. Effects of different land use (abandoned farmland, intensive agriculture and forest) on soil hydrological properties in Southern Spain. *Water*, **11**(3): 503.
- Maini, A., Sharma, V. and Sharma, S. 2020. Assessment of soil carbon and biochemical indicators of soil quality under rainfed land use systems in North Eastern region of Punjab, India. *Carbon Management*, **11**(2): 169-182.

- Majumder, B., Mandal, B., Bandyopadhyay, P.K. and Chaudhury, J. 2007. Soil organic carbon pools and productivity relationships for a 34 year old rice-wheat-jute agroecosystem under different fertilizer treatments. *Plant Soil*, **297**: 53-67.
- Malo, D.D., Schumacher, T.E. and Doolittle, J.J. 2005. Long-term cultivation impacts on selected soil properties in the northern Great Plains. *Soil & Tillage Research*, **81**: 277-291.
- Mandal, A., Toor, A.S. and Dhaliwal, S.S. 2020. Assessment of sequestered organic carbon and its pools under different agricultural land-uses in the semi-arid soils of South-Western Punjab, India. *Journal of Soil Science and Plant Nutrition*, **20**(1): 259-273.
- Mandal, A.S., Toor and Dhaliwal, S.S. 2018. Effect of Land-uses on Physico-Chemical Properties and Nutrient Status of Surface (0-15 cm) and Sub-Surface (15-30 cm) Layers in Soils of South-Western Punjab, India. *International Journal of Current Microbiology and Applied Sciences*, **7**(6): 2659-2671.
- Mandal, B., Majumder, B., Adhya, T.K., Bandopadhyay, P.K., Gangopadhyay, A., Sarkar, D., Kundu, M.C., Gupta, S., Choudhury, G.C., Hazra, G.C., Kundu, S., Samantaray, R.N. and Misra, A.K. 2008. Potential of double-cropped rice ecology to conserve organic carbon under subtropical climate. *Global Change Biology*, **14**: 1-13.
- Manlay, R., Feller, C. and Swift, M.J. 2007. Historical evolution of soil organic matter concepts and their relationships with the fertility and sustainability of cropping systems. *Agriculture Ecosystem & Environment*, **119**: 217-233.
- Maqbool, M., Rasool, R. and Ramzan, S. 2017a. Soil physico-chemical properties as impacted by different land use systems in district Ganderbal, Jammu

and Kashmir: India. *International Journal of Chemical Studies*, **5**(4): 832-840.

Maqbool, M., Shafi, S. and Rehman, N.Z. 2017b. Comparison between Forest and Agriculture Land uses in Relation to Physico-chemical Properties and Nutrient Status of Soil in district Ganderbal, J & K. *Research Journal of Agricultural Sciences*, **8**(3): 559-566.

Meena, V.S., Mondal, T., Pandey, B.M., Mukherjee, A., Yadav, R.P., Choudhary, M., Singh, S., Bisht, J.K. and Pattanayak, A. 2018. Land use changes: Strategies to improve soil carbon and nitrogen storage pattern in the mid-Himalaya ecosystem, India. *Geoderma*, **321**: 69-78.

Meetei, T.T., Manik, C.K., Yumnam, B.D. and Nirmala, K. 2017. Soil Organic Carbon Pools as Affected by Land Use Types in Hilly Ecosystems of Manipur. *International Journal of Bio-resource and Stress Management*, **8**(2): 220-225.

Mhete, M., Eze, P.N., Rahube, T.O. and Akinyemi, F.O. 2020. Soil properties influence bacterial abundance and diversity under different land-use regimes in semi-arid environments. *Scientific African*, **7**, e00246.

Mikha, M.M., Vigil, M.F. and Bemjamin, J.G. 2013. Long-term tillage impacts on soil aggregation and carbon dynamics under wheat fallow in the central Great Plains. *Soil Science Society of America Journal*, **77**: 594-605.

Mir, S., Wani, J.A., Sofi, J.A., Chesti, M.H., Mir, A.H., Khan, I.M., Juvairia, J., Wani, F. and Sofi, N. 2020. Soil organic carbon pools and stocks in different land uses of a temperate Himalayan region. *Journal of the Indian Society of Soil Science*, **68**(2): 162-169.

- Mirsky, S.B., Lanyon, L.E. and Needelman, B.A. 2008. Evaluating soil management using particulate and chemically labile soil organic matter fractions. *Soil Science Society of America Journal*, **72**(1): 180-185.
- Mishra, G. and Sarkar, A. 2020. Studying the relationship between total organic carbon and soil carbon pools under different land management systems of Garo hills, Meghalaya. *Journal of Environmental Management*, **257**: 110002.
- Mohamed, E.S., Abu-hashim, M., AbdelRahman, M.A., Schütt, B. and Lasaponara, R. 2019. Evaluating the effects of human activity over the last decades on the soil organic carbon pool using satellite imagery and GIS techniques in the Nile Delta Area, Egypt. *Sustainability*, **11**(9): 2644-2658.
- Mojiri, A., Aziz, H.A. and Ramaji, A. 2012. Potential decline in soil quality attributes as a result of land use change in a hillslope in Lordegan, Western Iran. *African journal of agricultural research*, **7**(4): 577-582.
- Molla, Eyayu., Heluf, G., Tekaliign, M. and Mohammed, A. 2010. Patterns of land use/cover dynamics in the mountain landscape of Tara Gedam and adjacent agro-ecosystem, northwest Ethiopia. *SINET: Ethiopian Journal of Science*, **33**(2): 75-88.
- Monisa, R. and Tahir, A. 2018. Labile and non-labile fractions of soil carbon under different land uses and depths in South Kashmir. *The Bioscan*, **13**(1): 273-276.
- Monisa, Raza. 2015. Carbon mineralization potential and soil carbon pool under different land uses in South Kashmir. M.Sc. Thesis Submitted to Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, India. **pp.** 129-130.

