IMPACT OF LAND USE SYSTEM AND SEASONAL VARIATIONS ON AGGREGATE ASSOCIATED SOIL CARBON IN OUTER HIMALAYAS

By

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SOIL SCIENCE AND AGRICULTURE CHEMISTRY

Division of Soil Science and Agriculture Chemistry

Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu
Main Campus, Chatha, Jammu-180009

2021

CERTIFICATE-I

This is to certify that the thesis entitled **"Impact of Land Use System and Seasonal Variations on Aggregate Associated Soil Carbon in Outer Himalayas"** submitted in partial fulfillment of the requirements for the degree of **Master of Science in Agriculture (Soil Science and Agriculture Chemistry)** to the Faculty of Agriculture, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, is original work and has similarities with published work not more than minor similarities as per UGC norms of 2018 adopted by the university. Further the level of minor similarities has been declared after checking the manuscript with Urkund software provided by the University.

This work has been carried out by **Ms. Japneet Kour Kukal**, Registration No. **J-19-M-689,** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma. It is further certified that help and assistance received during the course of thesis investigation have been duly acknowledged.

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ABSTRACT

Title of the Thesis	:	**IMPACT OF LAND USE SYSTEM AND SEASONAL VARIATIONS ON AGGREGATE ASSOCIATED SOIL CARBON IN OUTER HIMALAYAS**
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Abstract

An investigation was carried out to study the impact of land use system and seasonal variations on aggregate associated soil carbon in outer Himalayas. The soil samples were collected in *Kharif* and *Rabi* season at five different depths. The mean value of total organic carbon was highest in forest land (26.03 g kg^{-1}) and lowest in barren land (12.55 g kg^{-1}). *Rabi* season showed higher value of total organic carbon (18.19 g kg^{-1}) than *Kharif* season (17.39 g kg^{-1}). The mean value of soil oxidizable organic carbon was highest in forest land (4.82 g kg^{-1}) and was lowest in barren land (2.96 g kg^{-1}). Soil oxidizable organic carbon was lowest in *Rabi* season (3.69 g kg^{-1}) and highest in *Kharif* season (3.89 g kg^{-1}). The value of aggregate associated organic carbon was highest in forest land (6.36 g kg^{-1}) and was lowest in barren land (5.00 g kg^{-1}). The *Rabi* season showed greater values of aggregate associated organic carbon (5.98 g kg^{-1}) than *Kharif* season (5.40 g kg^{-1}).The value of hot water-soluble carbon was highest in forest land (0.46 g kg^{-1}) and was lowest in barren land (0.18 g kg^{-1}). The *Kharif* season had higher values of hot water-soluble carbon (0.35 g kg^{-1}) than the *Rabi* season (0.27 g kg^{-1}). The mean value of particulate organic carbon was highest in forest land (4.33 g kg^{-1}) and was lowest in barren land (3.00 g kg^{-1}). The *Rabi* season had higher values of particulate organic carbon (3.63 g kg^{-1}) when compared to *Kharif* season (2.98 g kg^{-1}). The microbial biomass carbon was highest in forest land (76.75 mg kg^{-1}) and lowest in barren land (52.85 mg kg^{-1}). The microbial biomass carbon was lowest in *Rabi* season (64.53 mg kg^{-1}) and was highest in *Kharif* season (66.80 mg kg^{-1}). All carbon pools showed the highest values in the surface layers (0-5 and 5-15) cm and lowest in sub-surface layers (60-100) cm.

Keywords: Land use systems, seasonal variation, Himalayas, Shiwalik, aggregate associated carbon, carbon pools

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Signature of Major Advisor

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LIST OF ABBREVIATIONS

’	Minutes
’’	Seconds
-	Minus
%	Per cent
°	Degree
+	Plus
<	Less than
>	Greater than
≤	Less than or equal to
α	Alpha
@	At the rate
$\mu g\ g^{-1}$	Micro gram per gram
µm	Micrometer
C	Carbon
°C	Degree Celsius
LSD	Least Significant Difference
CEC	Cation Exchange Capacity
cm	Centimeter
$dS\ cm^{-1}$	Deci siemens per centimeter
$dS\ m^{-1}$	Deci siemens per meter
et al.	And co-workers/ and others
g	Grams
$g\ kg^{-1}$	Grams per kilogram
H^+	Hydrogen ions

i.e.,	*Id est*, that is
K	Potassium
km	Kilometer
m	Meter
M	Molar
Mg ha^{-1}	Megagram per hectare
mg kg^{-1}	Milligram per kilogram
Mg m^{-3}	Megagram per cubic meter
ml	Millilitre
mm	Millimeter
mmol ml^{-1}	Millimole per millilitre
N	Nitrogen
NO_3^-N	Nitrate nitrogen
OC	Organic Carbon
OM	Organic Matter
p	Probability
P	Phosphorus
Pg	Peta gram
rpm	Revolutions per minute
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
t ha^{-1}	Tonnes per hectare
Tg	Teragram
viz.	Videlicet/ which is
μS cm^{-1}	Micro siemens per centimetre

Chapter-1

Introduction

Chapter-1

Introduction

Soil is a valuable natural resource because it allows food, fiber, and forage to be produced. The United Nations' Food and Agriculture Organization (FAO), designated 2015 as the international year of soils, honoring the life-giving soil beneath our feet. Soil is essential to the future of the planet, and how we use it will help us combat climate change. Anthropogenic activities such as inadequate soil conservation, removal of organic matter from land without replacing it with crop cover, widespread tillage, soil erosion, atmospheric contamination and desertification, on the other hand, have resulted in soil loss and deterioration of soil quality. As a result, long-term investment in its protection is essential, as it renews slowly– producing three centimeters of topsoil takes around 1,000 years. Soil quality is critical for a safe food production. Another significant factor is that the soil contributes to climate change mitigation by sustaining or increasing soil organic carbon (SOC).

Carbon (C) is an essential component of life on earth, and it can be found in all living things. It is present in plants and animals, organic matter in soil, geological layers, carbon dioxide (CO_2) in the atmosphere, and dissolved in sea water. Soils store more C than the atmosphere and terrestrial plants put together. SOC is an important soil health indicator because it helps in food production, climate change mitigation and adaptation, and achieving sustainable development goals. SOC also enhances soil structural stability by encouraging aggregate formation, which, in combination with porosity, ensures adequate aeration and water infiltration for plant development. Concerns about the CO_2 levels in the atmosphere have prompted a greater public understanding and research focus on the global C cycle. In the global C cycle, the pedosphere plays a significant role (Lal, 1997). Soil C dynamics is critical for production system sustainability while also contributing significantly to global C cycling (Chen *et al.* 2004). C is found in biomass and soil organic matter (SOM) as inseparable elements. In addition, the soil is the largest source of organic C on the planet (Batjes, 1996). Not only in terms of soil fertility, but also as a C sink, SOC is important. It improves all soil properties including nutrient supply and moisture preservation, which boosts land productivity (Van Keulen, 2001). The SOC is a key factor in regulating other soil characteristics, which are then responsible for the long-term preservation of soil quality (Gregory *et al.* 2009 and Hazarika *et al.* 2014). SOC is more than just an inert C store; it also affects the physical, chemical, and biological properties of the soil, all of which have a significant impact on agriculture's long-term viability (Dexter *et al.* 2008). Its deposition in SOM aids in the mitigation of global climate change while also improving the livelihood of resource-scarce farmers.

There are two types of carbon in soil: inorganic and organic. Soil inorganic carbon is made up of mineral types of C that are formed either by weathering of parent material or by soil minerals reacting with atmospheric CO_2. SOC, on the other hand, is the product of root biomass, litterfall and soil fauna present as SOM more specifically called as soil humus. It contains both readily available C in the form of fresh plant remains and relatively inert C in plant-derived materials. In the top 1 m of soil depth, estimates of SOC storage range from 1,200 to 1,600 Pg, while the inorganic portion amounts to 695-930 Pg down to the same depth (Sombroek *et al.* 1993; Batjes, 1996). Organic soils are described as those that contain between 12 and 18 per cent organic C. The dynamics of SOC is critical to the long-term viability of agricultural systems (Chen *et al.* 2004). Organic matter has become a primary indicator of soil quality, with its quantity and composition having a direct effect on soil processes. Organic matter dynamics, according to (Post and Kwon, 2000) determine whether C is sequestered in the soil or lost to the atmosphere. The physical and chemical stability of SOC is used to separate it into various pools:- I) Fast pool (labile or active pool) - decomposition results in a large proportion of the initial biomass being lost in 1–2 years after adding fresh organic C to the soil. II) Intermediate pool - organic C that has been partially stabilized on mineral surfaces and/or protected within aggregates by microbes, with turnover periods ranging from 10 to 100 years and III) Slow pool (refractory or stable pool) - highly stabilized SOC that enters a very slow turnover cycle of 100 to >1000 years.

Different land use systems influenced the dynamics of soil C. The effect of land use on soil C is the most influential among the numerous factors such as land use, altitudinal variations and agro-physical variables (Choudhury *et al.* 2016). Ciais *et al.* 1995 and Sellers *et al.* 1997 found that this had a significant impact on the global C cycle, affecting C storage and fluxes (Bolstad and Vose, 2005). Most of the impact has been negative, resulting in a decline in soil C (Li *et al.* 2007). The rate at which C is lost to the atmosphere, on the other hand, is determined by the type of agricultural system used (Buyanovsky and Wagner, 1998). Anthropogenic activities have systematically removed forest cover for construction purposes, with land conversion to agricultural use being a common practice. The grass lands of world viz: Steppe, Pustaz, Pampas etc are converted for intensive agriculture cultivation. This is an example how human intervention are changing the planet landscape. Land use practices can conserve, sequester, or release C into the environment, either directly or indirectly. Changes in land use or farming practices may influence SOM (Howard *et al.* 1998). Since it influences the amount and quality of litter input, litter decomposition rates, and organic matter stabilization processes in soils, the type of land use system is an important factor in controlling SOM levels (Romkens *et al.* 1999; Six *et al.* 1999, 2002a). The amount and rate of SOM losses are influenced by changes in land use and management practices (Guggenberger *et al.* 1994, 1995). It is usually observed that SOC accumulation was higher in land management with less soil disturbance than in land management with more soil disturbance. Land use change can have a major impact on soil C concentration (Tate, 1987), which has long-term implications for soil fertility and ecosystem sustainability (Bouwman, 1990).