- Moraes Sa, J.C., Goncalves, D.R.P., Ferreira, L.A., Mishra, U., Inagaki, T.M., Furlan, F.J.F. and de Oliveira Ferreira, A. 2018. Soil carbon fractions and biological activity based indices can be used to study the impact of land management and ecological successions. *Ecological Indicators*, **84**: 96-105.
- Mostafa, E., Mehdi, E., Mojid, B. and Hamed, F. 2008. Effect of land use change on selected soil physical and chemical properties in Northern highland of Iran. *Journal of Applied Science*, **8**(3): 496-502.
- Muche, M., Addis, K.A. and Molla, E. 2015. Assessing the physiochemical properties of soils under different land use types. *Journal of Environmental and Analytical Toxicology*, **5**(5): 1-5.
- Mulat, Y., Kibret, K., Bedadi, B. and Mohammed, M. 2018. Soil organic carbon stock under different land use types in Kersa Sub Watershed, Eastern Ethiopia. *African Journal of Agricultural Research*, **13**: 1248-1256.
- Munoz, A.L.C., Fusaro, C., Hernandez- Guzman, M., Dendooven, L., Estrada- Torres, A. and Navarro- Noya, Y.E. 2020. Soil microbial diversity drops with land- use change in a high mountain temperate forest: a meta-genomics survey. *Environmental Microbiology Reports*, **12**(2): 185-194.
- Munoz, R.M., Jordan, L.A., Martinez, Z.L.M., Rosa, D.D.L., Elmabod, A., Mohamed, S.K. and Anaya, R.M. 2012. Organic carbon stocks in Mediterranean soil types under different land uses (Southern Spain). *Solid Earth*, **3**: 375-386.
- Murage, E.W., Karanja, N.K., Smithson, P.C. and Woomer, P.L. 2001. Differences in soil properties between productive and non-productive fields identified by small hold farmers in the Central Highlands of Kenya. *Agriculture, Ecosystems & Environment*, **79**: 1-8.

- Musinguzi, P., Tenywa, J.S., Ebanyat, P., Basamba, T.A., Makooma Tenyawa, M., Mubiru, D.N. and Zinn, Y.L. 2015. Soil organic carbon fractions in cultivated and uncultivated Ferralsols in Uganda. *Geoderma Regional*, **4**: 108-113.
- Naik, S.K., Maurya, S. and Bhatt, B.P. 2017. Soil organic carbon stocks and fractions in different orchards of eastern plateau and hill region of India. *Agroforestry Systems*, **91**(3): 541-552.
- Nakhro, N. and Dkhar, M.S. 2010. Impact of Organic and Inorganic Fertilizers on Microbial Populations and Biomass Carbon in Paddy Field Soil. *Journal of Agronomy*, **9**: 102-110.
- Namgial, J., Prabhakar, M., Gautam, K.L., Panda, S. and Sharma, A. 2020. Nutrient status of soil under different land use systems in Leh region of Himalayan cold desert. *Journal of Pharmacognosy and Phytochemistry*, **9**(4): 1192-1197.
- Nath, A.J., Brahma, B., Sileshi, G.W. and Das, A.K. 2018. Impact of land use changes on storage of soil organic carbon in active and recalcitrant pools in a humid tropical region of India. *Science of the Total Environment*, **624**: 908-917.
- Nazir, G.R. 1993. Characterization and management of salt affected soils of Jammu districts. (MSc Thesis). Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu. **pp.** 85
- Nega, E. 2006. Land use changes and their effects on physical and chemical properties in Senbat sub-watershed, western Ethiopia. M.Sc. Thesis Submitted to School of Graduate Studies, Alemaya University, Ethiopia. **pp.** 72.