Soil C depletion is commonly observed because of land intensification and land use transition from natural environment to cultivated ecosystem. Vegetation production on abandoned agricultural land, on the other hand, improves C sequestration. Cultivation improves microbial decomposition of organic C in general. Land use and land use transitions, in addition to soil depth, influence SOC. Because of the obvious variations in root architecture and density, the process of C sequestration in grassland and forest soils, for example, is different (Six *et al.* 2000). Appropriate land use and climate smart soil management will result in an increase in SOC, improved physical and biochemical soil quality, and a partial reduction in CO_2 levels in the atmosphere (Lal and Bruce, 1999). Afforestation is also the land use transition that accounts for the smallest portion of the lost C sink and offers a possible short-term mitigation solution for reducing CO_2 emissions (Vitousek, 1991; Moffat, 1997). Because of their extensive deep root systems, forest trees aid in the transition of SOC into the deeper soil profile, while grasses have a finer but denser root mass, which favors smaller but stable aggregates in which C may have stabilized in the shallow layer of surface soils. SOC confinement in deeper layers of forest subsoil is important for long-term C sequestration because it is less susceptible to changes caused by human manipulation and has a longer turnover time. Significant stable SOC reservoirs, on the other hand, could be stored at greater depths (Meersmans *et al.* 2009). While root C contributions to the deeper soil SOC pools are limited in comparison to above-ground biomass, it is actively exchanging with atmospheric C and may be a significant contributor to total soil CO_2 efflux. As a result, relying solely on surface soil C to produce an efficient ecosystem C budget would be inaccurate. Cultivation, on the other hand, causes a major reduction in SOC and soil structural strength (Eynard *et al.* 2004). Furthermore, degraded lands may produce a different image in the deeper soil layers than in the surface soils, where much of the SOC has been lost by runoff water, while the SOC buried deep in the soil may have avoided loss. A loss of SOC due to soil erosion and incompatible land use change degrades the soil ecosystem and environmental quality (Lal, 2002). Land use change has led to soil depletion and improvements in the quantity and nature of SOC, resulting in increased C emissions to the atmosphere (Watson *et al.* 2002; Ogle *et al.* 2005). Soil erosion can be exacerbated by a few poorly managed land use schemes, while a cover crop and leguminous species-based land use system can reduce soil and nutrient loss. Soil erosion caused by improper land use system changes is the leading cause of soil health degradation in many parts of the world, including India.

Aggregate stability of different land use systems may also be influenced by seasonal variation. Different seasons, temperature, rainfall, and moisture regimes all have a major impact on aggregate stability. Seasonal variations had a significant impact on SOC material, according to previous studies (Wuest, 2014; Liu *et al.* 2015). However, changes in total SOC normally happen gradually over time. Smaller, faster changes in soil C due to seasonal inputs of plant residues, roots, and exudates, or decomposition of such inputs, could obscure these long-term trends. In such cases, land use may have a significant effect on soil C storage. Soil labile C pools are strong measures of small changes in organic C in the soil (Xia *et al.* 2010). While labile C pools account for a small percentage of total C, they play a critical role in soil health by influencing nutrient availability and microbial transformations (Haubensak *et al.* 2002). As compared to recalcitrant fractions, it has a faster turnover rate. Understanding and awareness of labile C pools, as well as SOC stocks, is therefore critical in assessing an ecosystem's long-term viability. Increased rates of SOM mineralization have resulted in poor soil quality due to agricultural intensification. Land use changes are important to feed the world's increasing population, they also have a negative impact on soil health. Deforestation, incompatible land use changes, and soil fertility decline are all contributing to severe soil erosion in the Shiwalik area, which is in the outer Himalayas and stretches for 2400 kilometers across northwestern India. In northwestern India, SOC and aggregate stability have been recorded to vary as a feature of land use and have been declining due to a lack of proper soil management practices and various land use systems.

Agriculture practices and land use system should be designed in such a way that not only soil aggregate stability can be enhanced, but also there must be stability of C pools and stocks in soil. Keeping in view of above stated important aspects of land use system, C stocks and pools, aggregate stability and importance of seasonal variations a study with following objectives was proposed:

1. To study the effects of different land-use systems on aggregate associated soil carbon pools and carbon stocks.

2. To study the effect of seasonal variations on aggregate associated soil carbon pools and carbon stocks.

Chapter-2

Review of Literature

Chapter-3

Chapter-2

Review of Literature

The aggregation and soil carbon (C) sequestration processes necessitates a knowledge of proportionate fluctuations in soil organic carbon (SOC) and its fractions under different land uses. The dynamics of terrestrial C pools are influenced by the nature and type of land use systems. Similarly, understanding how soil C reacts to seasonal changes is crucial to agriculture's long-term viability. SOC has been overlooked for a long time because it was thought to be dead biomass. Soil contains a lot of active C, which is important for the global C cycle (Prentice *et al.* 2003). In determining the feasibility of a long-term ecosystem, knowledge and awareness of labile C pools, as well as SOC stocks, is essential. However, little is known about the Himalayan foothill's labile C pools and organic C storage. In this chapter, a quick review of the existing current research “Impact of land use system and seasonal variations on aggregate associated soil carbon in the outer Himalayas” is presented under the following headings:

2.1 Soil Organic Carbon and Soil Properties in Relation to Land Use Systems.

2.2 Soil Organic Carbon and Soil Properties in Relation to Seasonal Variations.

2.1 Soil Organic Carbon and Soil Properties in Relation to Land Use Systems.

Deforestation and conversion to intensive land uses such as agriculture resulted in a drop in soil organic matter (SOM) in the tropics (Van Noordwijk *et al.* 1997; Rhoades *et al.* 2000). The C stock in the soil profile is influenced by land use patterns. When a natural ecosystem is converted to cultivated land, the upper surface of the soil loses a lot of C. In a soil profile, the sequestration capacity of grassland and forest are very different. The transfer of C into the deeper soil layers is favoured by forest trees. Because there is more above and below ground biomass in forest soils, the overall C stock is higher. However, most research focus on the top few cm of soils, even though significant amounts of C may exist in deeper levels, particularly in forest soils that are protected. Thus, a thorough understanding of the dynamics of the C stock in relation to land use and land management strategies is essential for identifying C sequestration pathways in soils and maintaining SOC at a level that is necessary for maintaining soil fertility and coping with the impact of global warming.

In their study, Potter *et al.* (1999) studied the amount of SOC degraded by agricultural operations and the rate of C sequestration in soils after grass restoration for various time periods. SOC levels at the surface (0-5 cm) decreased from 4.44% on the prairie to 1.53-1.88% in agricultural areas. In the top 120 cm, the SOC mass of agricultural soil was 25-43% lower than that of native prairie areas. There is a linear link between the durations of time intervals from 6 to 60 years.

Scott *et al.* (1999) used national soil C databases and paired site studies in New Zealand to quantify variations in soil C content between pasture and exotic pine forest plantations dominated by *P. radiata* (D. Don) and to quantify changes in soil C with pasture to plantation forest conversion. Their findings revealed that overall, mineral soil C up to 0.10 m depth was 20–40% lower under pine for all soil types ($p < 0.01$), except for soils with high clay activity (HCA), where no difference was seen. In the 0.1–0.3 m layer, similar trends were seen. Furthermore, in side-by-side comparisons, mineral soil C up to 0.1 m depth was 17–40% lower under pine than pasture. The sole non-significant difference ($p=0.08$) was found at a site with HCA soil.

Ghani *et al.* (2003) investigated the impact of long-term pastoral management practises such as fertilisation and grazing intensity on several soil biological and biochemical properties, such as hot water extractable carbon (HWC), water-soluble carbon (WSC), hot water extractable total carbohydrates, microbial biomass carbon (MBC), nitrogen (N), and mineralizable nitrogen. Changes in SOM content are caused by changes in land use or agricultural management methods. However, because these changes are generally gradual, they are difficult to detect in the short or medium term against a larger background (Ghani *et al.* 1996; Bolinder *et al.* 1999). Fischer (1993) discovered that HWC levels in soils were closely associated with CO_2 levels, implying that a portion of the HWC must be readily available for microbial use. The hot-water extraction methods can be used to determine the pool of organic N that is readily available (Keeney and Bremner, 1966).

As a result of the change of tropical forest to pasture and sugarcane fields, Osher *et al.* (2003) investigated organic C storage and turnover in volcanic ash-based soils (Andisols). Total organic carbon (TOC) stored in soils varied as a function of management, with pasture soils showing net C gain and sugarcane soils showing net C loss, according to their findings. The amount of C stored in soils appears to be controlled by the concentration of Fe/Al oxides (soil minerals that bind with organic matter to form oxide-humus complexes), as well as the differences in the depth and magnitude of C storage changes that occur with each type of land use change. Sugarcane land usage appears to cause Fe/Al oxide-humus complexes to dissociate and oxide-associated organic materials to disappear from the profile. The translocation of Fe/Al oxide-humus complexes to deeper layers in pastures results in higher profile C storage and a longer apparent turnover period of C stored below 50 cm depth. C losses from the soil appear to occur via downward transportation, either as colloids or in solution, in this high-precipitation zone, in addition to the commonly assumed pathway of flux to the atmosphere as CO_2.

Conant *et al.* (2004) explored how soil C and N cycling is affected by the conversion of forests and cultivated to grazing fields. To understand the mechanisms by which soil C is sequestered or lost, their investigation revealed that total soil C is less reliable than soil physicochemical C components. Total soil C did not change considerably over time after forest conversion, whereas coarse (250-2000 m) particle organic matter C increased by a factor of 6 shortly after conversion.

In Ethiopia's southern highlands, Lemenih and Itanna (2004) reported soil C stock and turnover in five vegetation types after deforestation and conversion of each vegetation type to arable fields. Farmland soils had a tremendous impact on Ethiopia's southern highlands. Soil C stock was substantially lower in farmed soils than in natural vegetation. The loss of C from the upper 0-10 cm soil depth because of conversion of natural vegetation to farming was greatest in humid climate forests and lowest in semiarid climate forests. In the sub-humid to humid eco-climatic zone, soil C losses averaged 2.0 to 3.0% per year, while in the semiarid lowland or cool sub-afroalpine eco-climatic zones, losses averaged 0.5-1.0% per year.

Shrestha *et al.* (2004) investigated the amount and distribution of SOC stock within the soil profile in a mid-hill watershed in Western Nepal under dominant land use types (khet, bari, forest, and grazing land). Grazing land had the greatest SOC stock in the surface soil, followed by Bari, forest, and Khet. Bari lands had the highest SOC stock in depths below 20 cm, due to C translocation in the form of dissolved organic carbon (DOC), soil faunal activity (particularly earthworms), and the effects of deep rooting crops. In grazing area, there was a 35% decrease in SOC stock from the first to the second layer. The topsoil had a much higher SOC stock than the other depths within the profile of the same land use. The total SOC stock was 82% in Bari soil and 18% in Kheti soil (1 m depth). Forests accounted for 83% of total SOC stocks in natural vegetation areas, compared to 17% in grazing land. The conversion of forest, pasture, and Bari to khet, as well as the conversion of grazing land to other land uses, may contribute to SOC losses from the watershed over time, according to this study.

The impacts of land use (forest, grassland, and agricultural areas) and management practises (crop rotation, fertilisation, and cover crops) on SOC fractions in a watershed were investigated by Yang *et al.* (2004). In comparison to grassland and agricultural soils, forest soils have a higher concentration of SOC. When grain was rotated with grass, the SOC was substantially higher than when grain was used alone.

Macros and Juan (2006) discovered that cultivation reduces the levels of various SOC fractions such as particulate organic matter, carbohydrate, and humic acid. Long-term cultivation promotes an increase in micro-aggregates, which leads to a full loss of particulate organic carbon (POC) due to the collapse of macro-aggregates, resulting in fast oxidation and microbial attack. There was some evidence that the levels of POC and hot water extractable carbohydrate could be useful indicators of soil structure degradation due to the extensive agriculture practices. Although it is commonly known that humic substances are chemically and structurally more stable than non-humic substances, the results revealed a significant drop in humic substances when cultivation was continued.

Zhang *et al.* (2006) analysed soil profiles to evaluate land use effects on the distribution of labile fraction organic C. The impacts of land use on TOC and labile fraction organic C were mostly detected in the topsoil (0-20 cm) of upland forests, with abandoned cultivated and cultivated soils showing a significant drop in labile fraction organic C content as soil depth increased. In the *Deyeuxia angustifolia* wetland, but not in the other land use types, the percentage of DOC, HWC and MBC to TOC was found to be maximum at a depth of 20 to 30 cm, then fell with increasing soil depth.

Tan *et al.* (2007) studied how land use and management practices influenced the distribution of light and heavy SOC fractions. Their findings revealed that the C concentrations of light fractions in all aggregate classes were considerably greater in soils under forests than in soils under conventional tillage. Both heavy and light fractions were proposed in this investigation. The destruction of bigger aggregates by mechanical disruption and subsequent oxidation of protected light fractions is attributable to the lower concentration of light fractions in macro-aggregates in conventional tillage compared to no-tillage.

Abera and Belachew (2011) studied the impacts of various land uses on SOC. They discovered that SOC responds to changes in land usage. The maximum SOC (12.95%) was found in natural forests, while the lowest (2.56%) was found in cultivated areas, and they concluded that the lower SOC content in cultivated soils could be due to lower organic matter inputs and frequent tillage, both of which stimulate organic matter oxidation. In all land use systems, SOC decreased with increasing soil depth.

At four different soil depths, Koul *et al.* (2011) compared the C sequestration potentials of seven different land uses: fallow land, agriculture field, tea garden, agri-horticulture, agro-forestry system, *Dalbergia sissoo* plantation, *Terminalia arjuna* plantation, and natural forest of *Shorea robusta* (0-10, 10-20, 20-30, and 30-40 cm). The natural forest of *Shorea robusta* had the greatest mean SOC content of all the land uses studied and the agriculture field had the lowest SOC content. Their research also discovered that the organic C content of the soil varied depending on its depth. Because of the abundance of litter on the uppermost soil layer, it had the highest SOC. Due to the extreme presence of vegetation, natural forests have always had the highest SOC content due to the constant creation and breakdown of litter. Agricultural fields with solely herbal flora, the bulk of which is eliminated by harvesting, contribute the least amount of crop residues to soil, resulting in the soil having the lowest SOC content. This is since SOC fluctuates depending on the amount and kind of vegetation on the ground.

Singh and Ghoshal (2011) in their study, analysed the effects of land use change in the dry tropics, including forest, degraded forest, Jatropha plantation, and agroecosystems, as well as the capacity of soil C sequestration in terms of SOC concentration. They reported that changes in land use may influence many ecological processes, resulting in changes in soil physical and chemical properties (Chen *et al.* 2010). The highest SOC concentration in natural forest identified in this study could be due to the frequent accumulation of plant litter, both above and below ground plant components, as well as restricted disturbances such as grazing, logging, and other activities (Steibiss *et al.* 2008).

Saha *et al.* (2012) conducted a study in a mixed vegetation cover watershed with forest, grass, cultivated, and eroded lands to assess land-use effects on profile SOC distribution and storage and to quantify SOC fractions in water-stable aggregates (WSA) and bulk soils for the investigation of SOC fractions and aggregate stability in the degraded Shiwaliks of the lower Himalayas. It was found that SOC content was higher in larger water-stable macro-aggregates (WSA > 2 mm) than in smaller water-stable micro-aggregates (WSA < 0.25 mm). Based on their findings they concluded that SOC contained in micro-aggregates was shown to be better protected and less sensitive to changes in land use and the water stability of aggregates could explain a lot of the variation in the SOC stock. The amount of POC in aggregates was also found to be higher than in bulk soils. Furthermore, their results concluded that the POC component of the soil C pool tends to concentrate under ecosystems with sufficient C inputs and embedded within soil aggregates, providing protection against C loss.

Gupta *et al.* (2014) investigated soil SOC in various land uses such as forests, block plantations, horticulture, agro-forestry, and agriculture in the districts of Faridabad, Gurgaon, Mahendragarh, Mewat, Palwal, and Rewari in Haryana's southern area and showed that forests had the highest SOC stock (37.61 t ha^{-1}), followed by horticulture (27.26 t ha^{-1}), plantation (27.96 t ha^{-1}) and agriculture (17.72 t ha^{-1}).

Li *et al.* (2014a) showed through their study that SOC and total nitogen (TN) storage were strongly influenced by land-use and cover type in the semiarid Horqin Sandy Land in northern China. SOC and TN storage were in the sequence of productive farmland on former grassland > grassland > afforested dunes > unproductive cropland on former dunes > sand dunes under various land-use and cover types, although soil bulk density (BD) was in the reverse pattern. According to their findings, converting desertified sandy area to farmland, afforested dunes and grassland has a great potential for sequestering C and N in the soil. Soil SOC and TN sequestration driven by land-use and cover-type changes could compensate for much of the C and N losses that occurred throughout the Horqin Sandy Land's desertification process over the last century.

Barančíková *et al.* (2016) concluded that land use change is a determining factor of SOC concentration and quality. It was also discovered that after land conversion, grasslands have higher SOC content than arable land. In grassland soils, increased plant and root residual input stabilises SOC stock in the topsoil.

Bessah *et al.* (2016) carried out a study to observe how savanna woodland, farmland and tree plantations affected Soil Organic Carbon Stocks (SOCS) in depths of 0–10 cm, 10–20 cm and 20–30 cm and to see how SOC varies with depth. With increasing depth, SOCS decreased for all land use/cover types. They also discovered that at all depths, savanna woodland had the highest SOCS, while cashew plantations had the lowest. In comparison to croplands, soils beneath plantations were less disturbed when crops were fully grown, according to observations made during sampling. The maximum cover or litter on topsoil was found in fully established mango and cashew orchards, with less direct sunlight heating the soil. Due to the frequent bush fires in the municipality, this was not the case for teak plantations.

Islam *et al.* (2016) investigated the impact of diverse land uses and soil management strategies on SOC in different agricultural soils in the Mymensingh district in northern Bangladesh, including single, double, and triple cropped, agro-forestry, fallow land, and grassland land uses. Their findings revealed that among all land use patterns, agro-forestry had the greatest SOC, and fallow land had the lowest. In addition, across all land use patterns, TOC declined as soil depth increased.

Guo *et al.* (2018) investigated SOC vertical variations and labile pools. In a pure ginkgo planting system, a pure wheat field, a pure metasequoia seedling system, a ginkgo and wheat agro-forestry system, and a ginkgo and metasequoia seedling agro-forestry system. The vertical and seasonal distribution of SOC and labile C pools were strongly influenced by the planting system, according to their findings. The ginkgo and wheat planting systems had a much greater SOC content throughout the year than the other four. Furthermore, the highest changes in SOC were seen in surface soil, with significant variability being found in deeper soil layers. Their findings revealed that agro-forestry systems result in significant increases in soil C sinks; the ginkgo and wheat system produced the best results.

Kumar *et al.* (2018) conducted research in sub-montane areas of India's north-western Himalayas to analyse the impact of SOC stock under various land use systems. Soil samples were taken to a depth of 1 m from the five land use systems: forest, horticulture, agricultural, pasture, and degraded land. They discovered that on the surface soil (0-15 cm), the soil BD was highest in degraded and lowest in pasture and forest land use systems, respectively. Surface soil layer BD (0-15 cm) was found to be much lower than subsurface soil layer BD (15-30 cm, 30-60 cm and 60-100 cm) and concluded that with increasing soil depth, the BD of the soil rose. The pasture had the highest concentration in the surface soil and the least in land-use systems that have been degraded. Forest land had the largest SOC stock in 0-100 cm layer (53.38 Mg ha^{-1}), while agricultural had the lowest (42.09 Mg ha^{-1}). The results showed that Organic C in the soil concentrations fell as the depth of the soil was increased. According to their findings, forest systems are a better alternative for increasing SOC stocks in submontane environments.

The results of Sainepo *et al*. (2018) investigation revealed that the mean values of TOC, POC, and mineral organic carbon (MOC) differ significantly amongst land use types. Shrublands have a much higher TOC (22.26 g kg^{-1}) than grasslands (10.29 g kg^{-1}) or barren lands (7.56 g kg^{-1}). In addition, they have much greater POC (7.79 g kg^{-1}) and MOC (10.04 g kg^{-1}) than all other land use forms. Agricultural fields have a higher carbon management index (CMI) than grasslands (53% vs. 41% for shrublands), implying that grasslands are suffering from overgrazing. They concluded that different land use types have an impact on SOC pools, and therefore on the CMI, and that the CMI might be utilised as an indicator for soil deterioration or improvement in response to changes in land use and land cover.

Yang *et al.* (2018) analysed data from 1973 to 2008 regarding land use changes in the Shiyang River Basin. Their results revealed that land use change had a major influence on the soil C budget, with soil C storage decreasing by 3.89 Tg between 1973 and 2012. Grassland stored the most C in the soil (114.34 Mg ha^{-1}), while woods (58.53 Mg ha^{-1}), farmland (26.75 Mg ha^{-1}), and unoccupied land (13.47 Mg ha^{-1}) all stored significantly less. They discovered that soil C storage significantly diminished as grasslands were converted to farmland and woods were converted into grassland, indicating that actions should be taken to reverse this trend to boost soil productivity.

Under tropical conditions, Almeida *et al.* (2019) examined the impact of land-uses on C stocks and losses. Their research aimed to find a possible alternative to recover degraded areas with low levels of recalcitrant C. Their data revealed that labile and recalcitrant C pools were most strongly associated to the soil surface, as seen by higher labile-C and MBC concentrations in the surface layer compared to the deeper layer. The increased plant biomass output and related organic material deposition produced the results obtained. Their findings also concluded that the absence of human intervention and the consistent maintenance of plant residues resulted in the highest values for resistant C pool accumulation in forested soil due to increased environmental stability. Soil disturbance appears to break the aggregation, exposing the C and making it more accessible to microbes.

According to Bhowmik *et al.* (2019), aggregate-associated organic carbon (AAOC) served as a stronger indicator of soil micro floral population dynamics in these distinct land use systems than enzymatic activity, especially in eroded areas that had deposited organic matter debris. Unlike the agro-forestry land use systems that demonstrated the ability to augment AAOC, thus protecting it from erosion by agents such as air or water and improving soil health, the agricultural land use system evaluated in this study used extensive soil disturbance through tillage and a lack of cover cropping, which may have resulted in soil health decline. Overall, their research revealed that biological soil health indicators are useful tools for determining ecosystem sustainability and biogeochemical nutrient cycling in various land use management systems.

In the foothill Himalayas, Hussain *et al.* (2019) discovered that forest soils had the highest TOC, followed by horticulture soils. In deteriorated and agricultural soils, the least was found. In woods and orchards, higher organic inputs through litter fall, as well as deeper and well-established root systems, lead to high soil SOC levels.

2.2.1 Soil Organic Carbon and Soil Properties in Relation to Seasonal Variations.

Dormaar *et al.* (1984) studied seasonal changes in C content, dehydrogenase, phosphatase and urease activities in mixed prairie and fescue-grassland. Even though the phosphatase activities differed between the two locations, the seasonal trends were consistent, with potentially higher activities in the winter than in the summer.

Garcia-Olivia *et al*. (2003) showed the impact of seasonal rains on SOC dynamics in a tropical deciduous forest ecosystem in Western Mexico through their study. An accumulation of labile nutrient forms developed at the end of the wet season and was sustained during the dry season. During the first rains of the rainy season, this accumulation enhances the microbial activity. The dry season litter samples showed more C and N mineralization than the rainy season litter samples. Similarly, the C mineralization in January soil samples was higher than in October soil samples. These findings imply that the seasonality of precipitation has a significant impact on the quality of C, which in turn regulates microbial activity. Seasonality has an impact on nutrient redistribution within soil aggregate fractions as well. Chemical differences between seasons indicate that SOM linked with macro-aggregates is the primary source of energy for microbial activity at the start of the rainy season, while micro-aggregates preserve labile nutrient forms throughout the growing season.