- Nega, E. and Heluf, G. 2013. Effect of Land Use Changes and Soil Depth on Soil Organic Matter, Total Nitrogen and Available Phosphorus Contents of Soils in Senbat Watershed, Western Ethiopia. *Journal of Agricultural and Biological Science*, **8**(3): 206-212.
- Negasa, T., Ketema, H., Legesse, A., Sisay, M. and Temesgen, H. 2017. Variation in soil properties under different land use types managed by smallholder farmers along the toposequence in southern Ethiopia. *Geoderma*, **290**: 40-50.
- Niaz, S., Ijaz, S.S., Hassan, A. and Sharif, M. 2017. Landuse impacts on soil organic carbon fractions in different rainfall areas of a subtropical dry land. *Archives of Agronomy and Soil Science*, **63**(10): 1337-1345.
- Nicodemo, F., Borges, W.L.B. and Souza, I.M.D. 2018. Atributos físicos do solo em quatro sistemas de uso da terra em São Carlos, SP. *Revista Brasileira de Ciências Agrárias*, **13**(2): 1-7.
- Nigussie, A. and Kissi, E. 2012. Physicochemical characterization of nitisol in Southwestern Ethiopia and its fertilizer recommendation using NuMaSS. *Global Advanced Research Journal of Agricultural Science*, **1**(4): 66-73.
- Noordwijk, M., Rahayu, S., Hairiah, K., Wulan, Y.C., Farida, A. and Verbist, B. 2002. Carbon stock assessment for a forest-to coffee conversion landscape in Sumber-Jaya (Lampung, Indonesia): from allometric equations to land use change analysis. *Science China*, **45**: 75-86.
- Okonkwo, C.I. 2010. Effect of burning and cultivation on soil properties and microbial population of four different land use systems in Abakaliki. *Research Journal of Agriculture and Biological Sciences*, **6**(6): 1007-1014.

- Oliveira, D.M., Paustian, K., Cotrufo, M.F., Fiallos, A.R., Cerqueira, A.G. and Cerri, C.E.P. 2017. Assessing labile organic carbon in soils undergoing land use change in Brazil: A comparison of approaches. *Ecological indicators*, **72**: 411-419.
- Olorunfemi, I., Fasinmirin, J. T., Olufayo, A. A. and Komolafe, A.A. 2020. Total carbon and nitrogen stocks under different land use/land cover types in the Southwestern region of Nigeria. *Geoderma Regional*, e00320.
- Ono, K. and Kanomata, H. 2004. Organic carbon stock in forest soils in Japan. *Geoderma*, **119**: 21-32.
- Pal, S., Panwar, P. and Bhardwaj, D.R. 2013. Soil quality under forest compared to other land uses in acid soil of North Western Himalaya, India. *Annals of Forest Research*, **56**(1): 187-198.
- Pan, G., Zhou, P., Li, Z., Smith, P., Li, L., Qiu, D. and Chen, X. 2009. Combined inorganic/organic fertilization enhances N efficiency and increases rice productivity through organic carbon accumulation in a rice paddy from the Tai Lake region, China. *Agriculture, Ecosystems & Environment*, **131**(3-4): 274-280.
- Pan, G.X., Li, L.Q., Zhang, X.H., Dai, J.Y., Zhou, Y.C. and Zhang, P.J. 2003. Soil organic carbon storage of China and the sequestration dynamics in agricultural land. *Advanced Earth Sciences*, **18**(4): 609-618.
- Pandher, L.K., Gupta, R.K. and Kukal, S.S. 2020. Soil organic carbon, its fractions and soil organic carbon stocks under different land use systems in Typic Ustochrepts of northwest India. *Tropical Ecology*, **8**(3): 278-288.
- Papini, R., Valboa, G., Favilli, F. and L. Abate, G. 2011. Influence of land use on organic carbon pool and chemical properties of Vertic Cambisols in

central and southern Italy. *Agriculture, Ecosystems and Environment*, **140**(1-2): 68-79.

Pasricha, N.S. and Ghosh, P.K. 2020. Soil Organic Carbon Dynamics in Tropical and Subtropical Grassland Ecosystem. In *Carbon Management in Tropical and Sub-Tropical Terrestrial Systems*, pp 283-297.

Percival, H.J., Parfitt, R.L. and Scott, N.A. 2000. Factors controlling soil carbon levels in New Zealand grasslands: Is clay content important? *Soil Science Society of America Journal*, **64**: 1623-1630.

Pere, R., Montserrat, J. and Joan, R. 2010. Active and passive organic matter fractions in Mediterranean forest soils. *Biology and Fertility of Soils*, **46**: 355-369.

Perie, C. and Ouimet, R. 2008. Organic carbon, organic matter and bulk density relationships in boreal forest soils. *Canadian Journal of Soil Science*, **88**: 315-325.

Pham, T.G., Hung, T.N. and Martin, K. 2018. Assessment of soil quality indicators under different agricultural land uses and topographic aspects in Central Vietnam. *International Soil and Water Conservation Research*, **6**(4): 280-288.

Post, W.M. and Kwon, K.C. 2000. Soil carbon sequestration and land-use change: Processes and potential. *Global Change Biology*, **6**: 317-327.

Preetha, S.S., Kaladevi, V. and Aswathy, A.J. 2017. An Assessment of Carbon Sequestration Potential of Different Land Use Patterns in Southern Region of Kerala. *Journal of Advances in Biological Science*, **4**(1): 40-44.

- Qian, T.J., Yong, Z.Z., Bin, B. and 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*, **32**(3): 601-610.
- Qiao, J., Zhu, Y., Jia, X., Huang, L. and Shao, M. 2018. Vertical distribution of soil total nitrogen and soil total phosphorus in the critical zone on the Loess Plateau, China. *Catena*, **166**: 310-316.
- Raheb, A. and Heidari, A. 2012. Effects of clay mineralogy and physico-chemical properties on potassium availability under soil aquatic conditions. *Journal of Soil Science and Plant Nutrition*, **12**(4): 747-761.
- Raina, A.K. and Gupta, M.K. 2013. Fertility and Sequestered Organic Carbon Status in the Soils under different Forest Stands in Garhwal Himalayas, India. *Concepts in pure and applied science*, **1**(1): 10-16.
- Ravina, M. 2012. Impact of *Eucalyptus* plantations on pasture land on soil properties and carbon sequestration in Brazil. Swedish University of Agricultural Sciences, Uppsala.
- Rebecca, E., Drenovsky, K.L., Steenwerth, L.E.J. and Kate, M.S. 2010. Land use and climatic factors structure regional patterns in soil microbial communities. *Global Ecology and Biogeography*, **19**: 27-39.
- Reddy, D.D. 2010. Determination of labile SOC by KMnO₄ oxidation technique and its use in carbon management index In: Muralidharadu Y, Reddy SK and Subba Rao A, editors. Farmers Resource based site specific integrated nutrient management and online fertilizer recommendations using GPS and GIS tools. Bhopal: Indian Institute of Soil Science, **pp** 66-69.
- Ren, W., Banger, K., Tao, B., Yang, J., Huang, Y. and Tian, H. 2020. Global pattern and change of cropland soil organic carbon during 1901-2010:

Roles of climate, atmospheric chemistry, land use and management. *Geography and Sustainability*. pp 59-69

Roheela, Ahmad. 2019. Soil Quality Assessment under Different Land uses in District Bandipora. M.Sc. Thesis Submitted to Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, India. pp. 68-69.

Sa Joao Carlos, M. and Lal, R. 2009. Stratification ratio of soil organic matter pools as an indicator of carbon sequestration in a tillage chronosequence on a Brazilian Oxisol. *Soil and Tillage Research*, **103**: 46-56.

Saha, D., Kukul, S.S. and Sharma, S. 2011. Landuse impacts on SOC fractions and aggregate stability in typicustochrepts of Northwest India. *Plant Soil*, **339**: 457-470.

Sahani, U. and Behera, N. 2001. Impact of Deforestation on Soil Physicochemical Characteristics, Microbial Biomass and Microbial Activity of Tropical Soil. *Land Degradation and Development*, **12**: 93.

Sahoo, U.K, Singh, S.L, Gogoi, A., Kenye, A. and Sahoo, S.S. 2019. Active and passive soil organic carbon pools as affected by different land use types in Mizoram, Northeast India. *PLoS ONE*, **14**(7): e0219969.

Sainepo, B.M., Gachene, C.K. and Karuma, A. 2018. Assessment of soil organic carbon fractions and carbon management index under different land use types in Olesharo Catchment, Narok County, Kenya. *Carbon Balance and Management*, **13**(1): 143-156.

Saki, E., Deliboran, A. and Tutar, E. 2011. Bulk density of Harran plain soils in relation to other soil properties. *African Journal of Agricultural Research*, **6**(7): 1750-1757.

- Samani, K.M., Pordel, N., Hosseini, V. and Shakeri, Z. 2020. Effect of land-use changes on chemical and physical properties of soil in western Iran (Zagros oak forests). *Journal of Forestry Research*, **31**(2): 637-647.
- Schmitt, H.M., Castellanos, E.J., Evans, T.P. and Randolph, J.C. 2012. Carbon stock in coffee agroforests and mixed dry tropical forests in the western highlands of Guatemala. *Agroforestry Systems*, **86**: 141-157.
- Selassie, Y.G., Anemut, F. and Addisu, S. 2015. The effects of land use types, management practices and slope classes on selected soil physico-chemical properties in Zikre watershed, North-Western Ethiopia. *Environmental Systems Research*, **4**(1): 1-7.
- Semahugne, W. 2008. Land use changes and soil organic carbon and soil nitrogen in the Northwestern Highlands of Ethiopia”. MSc Thesis, University of Natural Resources and Applied Life Sciences, Vienna.
- Senechkin, I.V., Van, L.S. and Ahc, V.B. 2014. Greater Fusarium wilt suppression after complex than after simple organic amendments as affected by soil pH, total carbon and ammonia-oxidizing bacteria. *Applied Soil Ecology*, **73**: 148-155.
- Sevgi, O. and Tecimen, H.B. 2008. Changes in Austrian Pine forest floor properties in relation with altitude in mountainous areas. *Journal of Forest Science*, **54**: 306-313.
- Shao, X., Yang, W. and Wu, M. 2015. Seasonal dynamics of soil labile organic carbon and enzyme activities in relation to vegetation types in Hangzhou Bay tidal fat wetland. *PLoS One*, **10**: e0142677.
- Sharma, R. and Sood, K. 2020. Characterization of spatial variability of soil parameters in apple orchards of Himalayan region using geostatistical

analysis. *Communications in Soil Science and Plant Analysis*, **51**(8): 1065-1077.

Sharma, V., Hussain, S., Sharma, K.R. and Arya, V.M. 2014. Labile carbon pools and soil organic carbon stocks in the foothill Himalayas under different land use systems. *Geoderma*. pp 232-234.

Sharma, Y.K., Sharma, A. and Sharma, S.K. 2013. An appraisal of physico-chemical characteristics and soil fertility status of forest and rice land use systems in mokokchung district of Nagaland. *Journal of the Indian Society of Soil Science*, **61**(1): 38-43.