Boerner *et al.* (2005) studied the acid phosphatase, α-glucosidase, phenol oxidase, chitinase, and L-glutaminase activity in Ultisols of burned and unburned areas in Quercus-dominated forests in Ohio, USA. Variations in SOC content were also investigated. The low-intensity, prescribed fires were held in April 2001, with temperatures averaging 160 to 240˚C, 10 cm above the forest floor. Two years after the fire, sampling was done during the span of a six-month growing season (May–October) in 2003. Their findings revealed that in May, early June and July, organic C content did not change significantly between control and burned sample plots, nor did it vary considerably over the growth season in the control sample plots. Organic C level in the burned plots, on the other hand, increased by 20 to 40% from July to September and organic C content was considerably higher in the burned region than in the control in late June, August, September, and early October. However seasonal impacts on the activities of all the enzymes whose activity they assessed were not seen.

Sugihara *et al.* (2010) studied seasonal variations in MBC and microbial biomass nitrogen (MBN), as well as microbial activity (as qCO_2) in both clayey (38%) and sandy (4%) croplands in Tanzania for 16 months in relation to several factors relating to soil moisture and nutrients under different land management practises (plant residue application, fertiliser application). In all treatment plots at both of their test sites, MBC and MBN tended to decline during the rainy season, whereas they tended to increase and remain at high levels during the dry season.

Wuest (2014) found that soil organic C can fluctuate significantly over the course of a year, with seasonal patterns that varied depending on soil management. These changes can be big enough to accidentally obfuscate precise C sequestration estimates over years or decades. Accurate estimates of organic C changes over time will necessitate either a thorough understanding of seasonal fluctuation patterns in each ecosystem or sampling strategies that appropriately average out seasonal variation. Their findings also revealed that while it is possible to reduce seasonal variation by processing soil samples to remove the light fraction, particulate organic matter, or another component of SOM, the remaining seasonal component must still be evaluated, as well as whether the removed fractions are or are not important components.

Divya and Belagali (2015) investigated the seasonal variations of physiochemical characteristics of soil with chemical fertiliser residues under various cropping patterns and found the following trend for electrical conductivity (EC): summer (0.52 dS m^{-1}) >

winter (0.48 dS m^{-1}) > rainy season (0.45 dS m^{-1}). Their research also found that the pH value was higher in the rainy season than in the winter and summer.

In the northern Guinea Savanna ecosystem of Nigeria, Olojugba and Fatubarin (2015) investigated the effects of seasons (dry season, beginning of rains, peak of rains and end of rains) on various soil properties, finding that soil pH was higher during the dry season and the beginning of rainy season.

Patel *et al.* (2015) examined soil samples for physico-chemical such as soil texture, BD, porosity, water holding capacity (WHC), moisture content (MC), pH, EC and organic matter in the pre-monsoon, post-monsoon, and summer seasons of 2013-2014. In the North Gujarat zone, soil samples showed no significant differences in mean sand, silt, or clay content during three seasons. Because of the lower rainfall zone, post-monsoon soil samples showed a slight drop in BD. Porosity, WHC and MC all exhibited an increase from pre- to post-monsoon, but a downward trend over the summer. In the pre-monsoon and summer seasons, the pH of the soil was neutral (Pr 6.87 to 7.23), however in the post-monsoon season, it shifted from neutral to alkaline (Po 6.98 to 8.20). In the pre-monsoon, post-monsoon and summer seasons, the maximum values of EC were 1.72, 6.25, and 1.19 dS cm^{-1}, respectively. Their findings also showed that SOM levels vary from 0.21 to 1.83 % in the pre-monsoon, 1.09 to 3.07 % in the post-monsoon, and 1.04 to 1.82 % in the summer.

Salim *et al.* (2015) investigated soil parameters in the Jhilmil Jheel wetland of Uttarakhand across four seasons: autumn, winter, spring, and summer, under various land use regimes, and discovered that soil pH was highest in the summer and lowest in the fall.

Sahu *et al.* (2016) studied seasonal changes in soil EC in Odisha, India, and found that EC was highest during monsoon (250 to 379 $\mu S\ cm^{-1}$), followed by post-monsoon (206 to 218 $\mu S\ cm^{-1}$) and pre-monsoon (76 to 135 $\mu S\ cm^{-1}$). Their findings also revealed that soil pH fluctuated from 6.5 to 8.1 during the pre-monsoon, 6.6 to 7.0 during the monsoon, and 6.8 to 7.9 during the post-monsoon period.

Wang *et al.* (2016) discovered that as temperature rose, the levels of TOC, easily oxidizable carbon (EOC), humic components carbon, and AAOC dropped. The fraction of 2 to 0.25-mm macroaggregates dropped, as did the aggregates' mean weight diameter (MWD). They also discovered that rising temperatures have an adverse effect on SOC content, soil aggregation, and aggregate stability.

Zhang and Dhing (2017) studied the impact of seasons on SOC, TN, and inorganic nitrogen (IN) in five distinct typical *Pinus massoniana* forests in Guizhou Province. The topsoil exhibited more seasonal change than the lower layers. During fall, the SOC and TN contents varied the least among the soil layers, whereas the IN contents had the highest values and ranges. The carbon-to-nitrogen ratio (C/N) did not show a seasonal trend. During fall, C/N was either maximal or minimal depending on the sites, indicating that biological processes in summer soils would have a significant impact.

According to Bargali *et al.* (2018) investigation in Central Himalayan forests, MBC rises in the rainy season and declines in the winters. During the rainy season, higher MBC indicates increased microbial immobilisation of soil nutrients via litter decomposition. Furthermore, higher humidity during the rainy season led to enhanced fungal growth, which increased microbial biomass, whereas lower values in the winter season were due to lower soil microbe activity, which resulted in a slower rate of decomposition in the cold and dry season.

Omer *et al.* (2018) analysed the samples taken at a depth of 0-0.15 m and at several sampling dates throughout the year, including the fall of 2015, winter of 2015/2016, spring of 2016, and summer of 2016 to select the soil quality indicators. Alfalfa (*Medicago sativa*), upland cotton (*Gossypium hirsutum*), and pecan were among the three crop management techniques studied (*Carya illinoinensis*). Their findings revealed that 15 of the 21 soil parameters changed significantly with sampling time within a year, while no consistent trends in variability were seen. Only a few measurements, however, were significantly different from the crop management strategies tested. Summer saw significant increases in wet aggregate stability, MWD, available water capacity, and BD, whereas fall and winter saw significant increases in permanganate oxidizable carbon and SOM, respectively. During the spring, soil quality indicators such as NO_3^-N, K, and P declined dramatically. Their research found that in dry agro-ecosystems, seasonal fluctuation of soil measurements can be significant, with the extent of change depending on the measurement type. To measure changes in soil quality, soil managers in the region must account for this variability. Also, due of the variability that might occur between different sampling dates within a year, sampling during the same period every year is recommended for a consistent interpretation of directional changes in soil quality indicators.

Osobamiro and Adewuyi (2018) investigated how soil reacts to climate change. They examined variations in physicochemical qualities of farm settlement soils and the impact of climatic conditions (temperature, relative humidity, and rainfall) on these properties, as well as the implications for plant growth. Temperature has a substantial negative association with SOC, organic matter, cation exchange capacity (CEC), and % silt, according to their data. Meaning that when the temperature rises due to global warming, the amount of organic matter and CEC in the soil decreases, affecting crop productivity. Increased temperature is anticipated to have a negative impact on soil C allocation, resulting in lower soil SOC levels (Brevik, 2013). It has been reported that a 10°C increase in temperature doubles biochemical reaction rates, which can have a significant impact on soil chemistry. Most chemical reactions are extremely sensitive to alterations in temperature (Elder, 1989).

Yanez-Diaz *et al.* (2019) through their study revealed that the hydraulic conductivity, infiltration capacity, and cumulative infiltration showed significant differences due to seasonal variation. Soil penetration resistance, BD, and total porosity did not alter by seasonal changes.

Agbeshie *et al.* (2020) revealed through their study that the wet season had the largest MBC (281.77 mg kg^{-1}), MBN (109.50 mg kg^{-1}), and microbial biomass quotient (MBQ) (2.31 %) ($p < 0.001$).

Lepcha and Devi (2020) concluded through their study that the physical and chemical properties of the soil vary greatly depending on the season. Their findings revealed that in all the study sites, the rainy season had the highest values of soil properties, followed by summer and winter. MBC showed a strong seasonal difference ($p < 0.001$) in all land-use types, with a peak value in the rainy season (forest - 592.78 µg g^{-}

^{1}; agro-forestry - 499.84 µg g^{-1} and cropland- 365.21 µg g^{-1}) and a low value in the winter season (forest - 338.46 µg g^{-1}; agro-forestry - 320.28 µg g^{-1} and cropland - 265.70 µg g^{-1}).

Mirza and Patil (2020) studied the seasonal fluctuations of physicochemical parameters in the soil of 15 different locations within the Gautala reserve forest. Physicochemical parameters in the soil of the Gautala Reserve Forest were studied over the year 2017-18 at three seasonal intervals, namely rainy, winter and summer. Soil pH, texture, MC, BD, EC, SOC, N, P and K were all analysed. They revealed through their study that during the summer, the pH and SOC levels were low, but during the monsoon, they were high. Also, during the monsoon season, the total amount of available N, P, K as well as EC, WHC, MC were at their highest, while during the summer season, they were at their lowest.

On the Greek island of Lesvos, Evangelou *et al.* (2021) investigated the dynamics of soil microbial biomass carbon (Cmic) and nitrogen (Nmic) in five representative Mediterranean agroecosystems over two years on a seasonal basis. Soil samples were taken from plots that had been managed conventionally according to local practices, including natural woods, olive orchards, wheat cultivations, grassland, with yearly crop rotation. The Cmic and Nmic levels, which were affected by both land use and season, ranged from 86.8 to 565.1 and 14.7 to 101.6 mg kg^{-1} dry soil, respectively. Cmic and Nmic, like all land uses, demonstrated strong land-use dependence with seasonal change. The effects of hot and dry Mediterranean summers on soil microbial activity were indicated by summer minima and fall maxima.

Lalbiakdika *et al.* (2021) studied the impact of seasonal variation on soil chemical characteristics and soil enzyme activity. Soil fertility indicators such as pH, SOC, TN, P, K, and soil enzymes such as dehydrogenase, phosphatase and urease activity were examined in a total of fifteen samples taken from several paddy fields. Pre-planting had the highest pH value (5.79), followed by post-harvest (5.32), and paddy growing season had the lowest (5.08). The low pH during the growing season could be attributed to the increased breakdown of organic matter, which releases acidic components such as hydrogen, manganese, and aluminium to replace bases. The highest levels of SOC and SOM were found during post-harvest (1.41 % and 2.42 %, respectively), followed by growing (1.15 % and 1.98 %), and the lowest levels were found during paddy pre-planting (0.85 % and 1.46 %). P, K, N were found to be highest during the growth season, followed by post-harvest, and lowest during paddy pre-planting. The increased decomposition and application of NPK fertilizers throughout the growth season could be responsible for the high concentration of soil macronutrients. Soil enzyme activity in the study area follows a similar pattern, with the maximum levels occurring during the growing season, followed by post-harvest, and the lowest levels occurring during paddy pre-planting.