Shedayi, A.A., Xu, M., Naseer, I. and Khan, B. 2016. Altitudinal gradients of soil and vegetation carbon and nitrogen in a high altitude nature reserve of Karakoram ranges. *SpringerPlus*, **5**(1): 246-279.

Sheng, H., Zhou, P., Zhang, Y., Kuzyakov, Y., Zhou, Q. and Ge, T. 2015. Loss of labile organic carbon from subsoil due to land-use changes in subtropical China. *Soil Biology and Biochemistry*, **88**: 148-157.

Shepherd, T.G., Saggar, S., Newman, R.H., Ross, C.W. and Dando, J.L. 2001. Tillage-induced changes to soil structure and organic carbon fractions in New Zealand soils. *Australian Journal of Soil Research*, **39**: 465-489.

Sherrod, L.A., Peterson, G.A., Westfall, D.G. and Ahuja, L.R. 2005. Soil organic carbon pools after 12 years in no-till dryland agro-ecosystems. *Soil Science Society of American Journal*, **67**: 1533-1543.

Shi, P., Zhang, Y., Zhang, Y., Yu, Y., Li, P., Li, Z., Xiao, L., Xu, G. and Zhu, T. 2020. Land-use types and slope topography affect the soil labile carbon fractions in the Loess hilly-gully area of Shaanxi, China. *Archives of Agronomy and Soil Science*, **66**(5): 638-650.

- Singh, G., Jalota, S.K. and Singh, B.S. 2005. Soil physical and hydraulic properties in a rice-wheat system in India: Effect of rice straw management. *Soil Use Manage*, **21**: 17-21.
- Singh, H., Pathak, P., Kumar, M. and Raghubanshi, A.S. 2011. Carbon sequestration potential of indo-gangetic agroecosystem soils. *Tropical Ecology*, **52**: 223-228.
- Singh, P. and Benbi, D.K. 2018. Soil organic carbon pool changes in relation to slope position and land-use in Indian lower Himalayas. *Catena*, **166**: 171-180.
- Singh, R., Bhardwaj, D.R., Pala, N.A. and Rajput, B.S. 2019. Biomass production and carbon stock potential of natural vegetation, agroforestry and cultivated land use systems along altitudinal gradient in north western Himalaya. *Range Management and Agroforestry*, **40**(1): 94-103.
- Six, J., Conant, R.T., Paul, E.A. and Paustian, K. 2002. Stabilization mechanisms of soil organic matter: implications for C-saturation of soils. *Plant and Soil*, **241**: 155-176.
- Six, J., Elliott, E.T. and Paustian, K. 1999. Aggregate and soil organic matter dynamics under conventional and no-tillage systems. *Soil Science Society of America Journal*, **63**: 1350-1358.
- Smith, P. 2007. Land use change and soil organic carbon dynamics. *Nutrient Cycling in Agroecosystems*, **81**: 169-178.
- Soleimani, A., Hosseini, S.M., Massah Bavani, A.R., Jafari, M. and Francaviglia, R. 2019. Influence of land use and land cover change on soil organic carbon and microbial activity in the forests of northern Iran. *CATENA*, **177**: 227-237.

- Sondhi, A.K. 1992. Soil resources inventory of NARA, DADA Manshi-watershed of Hoshiarpur district. (MSc Thesis), Punjab Agricultural University, Ludhiana, Punjab. **pp.** 57
- SPSS, Statistical package for the social sciences, 2020, IBM SPSS, Version 27.0, Armonk, NY, USA.
- Sreekanth, N.P., Shanthi, P.V., Padmakumar, B. and Thomas, A.P. 2013. Soil carbon alterations of selected forest types as an environmental feedback to climate change. *International Journal of Environmental Sciences*, **3**(5): 1516-1530.
- Srinivasarao, C., Sharma, K.L. and Kundu, S. 2020. Potential Soil Carbon Sequestration in Different Land Use and Management Systems in Peninsular India. *Carbon Management in Tropical and Sub-Tropical Terrestrial Systems*, **pp** 3-21.
- Srivastava, R., Mohapatra, M., Latare, A., Singh, A. P., Singh, S. K., Rai, S. and Singh, B. 2020. Impact of land use changes on soil quality and species diversity in the Vindhyan dry tropical region of India. *Journal of Tropical Ecology*, **36**(2): 72-79.
- Sui, X., Feng, F., Lou, X., Zheng, J. and Han, S. 2012. Relationship between microbial community and soil properties during natural succession of forest land. *African Journal of Microbiology Research*, **6**(42): 7028-7034.
- Sun, X., Tang, Z. and Ryan, M.G. 2019. Changes in soil organic carbon contents and fractionations of forests along a climatic gradient in China. *Forest Ecosystems*. **6**: 1-24.
- Sun, Y., Guo, G. and Shi, H. 2020a. Decadal shifts in soil pH and organic matter differ between land uses in contrasting regions in China. *Science of The Total Environment*, **pp** 139904.