Lalmuansangi *et al.* (2021) studied seasonal fluctuations at monthly intervals for the investigation of soil characteristics in Kolasib town for a time span of two years, from November 2016 to October 2018. Six sampling sites were carefully selected, and monthly statistics were generated on a seasonal basis. pH, BD, MC, SOC, N, P, K were all analysed. The goal of this study was to examine the properties of soil in different seasons. The pH value was greater during the pre-monsoon and post-monsoon seasons and lower during the monsoon season, according to their observations. This could be because rainwater, which is acidic in nature, dilutes hydrogen ion concentrations. BD increases during the monsoon season and decreases during the post-monsoon season, possibly due to compaction of soil texture by rainfall. As a result of their analysis, it was also discovered that soil MC was higher during the monsoon period and lower during the pre-monsoon period, owing to an increase in soil humidity induced by rainwater. Carbon concentration was highest during monsoon seasons and lowest during pre-monsoon and post-monsoon seasons, which may be due the dumping location that has more organic C than the control site. The N concentration was found to be higher during the monsoon season and lower during the pre-monsoon season, which could be attributed to leachate that enters the soil via rainwater run-off. The value of available P was discovered to be higher during monsoon season and lower during pre-monsoon season based on their observations. This could be owing to the composting of phosphorus-containing leachate, particularly from household garbage. Exchangeable P was determined to be lower during the pre-monsoon and post-monsoon seasons, and higher during the monsoon season. This could be attributed to an increase in the rate of decomposition by rainwater, which raises humidity and allows leachate from run-off to easily penetrate the soil.

Singh and Kumar (2021) studied the effects of short-term (4 years) winter cover crop implementation on the dynamics of water-extractable fractions, microbial biomass, and enzymatic properties at three different dates corresponding to the three maize-growing seasons of the year (before planting in early spring, after planting in early summer, and during grain filling in early autumn) in a long-term (25 years) study. Seasonal variability altered labile soil microbial characteristics and enzyme activity, which could be attributed to soil moisture and temperature variations between sampling dates, according to their findings. Furthermore, they hypothesised that C residue inputs from rhizodeposition during the growing season, summer tillage, fertilization, and other interactions among weather factors such as snowmelt and freeze–thaw events during the spring could all contribute to relative seasonal variations in the studied soil biochemical attributes.

Wu *et al.* (2021) studied the seasonal patterns of SOC fractions in high-altitude wet meadows. They examined the impact of non-degraded (ND), lightly degraded (LD), moderately degraded (MD), and heavily degraded (HD) vegetation degradation levels on the measured vertical and seasonal changes in SOC and its various fractions. In the autumn, POC and light fraction organic carbon (LFOC) displayed similar vertical and seasonal fluctuations, dipping to their lowest levels. Furthermore, the highest levels of MBC and EOC were found in the summer and the lowest in the winter, while the highest levels DOC were found in the spring and lowest in summer.

Chapter-3

Materials and Methods

Chapter-4

Chapter-3

Materials and Methods

With an aim of achieving the stated objectives for the current study entitled "Impact of land use system and seasonal variations on aggregate associated soil carbon in outer Himalayas," investigations were carried out in various land use systems of lower Shiwalik region of outer Himalayas (Billawar) in *Kharif* and *Rabi* season. Under the following subheads, this chapter describes numerous materials and methods used and ap plied to achieve the objectives of the proposed study.

3.1 General Description of the Study Area

3.2 Meteorological Data Recorded during the Research Programme

3.3 Collection and Preparation of Soil and Aggregate Samples

3.4 Soil Physical Properties

3.5 Soil Carbon Pools

3.6 Initial Soil Properties of the Land Use Systems

3.7 Statistical Analysis

3.1 General Description of the Study Area

3.1.1 Physiographic features

Jammu & Kashmir is part of India's hill and mountain environment, with geographical coordinates 33˚31′11″N and 75˚15′41″E. It is India's second largest union territory by area. The J&K union territory is in India's northwestern corner, with a total size of 42,241 km^2. It is to the north of the Indian states of Himachal Pradesh and Punjab and to the west of Ladakh union territory. Geographically, the union territory is divided into three zones: The *Kandi* belt, comprising of plains of rain-fed areas and Shiwalik range, Pir Panjal range and Himalayas on the western side. The *Kandi* belt, Shiwalik range, plains and Pir Panjal range make up the Jammu division. Jammu's *Kandi* belt, which encompasses the lower Shiwalik region, is also known as the submontane region. In J&K, around 4% of the land is used for agriculture, while 13% is used for forest and horticulture. The remaining land is either left uncultivated or is barren. Forest, agriculture, and grasslands are recognised as land use patterns in Jammu (Kumar *et al.* 2004). The submontane is in a low-altitude zone with an elevation range of less than 1200 meters above mean sea level with a hot, sub-tropical climate. The soil samples were collected from different land use systems viz. rice-wheat, forest land, maize-wheat, and barren land from Billawar (Kathua district) of the *Kandi* Belt. Billawar is amongst the five tehsils of Kathua district i.e., Kathua, Hiranagar, Billawar, Basoli and Bani. The locations selected for the research work in Billawar were Mandli (32˚36′16″N and 75˚30′57″E), Dungara (32˚34′58″N and 75˚30′11″E) and Phinter (32˚34′59″N and 75˚32′31″E). The selected locations for research work are shown in fig. 3.1.

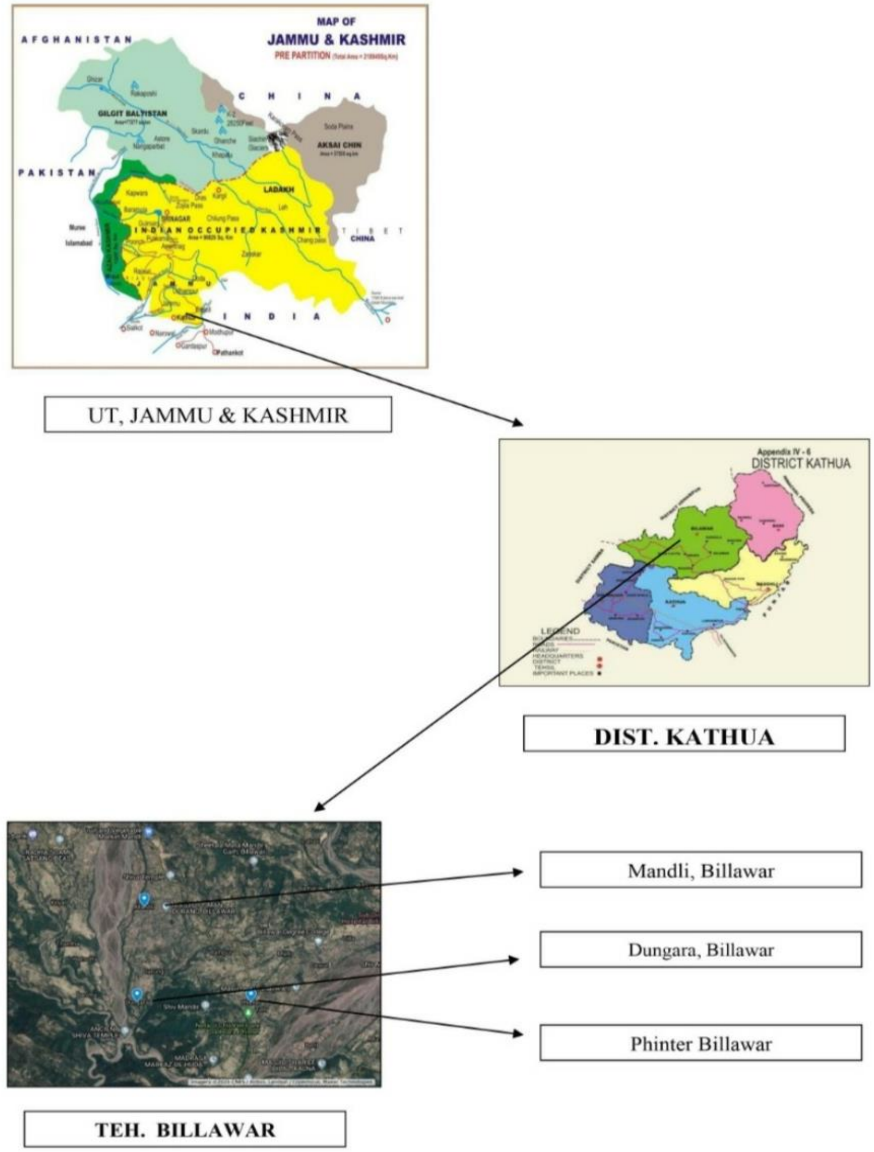

Fig. 3.1: Selected locations for research work

3.1.2 Climate

The lower areas of Himalayan range have a sub-tropical climate, which implies that the temperatures are extreme in both winter and summer. The annual rainfall in these locations is around 1100 mm. The unpredictable rainfall distribution patterns, both in time and space, result in moisture stress conditions almost throughout the year. Even though the overall rainfall appears to be sufficient for two crops in the area, the unpredictability of rainfall causes recurrent dryness. The South-West monsoon brings 70 to 80% of the yearly rainfall between July and September. Due to a lack of water, the driest months are May to June and October to November. Most of the rainstorms that occur during the summer season are brief and intense, whereas those that occur during the winter season are of low intensity and inconsistent. In the monsoons, the Rainfall Variability Index (RVI) ranges from -1.68 to 2.02; in the winter, it ranges from -1.38 to +3.60 (Sharma *et al.* 2010). The area's mean average temperature is 27°C, with the highest and lowest mean yearly temperatures being 33°C and 21°C respectively.

3.1.3 Topography and geology

The lower Shiwaliks are a mountainous region with little dry hillocks and rough, undulating topography. The Shiwalik deposits are mostly made up of alluvial detritus washed down by rivers and streams from higher mountain ranges. The Shiwalik, Muree, and Subathu sediment groups dominate most of these locations. Sandstone, conglomerate, shale, siltstone, and limestone are extensively bedded in the Shiwalik. Moderate erosion, slight to moderate stoniness, and occasional flooding are the principal land use restrictions in the Shiwalik hills, both structurally and constituently. The weathering of Shiwalik rocks has been going on at a breakneck speed. Several major and minor rivers drain the entire lower Shiwaliks.

3.1.4 Soils

The lower Shiwaliks have soils which are light to black in color, well-drained, extensively eroded, and are stony to variable degrees. These soils are neutral to alkaline, have low organic content, and are low in fertility. The soil of the submontane region and its surrounding areas is loose sandy loam, with stones and gravel in a ferruginous clay matrix. Alluvial soils range in depth from shallow to deep, are well to exclusively drained, and have a fine loamy texture. Most of these soil orders are Entisols and Inceptisols with ochric and cambric subsurface diagnostic horizons (Gupta and Verma 1992). These soils are classed as Ustifluvents, Ustipsamments, and Ustochrepts at the great group level, with local haplustalfs and fluvaquents that remain dry for 4-5 years months during a year along with udic and ustic as moisture regimes.

3.1.5 Agricultural practices

Maize and wheat are the most common crops cultivated on agricultural land, however Jowar and Bajra are also grown in some areas. In most of the *Kandi* region, maize-wheat is the most prevalent cropping pattern; however, in regions lacking irrigation, maize fallow cropping is frequent. Upland paddy is grown in some regions with good irrigation facilities. Gram, green gram and black gram are the most prevalent pulse crops. Oilseeds such as mustard and sesame are also produced. Citrus is the most common horticultural crop, followed by mango, aonla, ber, jamun and some local fruits.

3.1.6 Vegetation

The area's natural vegetation is diverse, including scrub-forest, chir woods, and moist and dry deciduous trees. Acacia Spp. (*Acacia modesta, A. Catechu, A. nilotica*) are the dominant tree species at lower elevations and *Pinusroxburgii* (Chir) at higher elevations. The forest vegetation of the area also includes trees like *Leucaena leucocephala* (Leucaena), *Terminalia bellirica* (behra), *Cedrelatoona* (Tooni) and *Dalbergiasissoo* (Shisham). *Lantana camera* (Phulnu), *Carissa opaca* (Karunda) and *Adhadota vassica* (Branker) are some of common bushes of this area. The dominant grasses are *saccharummunio* (Munj), *Cyprus rotundus* (Motha) and *Cynodondactylon* (Dub).

3.2 Meteorological Data Recorded during the Research Programme

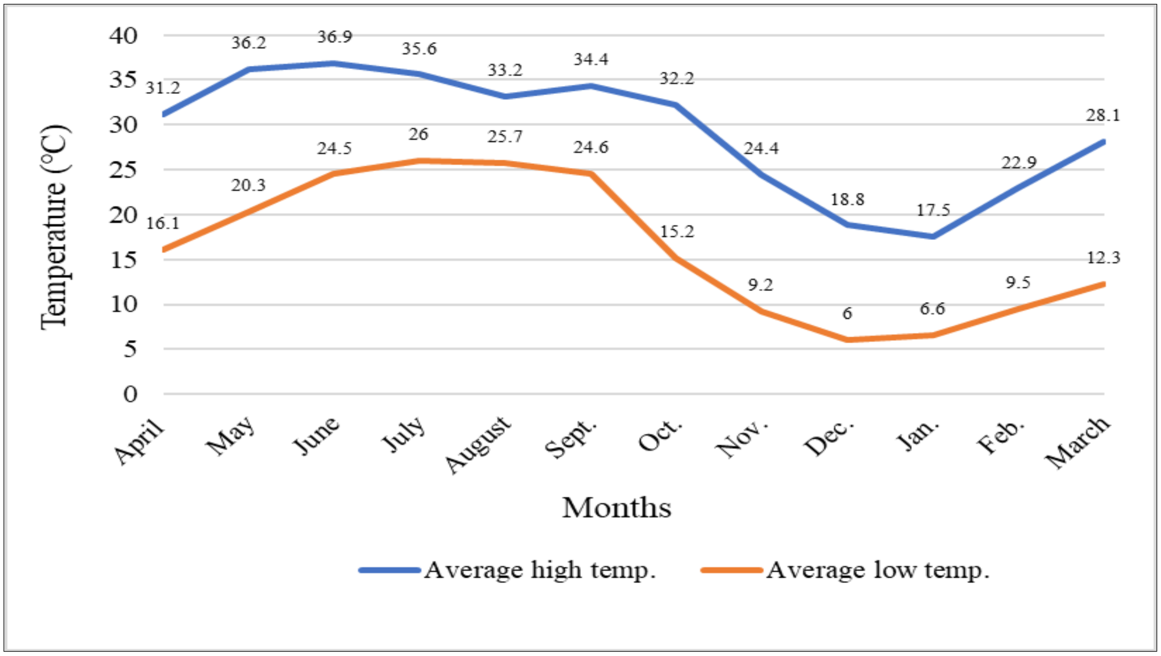

Fig. 3.2: Average max. and min. temperature from April 2020 to March 2021

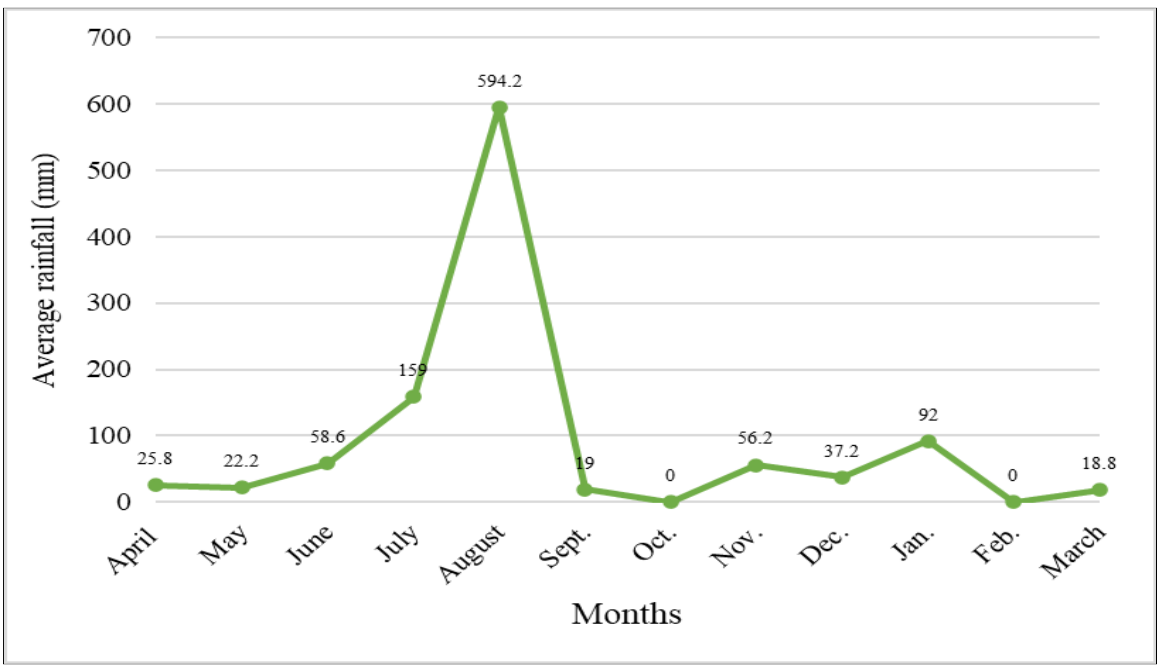

Fig. 3.3: Average rainfall recorded from April 2020 to March 2021

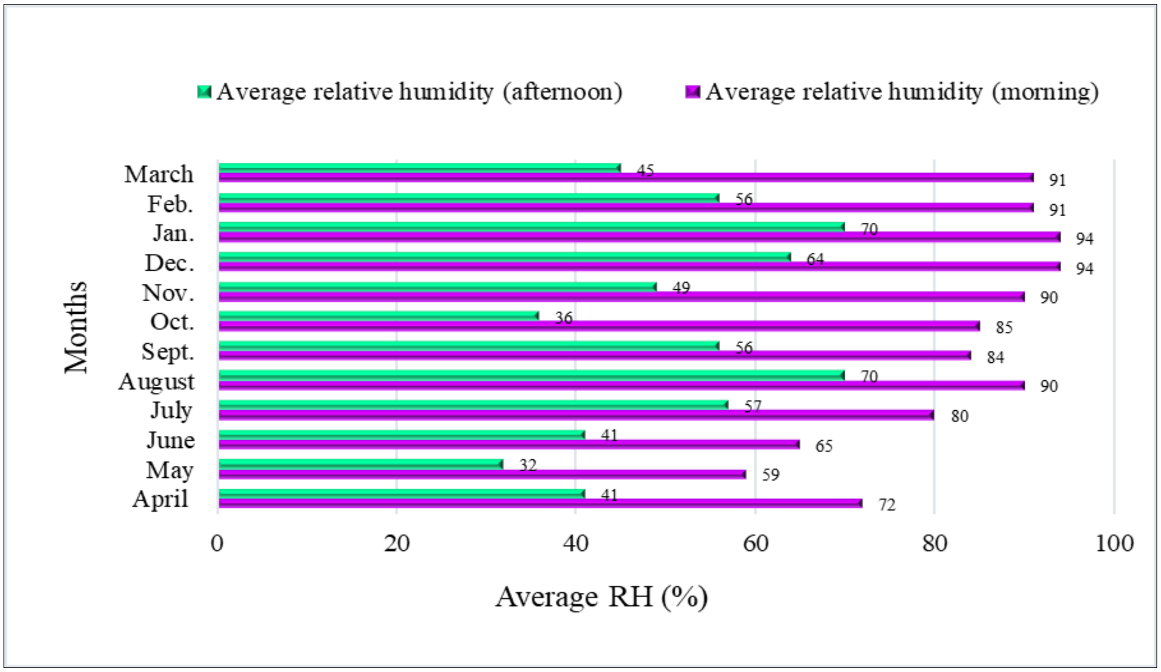

Fig. 3.4: Average relative humidity (morning and afternoon) from April 2020 to March 2021

3.3 Collection and Preparation of Soil and Aggregate Samples

The collection of soil samples was done from four different land use systems i.e., rice-wheat, maize-wheat, forest and barren lands at different locations in the lower Shiwalik region of outer Himalayas. In each of these land use systems five locations were selected. The samples were collected from Billawar (district Kathua) of Jammu province. A total of 200 representative soil samples were taken i.e., 100 in *Kharif* and 100 in *Rabi* season. These samples were collected from five different depths viz 0-5, 5-15, 15-30, 30-60 and 60-100 cm in each location. Using a tilling spade with a blade dimension of 7 cm width and 20 cm depth, ten soil samples were randomly sampled to produce a composite sample from each of the five locations for a particular land use and soil depth (0–5, 5-15, 15–30, 30-60, 60-100 cm). For sampling between land uses, the spade was sterilized with a 90% ethanol solution. Soil samples were collected, air dried, pounded in a wooden pestle with mortar, and passed through a 2 mm sieve to determine various soil properties and soil organic pools. However, separate samples were collected with the help of cores to determine the bulk density. Soil samples for aggregate stability were also taken at five depths: 0-5, 5-15, 15-30, 30-60 and 60-100 cm. With the use of a spade, clods of around 40-50 cm diameter were collected from five different locations in all five depths. The soil and aggregate samples were collected from cultivated lands in rice-wheat and maize-wheat cropping systems when there was no crop cover. Larger soil clods from various land uses were carefully brought to the laboratory to minimise forced breaking. The clods were then allowed to fall freely from a waist height of 90-100 cm onto a grassy ground collecting mat. This was done to allow the clods to break at their natural cleavage point. The aggregate samples from all four locations within a single land use location were then combined to create a composite soil sample. Aggregates that passed through an 8 mm sieve and were kept on a 4 mm sieve were utilised to determine the dry and wet stability of aggregates. A nest of sieves was used for rotary motion to obtain dry and wet stable aggregate as per the method given by Chepil and Bisal (1943). For the assessment of microbial biomass carbon, a portion of the fresh soil samples were frozen at 4°C.