- Sun, Y., Luo, C., Jiang, L., Song, M., Zhang, D., Li, J. and Zhang, G. 2020b. Land-use changes alter soil bacterial composition and diversity in tropical forest soil in China. *Science of The Total Environment*, **712**: 136526.
- Susmita, D., Madan, K., Eklabya, S. and Nab, R.S. 2010. Effect of Land Use Change on Soil Organic Carbon Stock in Balkhu Khola Watershed Southwestern Part of Kathmandu Valley, *Central Nepal World Academy of Science, Engineering and Technology*, **66**: 1-11.
- Szoboszlay, M., Dohrmann, A.B., Poeplau, C., Don, A. and Tebbe, C.C. 2017. Impact of land-use change and soil organic carbon quality on microbial diversity in soils across Europe. *FEMS Microbiology Ecology*, **93**(12): 146-161.
- Szopka, K., Kabała, C., Karczewska, A., Jezierski, P., Bogacz, A. and Waroszewski, J. 2016. The pools of soil organic carbon accumulated in the surface layers of forest soils in the Karkonosze Mountains, SW Poland. *Journal of Soil Science Annual*, **67**(2): 46-56.
- Tahir, M., Khalid, A.B., Mehmood, K., Khaliq, A. and Rahim, N. 2021. Variations in Soil Carbon and Nitrogen Contents under Different Land Uses in Sub-Temperate Highland of Azad Kashmir. *Eurasian Soil Science*, **54**(4): 586-596.
- Takoutsing, B., Weber, J.C., Tchoundjeu, Z. and Shepherd, K. 2016. Soil chemical properties dynamics as affected by land use change in the humid forest zone of Cameroon. *Agroforestry Systems*, **90**(6): 1089-1102.
- Tan, Z., Lal, R., Owens, L. and Zaurralde, R.C. 2007b. Distribution of light and heavy fractions of soil organic carbon as related to land uses and tillage practice. *Soil Tillage Research*, **92**: 53-59.

- Tan, Z., Liu, S., Li, Z. and Loveland, T.R. 2007a. Simulated responses of soil organic carbon stock to tillage management scenarios in the Northwest Great Plains. *Carbon Balance Manage*, **2**: 7-16.
- Tavakkoli, E., Rengasamy, P., Smith, E. and Mcdonald, G.K. 2015. The effect of cation & anion interactions on soil pH and solubility of organic carbon. *European Journal of Soil Science*, **66**: 124-136.
- Teshome, Y., Heluf, G., Kibebew, K. and Sheleme, B. 2013. Impacts of Land Use on Selected Physicochemical Properties of Soils of Abobo Area, Western Ethiopia. *Agriculture, Forestry and Fisheries*, **2**(5): 177-183.
- Thakur, M. and Verma, R.K. 2019. Biomass and Soil Organic Carbon Stocks Under Cedrus deodara Forests in Mandi District of Himachal Pradesh. *Nature Environment and Pollution Technology*, **18**(3): 879-887.
- Thangavel, R., Kanchikerimath, M., Sudharsanam, A., Ayyanadar, A., Karunanithi, R., Deshmukh, N.A. and Vanao, N.S. 2018. Evaluating organic carbon fractions, temperature sensitivity and artificial neural network modeling of CO₂ efflux in soils: Impact of land use change in subtropical India (Meghalaya). *Ecological Indicators*, **93**: 129-141.
- Tian, Q., Taniguchi, T., Shi, W. Y., Li, G., Yamanaka, N. and Du, S. 2017. Land-use types and soil chemical properties influence soil microbial communities in the semiarid Loess Plateau region in China. *Scientific reports*, **pp** 45289.
- Tirol, P. and Ladha, J.K. 2004. Assessing the reliability of permanganate-oxidizable carbon as index of soil labile carbon. *Soil Science Society of America Journal*, **98**: 969-978.