3.4 Soil Physical Properties

Table 3.1: Methods employed for the determination of various soil physical properties

	Parameters	Method	Reference
3.4.1	pH	Potentiometric method	Jackson, 1973
3.4.2	Electrical conductivity (dS m^{-1})	Salt bridge method	Jackson, 1973
3.4.3	Bulk density (Mg m^{-3})	Core sample method	Black, 1965
3.4.4	Particle density (Mg m^{-3})	Pycnometer	Black, 1965
3.4.5	Soil texture	Hydrometer method	Bouyoucos, 1962
3.4.6	Water holding capacity (%)	Keen Raczkowski box method	Keen & Raczkowski, 1921

3.4.7 Macro and micro-aggregates (wet and dry)

Using a nest of 2.00 mm, 0.25 mm sieves, diameter and pan, the size distribution of aggregates was determined using a dry and wet sieving method (Yoder, 1936). The bulk soil samples were sieved at 8 mm and the 4 mm sieved samples were used for analysis. 100 g of air-dried aggregates (4-8 mm) were placed on the top sieve (2 mm) of the sieve set for the water-stable aggregates (WSA). To prevent immersion of aggregates in water and minor explosion due to rushing out of water from aggregates, the water level in the container was adjusted so that the base of the top sieve just touched the water and aggregates could saturate by capillary rise of water. The sieve set, along with the saturated soil sample, was shaken under water for 30 minutes @ 30 vertical oscillations per minute after saturating the soil for 10 minutes. After sand correction, the amount of soil material retained on each sieve was dried at 105°C for 24 hours and expressed as a percentage of aggregates for each size class. The same process was used to obtain dry-stable aggregates (DSA) without the soil being soaked or immersed in water. A dry condition electrically operated vibrator was used to simulate the shaking that was employed in the water-stable aggregate determination. The data was evaluated to determine the percentage of dry-stable aggregates (DSA) and water-stable aggregates (WSA) of different sizes (Kemper and Rosenau, 1986). However, the boundary between micro and macro-aggregates was taken as 0.25mm (Mondal *et al.* 2019).

3.4.8 Mean weight diameter

The mean weight diameter (MWD) of the aggregates were calculated as (Kemper and Rosenau, 1986):

$$\text{MWD} = \frac{\sum_{i=1}^{n} diwi}{\sum_{i=1}^{n} wi}$$

Where di represents the mean diameter of each size fraction (mm), wi represents the proportion of total aggregate in each size fraction, and n represents the number of sieves used.

3.5 Soil Carbon Pools

Methods employed for the determination of various carbon pools are given below

3.5.1 Total organic carbon (TOC)

The total organic carbon (TOC) content was determined using dry combustion method of Houba *et al.* (1995). A 10 g finely ground soil sample was oven dried for 24 hours at 105^0, then weighed and dry combusted in a muffle furnace at 450^0 for 4 hours, with the weight reduction considered as carbon loss.

3.5.2 Soil oxidizable organic carbon (SOC)

It was analysed as per the wet oxidation method (Walkley and Black, 1934). In this method, organic matter is oxidized with chromic acid (potassium dichromate + sulphuric acid). The unconsumed potassium dichromate is back titrated against ferrous sulphate or ferrous ammonium sulphate.

$$\text{Organic carbon (\%)} = [(X-Y)*0.003*100*N]/W$$

Where X = Volume of 0.5 N FAS used for blank sample

Where Y = Volume of 0.5 N FAS used for soil sample

N = Normality of FAS used

W= Weight of the soil sample

3.5.3 Aggregate associated organic carbon (AAOC)

The aggregate associated organic carbon (AAOC) was assessed using Walkley and Black's rapid titration method (Walkley and Black, 1934) after oven-dried (at 50^0) soil aggregates of various size fractions were ground with a wooden pestle and mortar to size less than 0.25 mm.

3.5.4 Hot water-soluble carbon (HWC)

The Hot Water-Soluble Carbon (HWC) was determined be the method given by Schulz *et al.* (2003). In a 250 mL round bottomed flask, 20 g of soil sample was weighed, and 100 ml distilled water was added. The samples were quickly cooled to room temperature using a water bath after being heated to moderate boiling for one hour under reflex condenser, with 5 drops of magnesium sulphate added to aid sedimentation. After centrifuging the supernatant solution for 10 minutes at 3000 rpm, a 10 ml of chromo sulfuric acid was heated for 20 minutes in an Erlenmeyer Flask at 125. Using 5 drops of indicator solution (0.2 g N- Phenylicanthranilic acid + 0.2 sodium carbonate), the cooled mixture was titrated against a 0.2 *M* ammonium ferrous sulphate hexahydrate standard solution.

$$\text{HWC (mg kg}^{-1}\text{)} = \frac{(Va - Vb) * 12 * FR * \text{Volume of aliquat (ml)} * 1000 * 100}{10 * Wg * Wdm}$$

Where, Vb and Va represents volume of ammonium ferrous sulphate hexahydrate standard solution used to titrate blank and soil sample, FR is the reduction factor of the iron, ammonium, sulphate hexahydrate solution as equivalent of the reduction of $Kr_2Cr_2O_7$ by carbon in mmolml^{-1}. Wg is the soil sample weight, Wdm is the dry matter of the air-dried soil sample (%).

3.5.5 Particulate organic carbon (POC)

The particulate organic carbon (POC) was determined as described by Cambardella and Elliot (1992) and Hassink (1995). By dispersing 50 g of each sample in 150 ml of 0.5% sodium hexametaphosphate solution and shaking for 15 hours on a reciprocal shaker, the POC contained in the whole soil and each aggregate fraction was separated. The dispersed soil sample was passed between 250µm and 53µm sieves. The material in sieve 53µm was rinsed multiple times with distilled water before being dried overnight at 50℃. By using the Walkley and Black rapid titration method, the POC fraction (53µm-250µm) was properly ground and analysed for soil organic carbon.

3.5.6 Microbial biomass carbon (MBC)

The microbial biomass carbon was measured using the chloroform fumigation method (Vance *et al.* 1987). For 24 hours, 10 g of soil sample was fumigated using ethanol-free chloroform. Both fumigated and non-fumigated samples were extracted using 40 ml of 0.5 M K_2SO_4 on an end-to-end shaker for 30 minutes.

$$\text{MBC} = (C_{\text{org in fumigated soil}} - C_{\text{org in unfumigated soil}})/\text{Kec}$$

Where, Kec = 0.41 is the recovery factor used to convert organic C to MBC.

3.6 Initial Soil Properties of the Land Use Systems

Table 3.2: Initial soil properties of the land use systems

Parameters	Values			
Basic properties	Rice-wheat	Forest land	Maize-wheat	Barren land
pH	7.01	6.86	7.05	7.16
EC (dS m^{-1})	0.17	0.20	0.16	1.19
Texture				
Sand (%)	61.03	51.08	60.45	68.49
Silt (%)	18.16	20.88	19.73	16.92
Clay (%)	20.81	28.04	19.82	14.59
Available nutrients				
N (kg ha^{-1})	270.05	290.12	172.23	121.18
P (kg ha^{-1})	10.95	15.65	12.55	6.05
K (kg ha^{-1})	160.85	170.32	130.55	95.88
Carbon pools				
OC (g kg^{-1})	6.54	8.69	5.57	3.01

3.7 Statistical Analysis

For evaluating the impact of land use system and seasonal variations on aggregate associated soil carbon in outer Himalayas, statistical analysis was done by proper statistical technique.

Chapter-4

Results

Chapter-5

Chapter-4

Results

The results of the present study have been described in this chapter through tables and graphs wherever necessary. The results of the study have been discussed under the following headings and sub-headings:

4.1 Effect of Different Land Use Systems and Seasonal Variations on Physical Properties of Soil at Different Depths.

4.1.1 pH

4.1.2 Electrical conductivity (EC)

4.1.3 Bulk density

4.1.4 Particle density

4.1.5 Soil texture

4.1.6 Maximum water holding capacity

4.1.7 Water-stable macro-aggregates

4.1.8 Dry-stable macro-aggregates

4.1.9 Water-stable micro-aggregates

4.1.10 Dry-stable micro-aggregates

4.1.11 Mean weight diameter

4.2 Effect of Different Land Use Systems and Seasonal Variations on Carbon Pools and Stocks at Different Depths.

4.2.1 Total organic carbon

4.2.2 Soil oxidizable organic carbon

4.2.3 Aggregate associated organic carbon

4.2.4 Hot water-soluble carbon

4.2.5 Particulate organic carbon

4.2.6 Microbial biomass carbon

4.3 Coefficient of Correlation between the Different Soil Properties in *Kharif* Season

4.4 Coefficient of Correlation between the Different Soil Properties in *Rabi* Season

4.1 Effect of Different Land Use Systems and Seasonal Variations on Physical Properties of Soil at Different Depths.

4.1.1 Effect of different land use systems and seasonal variations on soil pH at different depths.

Table 4.1: Soil pH

Season	Land use	Depth (cm)				
		(0-5)	(5-15)	(15-30)	(30-60)	(60-100)
Kharif	Rice-wheat (RW)	6.78	6.92	7.19	7.48	7.67
	Forest land (FL)	6.96	7.07	7.03	7.30	7.94
	Maize-wheat (MW)	6.75	7.11	7.32	7.36	7.64
	Barren land (BL)	7.14	7.17	7.30	7.67	7.74
Rabi	Rice-wheat (RW)	7.07	7.10	7.46	7.57	7.77
	Forest land (FL)	6.71	7.15	7.05	7.46	7.56
	Maize-wheat (MW)	6.84	7.30	7.24	7.63	7.78
	Barren land (BL)	7.21	7.35	7.45	7.69	7.85
Factor means	Depth	(0-5)	(5-15)	(15-30)	(30-60)	(60-100)
		6.93	7.15	7.25	7.52	7.74
	Land use	RW	FL	MW	BL	
		7.30	7.22	7.30	7.46	
	Season	*Kharif*	*Rabi*			
		7.28	7.36			
LSD ($p \leq 0.05$)	Seasons (S) = 0.07 Land use (L) = 0.10 Depth (D) = 0.11 SxL = N/S SxD = N/S LxD = N/S SxLxD = N/S					

From the perusal of table 4.1, it was revealed that the soils of all land use systems varied from slightly acidic (6.70) to slightly alkaline (8.00) in nature. The mean value of pH was highest in barren land (7.46) followed by rice-wheat and maize-wheat (7.30) and was found to be lowest in forest land (7.22). The pH values increased with increasing soil depth in all land use systems. The mean value of pH was lowest in the 0-5 cm depth (6.93), followed by 5-15 cm depth (7.15) and was highest in the 60-100 cm depth (7.74). The soils of *Rabi* season showed higher pH (7.36) as compared to the soils of *Kharif* season (7.28). The effect of season, land use and depth were significant.

4.1.2 Effect of different land use systems and seasonal variations on electrical conductivity (EC) at different depths.

Table 4.2: EC

Season	Land use	Depth (cm)				
		(0-5)	(5-15)	(15-30)	(30-60)	(60-100)
Kharif	Rice-wheat (RW)	0.21	0.19	0.16	0.14	0.08
	Forest land (FL)	0.18	0.14	0.14	0.12	0.06
	Maize-wheat (MW)	0.24	0.18	0.16	0.08	0.10
	Barren land (BL)	0.35	0.28	0.23	0.18	0.13
Rabi	Rice-wheat (RW)	0.24	0.21	0.17	0.14	0.10
	Forest land (FL)	0.19	0.16	0.14	0.13	0.09
	Maize-wheat (MW)	0.28	0.22	0.18	0.11	0.10
	Barren land (BL)	0.36	0.30	0.26	0.18	0.13
Factor means	Depth	(0-5)	(5-15)	(15-30)	(30-60)	(60-100)
		0.26	0.21	0.18	0.14	0.10
	Land use	RW	FL	MW	BL	
		0.16	0.14	0.17	0.24	
	Season	*Kharif*	*Rabi*			
		0.17	0.18			
LSD ($p \leq 0.05$)	Seasons (S) = 0.01 Land use (L) = N/S Depth (D) = N/S SxL = N/S SxD = N/S LxD = 0.03 SxLxD = N/S					

Note: EC (dS m^{-1})

From table 4.2 it was concluded that the mean value of EC was highest in barren land (0.24 dS m^{-1}) followed by maize-wheat (0.17 dS m^{-1}), rice-wheat (0.16 dS m^{-1}) and was found to be lowest in forest land (0.14 dS m^{-1}). For all land use systems, surface soils had higher values than subsurface soils in general. The value of EC was highest in the 0-5 cm depth (0.26 dS m^{-1}), followed by 5-15 cm depth (0.21 dS m^{-1}) and was lowest in the 60-100 cm depth (0.10 dS m^{-1}). The soils of *Rabi* season showed higher EC (0.18 dS m^{-1}) as compared to the soils of *Kharif* season (0.17 dS m^{-1}). The effect of season and interactive effect of land use and depth were found to be significant.