- Toru, T. and Kibebew, K. 2019. Carbon stock under major land use/land cover types of Hades sub-watershed, eastern Ethiopia. *Carbon Balance Manage*, **14**: 7.
- Tufa, M., Melese, A. and Tena, W. 2019. Effects of land use types on selected soil physical and chemical properties: the case of Kuyu District, Ethiopia. *Euroasian Journal of Soil Science*, **8**(2): 94-109.
- Tumayro, M. and Dereje, T. 2020. Impact of land use types and soil depths on selected soil physicochemical properties in Fasha District, Konso Zone, Southern Ethiopia. *Journal of Soil Science and Environmental Management*, **12**(1): 10-16.
- Turner, J., Lambert, M.J. and Johnson, D.W. 2005. Experience with Patterns of Change in Soil Carbon Resulting from Forest Plantation Establishment in Eastern Australia. *Forest Ecology and Management*, **220**: 259-269.
- Ufot, U., Iren, O.B. and Chikere, N. 2016. Effects of Land Use on Soil Physical and Chemical Properties in Akokwa Area of Imo State, Nigeria. *International Journal of Life Sciences Scientific Research*, **2**(3): 273-278.
- Valentine, A.T., Bernard, P.K. and Yerima. 2018. Effects of land use change on soil physicochemical properties in selected areas in the North West region of Cameroon. *Environmental Systems Research*, **7**:3.
- Van, S.O., Corre, M.D., Wolf, K., Tchienkoua, M., Cuellar, E. and Matthews, R.B. 2015. Conversion of lowland tropical forests to tree cash crop plantations loses up to one-half of stored soil organic carbon. *Proceedings of the National Academy of Sciences of the United States of America*, **112**: 9956-9960.
- 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 Tillage Research*, **96**(1): 195-204.
- 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.
- Wang, Q., Xiao, F., He, T. and Wang, S. 2013. Responses of labile soil organic carbon and enzyme activity in mineral soils to forest conversion in the subtropics. *Annals For Science*, **70**: 579-587.
- Wang, S.P., Zhou, G.S., Gao, S.H. and Guo, J.P. 2005. Soil Organic Carbon and Labile Carbon Along a Precipitation Gradient and Their Responses to Some Environmental Changes. *Pedosphere*, **15**(5): 676-680.
- Wang, W., Sardans, J., Zeng, C., Zhong, C., LI, Y. and Penuelas, J. 2014. Response of soil nutrient concentrations and stoichiometry to different human land uses in a subtropical tidal wetland. *Geoderma*, **232**: 459-470.
- Wang, Y.Q., Zhang, X.C. and Huang, C.Q. 2009. Spatial variability of soil total nitrogen and soil total phosphorus under different land uses in a small watershed on the loess plateau, China. *Geoderma*, **150**: 141-149.
- Wang, Z., Liu, S., Huang, C., Liu, Y. and Bu, Z. 2017. Impact of land use change on profile distributions of organic carbon fractions in peat and mineral soils in Northeast China. *Catena*, **152**: 1-8.
- Wani, M.H., Baba, S.H. and Yousef, S. 2009. Land use Dynamics in Jammu and Kashmir. *Agricultural Economics Research Review*, **22**: 145-154.
- Wani, S.A., Najjar, G.R. and Padder, B.A. 2017. Altitudinal and Depth-wise Variation of Soil Physico-chemical Properties and Available Nutrients of Pear Orchards in Jammu & Kashmir, India. *Chemical Science Review and Letters*, **6**(23): 1638-1645.

- Wehr, J.B., Lewis, T., Dalal, R.C., Menzies, N.W., Verstraten, L., Swift, S., Bryant, P., Tindale, N. and Smith, T.E. 2020. Soil carbon and nitrogen pools, their depth distribution and stocks following plantation establishment in south east Queensland, Australia. *Forest Ecology and Management*, **457**: 117708.
- Wei, X., Shao, M., Gale, W.J., Zhang, X. and Li, L. 2013. Dynamics of aggregate-associated organic carbon following conversion of forest to cropland. *Soil Biology and Biochemistry*, **57**: 876-883.
- Weil, R.R., Islam, K.R., Stine, M.A., Gruver, J.B. and Samson-Liebig, S.E. 2003. Estimating labile carbon for soil quality assessment: a simplified method for laboratory and field use. *American Journal of Alternative Agriculture*, **18**(1): 3-17.
- Whitbread, A.M., Lefroy, R.D.B. and Blair, G.J. 1998. A survey of the impact of cropping on soil physical and chemical properties in north-western New South Wales. *Australian Journal of Soil Research*, **36**: 669-681.
- Wiesenberg, G.L.B., Dorodnikov, M. and Kuzyakov, Y. 2010. Source determination of lipids in bulk soil and soil density fractions after four years of wheat cropping. *Geoderma*, **156**: 267-277.
- Wiesmeier, M., Sporlein, P., Geub, U., Hangen, E., Haug, S., Reischl, A. and Kögel-Knabner, I. 2012. Soil organic carbon stocks in southeast Germany (Bavaria) as affected by land use, soil type and sampling depth. *Global Change Biology*, **18**(7): 2233-2245.
- Wong, M.K., Selliah, P., Ng, T.F., Amir Hassan, M.H., Van Ranst, E. and Inubushi, K. 2020. Impact of agricultural land use on physicochemical properties of soils derived from sedimentary rocks in Malaysia. *Soil Science and Plant Nutrition*, **66**(1): 214-224.

- Wu, J. 2011. Carbon accumulation in paddy ecosystems in subtropical China: evidence from landscape studies. *European Journal of Soil Science*, **62**(1), 29-34.
- Wu, S.J., Deng, J.J., Yin, Y., Qin, S.J., Zhu, W.X., Zhou, Y.B. and Jin, L. 2020. Bacterial community changes associated with land use type in the forest montane region of northeast China. *Forests*, **11**(1): 40.
- Xia, X.U., Xiaoli, C., Yan, Z., Yiqi, L.U.O., Honghua, R. and Jiashe, W. 2010. Variation of Soil Labile Organic Carbon Pools along an Elevational Gradient in the Wuyi Mountains, China. *Journal of Resources and Ecology*, **1**(4): 368-374.
- Xiang, H., Zhang, L. and Wen, D. 2015. Change of soil carbon fractions and water-stable aggregates in a forest ecosystem succession in south China. *Forests*, **6**(8): 2703-2718.
- Yang, C., Yang, L. and Ouyang, Z. 2005. Organic carbon and its fractions in paddy soil as affected by different nutrient and water regimes. *Geoderma*, **124**(1-2): 133-142.
- Yang, Z., Singh, B.R. and Sitaula, B.K. 2004. Fractions of organic carbon in soils under different crop rotations, cover crops and fertilization practices. *Nutrient Cycling in Agroecosystems*, **70**: 161-166.
- Yeasmin, S., Jahan, E., Molla, M.A., Islam, A.K.M.M., Anwar, M.P., Rashid, M. H. and Chungopast, S. 2020. Effect of Land Use on Organic Carbon Storage Potential of Soils with Contrasting Native Organic Matter Content. *International Journal of Agronomy*, **pp** 1-9.
- Yeomans, J.C. and Bremner, J.M. 1988. A rapid and precise method for routine determination of organic carbon in soil. *Communications in Soil Science and Plant Analysis*, **19**: 1467-1476.

- Yifru, A. and Taye, B. 2011. Effects of Land use on Soil Organic Carbon and Nitrogen in Soils of Bale, Southeastern Ethiopia. *Tropical and Subtropical Agro-ecosystems*, **14**(1): 229-235.
- Yimer, F., Ledin, S. and Abdelkadir, A. 2007. Changes in soil organic carbon and total nitrogen contents in three adjacent land use types in the Bale Mountains, south-eastern highlands of Ethiopia. *Forest Ecology and Management*, **242**(2-3): 337-342.
- Yu, P., Han, K., Li, Q. and Zhou, D. 2017b. Soil organic carbon fractions are affected by different land uses in an agro-pastoral transitional zone in Northeastern China. *Ecological Indicators*, **73**: 331-337.
- Yu, P., Liu, S., Han, K., Guan, S. and Zhou, D. 2017a. Conversion of cropland to forage land and grassland increase soil labile carbon and enzyme activities in northeastern China. *Agriculture, Ecosystems & Environment*, **245**: 83-91.
- Yu, X., Zhou, W., Chen, Y., Wang, Y., Cheng, P., Hou, Y., Wang, Y., Xiong, X. and Yang, L. 2020. Spatial variation of soil properties and carbon under different land use types on the Chinese Loess Plateau. *Science of The Total Environment*, **703**: 134946.
- Yuan, H., Ge, T., Zhou, P., Liu, S., Roberts, P., Zhu, H., Zou, Z., Tong, C. and Wu, J. 2013. Soil microbial biomass and bacterial and fungal community structures responses to long-term fertilization in paddy soils. *Journal of Soils and Sediments*, **13**(5): 877e886.
- Zhang, J., Song, C. and Yang, W. 2006. Land use effects on the distribution of labile organic carbon fractions through soil profiles. *Soil Science Society of America Journal*, **70**: 660-67.

- Zhang, J., Wang, S., Wang, Q. and Liu, Y. 2009. Content and seasonal change in soil labile organic carbon under different forest covers. *Chinese Journal of Eco-Agriculture*, **17**: 41-47.
- Zhao, D., Dong, J., Ji, S., Huang, M., Quan, Q. and Liu, J. 2020. Effects of Contemporary Land Use Types and Conversions from Wetland to Paddy Field or Dry Land on Soil Organic Carbon Fractions. *Sustainability*, **12**(5): 2094.
- Zhao, Y., Ding, Y., Hou, X., Li, F.Y., Han, W. and Yun, X. 2017. Effects of temperature and grazing on soil organic carbon storage in grasslands along the Eurasian steppe eastern transect. *PLoS ONE*, **12**: 10-22.
- Zhao, Z., Dong, S., Jiang, X., Zhao, J., Liu, S., Yang, M., Han, Y. and Sha, W. 2018. Are land use and short time climate change effective on soil carbon compositions and their relationships with soil properties in alpine grassland ecosystems on Qinghai-Tibetan Plateau. *Science of the Total Environment*, **625**: 539-546.
- Zhong, Z., Chen, Z., Xu, Y., Ren, C., Yang, G., Han, X. and Feng, Y. 2018. Relationship between Soil Organic Carbon Stocks and Clay Content under Different Climatic Conditions in Central China. *Forests*, **9**(10): 598.
- Zhou, W., Han, G., Liu, M. and Li, X. 2019. Effects of soil pH and texture on soil carbon and nitrogen in soil profiles under different land uses in Mun River Basin, Northeast Thailand. *PeerJ*, **7**:e7880.
- Zinn, Y.L., Lal, R. and Resck, D.V.S. 2005. Texture and organic carbon relations described by a profile pedotransfer function for Brazilian Cerrado soils. *Geoderma*, **127**(1-2): 168-173.

Zou, X.M., Ruan, H.H., Fu, Y., Yang, X.D. and Sha, L.Q. 2005. Estimating soil labile organic carbon and potential turnover rates using a sequential fumigation-incubation procedure. *Soil Biology & Biochemistry*, **37**: 1923-1928.

Sher-e-Kashmir
University of Agricultural Sciences & Technology of Kashmir
Faculty of Agriculture, Division of Soil Science and Agricultural
Chemistry, Wadura Campus Sopore-193201

Certificate

This is to certify that all the modifications/corrections as suggested by External Examiner during evaluation and viva-voce examination in the manuscript entitled, **“Functional Soil Organic Carbon Pools as Affected by Different Land Use Types in a Sub Mountainous Area of North Kashmir”** submitted by **Mr. Shamal Shasang Kumar (Regd. No. MSA/2019/1256)** have been taken care of before final binding of the same.

Dr. Shakeel Ahmad Mir
Major Advisor