4.1.3 Effect of different land use systems and seasonal variations on bulk density at different depths.

Table 4.3: Bulk density

Season	Land use	Depth (cm)				
		(0-5)	(5-15)	(15-30)	(30-60)	(60-100)
Kharif	Rice-wheat (RW)	1.42	1.44	1.48	1.48	1.48
	Forest land (FL)	1.29	1.31	1.31	1.34	1.34
	Maize-wheat (MW)	1.37	1.38	1.40	1.42	1.44
	Barren land (BL)	1.56	1.55	1.52	1.48	1.50
Rabi	Rice-wheat (RW)	1.41	1.42	1.47	1.48	1.49
	Forest land (FL)	1.29	1.31	1.33	1.34	1.35
	Maize-wheat (MW)	1.37	1.38	1.41	1.43	1.44
	Barren land (BL)	1.48	1.44	1.46	1.51	1.52
Factor Means	Depth	(0-5)	(5-15)	(15-30)	(30-60)	(60-100)
		1.39	1.40	1.42	1.43	1.44
	Land use	RW	FL	MW	BL	
		1.45	1.32	1.40	1.50	
	Season	*Kharif*	*Rabi*			
		1.42	1.41			
LSD ($p \leq 0.05$)	Seasons (S) = N/S Land use (L) = N/S Depth (D) = N/S SxL = N/S SxD = N/S LxD = N/S SxLxD = 0.02					

Note: Bulk density (Mg m^{-3})

It can be concluded from table 4.3 that the mean value of bulk density was highest in barren land (1.50 Mg m^{-3}) followed by rice-wheat (1.45 Mg m^{-3}), maize-wheat (1.40 Mg m^{-3}) and lowest in forest land (1.32 Mg m^{-3}). With increasing soil depth, the bulk density of all land use systems increased. The value of bulk density was lowest in the 0-5 cm depth (1.39 Mg m^{-3}), followed by 5-15 cm depth (1.40 Mg m^{-3}) and was highest in the 60-100 cm depth (1.44 Mg m^{-3}). The soils of *Kharif* season showed higher bulk density (1.42 Mg m^{-3}) as compared to the soils of *Rabi* season (1.41 Mg m^{-3}). The interactive effect of season, land use and depth were found to be significant.

4.1.4 Effect of different land use systems and seasonal variations on particle density at different depths.

Table 4.4: Particle density

Season	Land use	Depth (cm)				
		(0-5)	(5-15)	(15-30)	(30-60)	(60-100)
Kharif	Rice-wheat (RW)	2.45	2.46	2.62	2.66	2.71
	Forest land (FL)	2.37	2.45	2.60	2.61	2.68
	Maize-wheat (MW)	2.46	2.50	2.61	2.63	2.69
	Barren land (BL)	2.53	2.58	2.64	2.68	2.73
Rabi	Rice-wheat (RW)	2.34	2.42	2.53	2.70	2.72
	Forest land (FL)	2.34	2.44	2.59	2.60	2.64
	Maize-wheat (MW)	2.44	2.48	2.56	2.60	2.65
	Barren land (BL)	2.52	2.56	2.64	2.66	2.71
Factor Means	Depth	(0-5)	(5-15)	(15-30)	(30-60)	(60-100)
		2.43	2.49	2.60	2.64	2.69
	Land use	RW	FL	MW	BL	
		2.56	2.53	2.56	2.63	
	Season	*Kharif*	*Rabi*			
		2.58	2.56			
LSD (p≤0.05)	Seasons (S) = N/S Land use (L) = N/S Depth (D) = N/S SxL = N/S SxD = N/S LxD = 0.11 SxLxD = N/S					

Note: Particle density (Mg m^{-3})

It can be revealed from table 4.4 that the mean value of particle density was highest in barren land (2.63 Mg m^{-3}) followed by rice-wheat, maize-wheat (2.56 Mg m^{-3}) and was lowest in forest land (2.53 Mg m^{-3}). With increasing soil depth, the particle density of all land use systems increased. The value of particle density was lowest in the 0-5 cm depth (2.43 Mg m^{-3}), followed by 5-15 cm depth (2.49 Mg m^{-3}) and was highest in the 60-100 cm depth (2.69 Mg m^{-3}). The interactive effect of land use and depth were found to be significant.

4.1.5 Effect of different land use systems and seasonal variations on soil texture (Clay content) at different depths.

Table 4.5: Soil texture {clay content}

Season	Land use	Depth (cm)				
		(0-5)	(5-15)	(15-30)	(30-60)	(60-100)
Kharif	Rice-wheat (RW)	17.54	18.35	17.01	16.21	19.82
	Forest land (FL)	17.95	18.05	19.65	21.14	22.59
	Maize-wheat (MW)	15.12	15.29	15.56	15.90	16.04
	Barren land (BL)	13.31	13.39	14.41	16.14	17.01
Rabi	Rice-wheat (RW)	16.96	18.13	16.97	16.67	17.49
	Forest land (FL)	17.88	17.98	19.54	20.25	21.24
	Maize-wheat (MW)	14.81	15.15	15.26	15.88	16.01
	Barren land (BL)	13.10	13.20	13.99	15.66	16.54
Factor Means	Depth	(0-5)	(5-15)	(15-30)	(30-60)	(60-100)
		15.83	16.19	16.54	17.23	18.34
	Land use	RW	FL	MW	BL	
		17.51	19.62	15.50	14.67	
	Season	*Kharif*	*Rabi*			
		17.02	16.63			
LSD ($p \leq 0.05$)	Seasons (S) = N/S Land use (L) = N/S Depth (D) = N/S SxL = N/S SxD = N/S LxD = 1.95 SxLxD = N/S					

Note: Clay content (%)

It can be concluded from table 4.5 that the mean value of clay content was highest in forest land (19.62%) followed by rice-wheat (17.51%), maize-wheat (15.50%) and lowest in barren land (14.67%). The clay content increased with increasing soil depth in all land use systems. The value of clay content was lowest in the 0-5 cm depth (15.83%), followed by 5-15 cm depth (16.19%) and was highest in the 60-100 cm depth (18.34%). The interactive effect of land use and depth were found to be significant. However, the effect of season, land use and depth on sand and silt content were found to be non-significant.

4.1.6 Effect of different land use systems and seasonal variations on maximum water holding capacity at different depths.

Table 4.6: Maximum water holding capacity

Season	Land use	Depth (cm)				
		(0-5)	(5-15)	(15-30)	(30-60)	(60-100)
Kharif	Rice-wheat (RW)	36.71	36.38	34.19	31.21	31.75
	Forest land (FL)	41.37	40.18	40.08	38.12	36.54
	Maize-wheat (MW)	35.6	34.4	33.41	30.66	30.47
	Barren land (BL)	28.61	27.83	27.72	27.33	25.4
Rabi	Rice-wheat (RW)	35.87	35.61	33.86	29.69	29.52
	Forest land (FL)	40.18	39.75	39.48	36.68	34.67
	Maize-wheat (MW)	34.43	33.92	31.88	30.62	29.03
	Barren land (BL)	27.92	27.38	27.29	26.52	24.36
Factor Means	Depth	(0-5)	(5-15)	(15-30)	(30-60)	(60-100)
		35.09	34.43	33.49	31.35	30.22
	Land use	RW	FL	MW	BL	
		33.48	38.70	32.44	27.04	
	Season	*Kharif*	*Rabi*			
		33.40	32.43			
LSD (p≤0.05)	Seasons (S) = 0.64 Land use (L) = 0.90 Depth (D) = 1.01 SxL = N/S SxD =N/S LxD = N/S SxLxD =N/S					

Note: Maximum water holding capacity (%)

From the above table 4.6, it was concluded that the mean value of maximum water holding capacity was highest in forest land (38.70%) followed by rice-wheat (33.48%), maize-wheat (32.44%) and lowest in barren land (27.04%). With increasing soil depth, the maximum water holding capacity of all land use systems decreased .The value of maximum water holding capacity was highest in the 0-5 cm depth (35.09%), followed by 5-15 cm depth (34.43%) and was lowest in the 60-100 cm depth (30.22%). The soils of *Kharif* season showed higher maximum water holding capacity (33.40%) as compared to the soils of *Rabi* season (32.43%). The effect of season, land use and depth were found to be significant.

4.1.7 Effect of different land use systems and seasonal variations on water-stable macro- aggregates at different depths.

Table 4.7: Water-stable macro- aggregates

Season	Land use	Depth (cm)				
		(0-5)	(5-15)	(15-30)	(30-60)	(60-100)
Kharif	Rice-wheat (RW)	47.77	45.33	37.47	33.04	24.85
	Forest land (FL)	68.83	68.28	58.90	49.15	34.19
	Maize-wheat (MW)	47.24	45.5	36.14	27.4	24.93
	Barren land (BL)	38.62	36.81	27.96	25.19	19.05
Rabi	Rice-wheat (RW)	50.24	47.59	40.18	36.55	28.75
	Forest land (FL)	70.66	69.24	61.82	52.76	39.07
	Maize-wheat (MW)	49.24	46.66	38.08	30.28	27.51
	Barren land (BL)	40.4	37.7	31.08	27.5	21.39
Factor Means	Depth	(0-5)	(5-15)	(15-30)	(30-60)	(60-100)
		51.62	49.63	41.43	5.23	27.46
	Land use	RW	FL	MW	BL	
		39.17	57.29	37.29	30.57	
	Season	*Kharif*	*Rabi*			
		39.83	42.33			
LSD (p≤0.05)	Seasons (S) = 0.64 Land use (L) = N/S Depth (D) = N/S SxL = N/S SxD = N/S LxD = 2.03 SxLxD = N/S					

Note: Water-stable macro- aggregates (%)

From the data of table 4.7, it was concluded that the mean value of water-stable macro-aggregates (>0.25 mm) was highest in forest land (57.29%) followed by rice-wheat (39.17%), maize-wheat (37.29%) and lowest in barren land (30.57%). With increasing soil depth, the water-stable macro-aggregates of all land use systems decreased .The value of water-stable macro-aggregates was highest in the 0-5 cm depth (51.62%), followed by 5-15 cm depth (49.63%) and was lowest in the 60-100 cm depth (27.46%). The sub-surface layer (15-30 cm) of forest-land showed significantly higher water-stable macro-aggregates (58.90% and 61.82%) than the other land-use systems at the same depth in both the seasons. The soils of *Rabi* season showed higher water-stable macro-aggregates (42.33%) as compared to the soils of *Kharif* season (32.43%). The effect of season and interactive effect of land use and depth were found to be significant.

4.1.8 Effect of different land use systems and seasonal variations on dry-stable macro- aggregates at different depths.

Table 4.8: Dry-stable macro-aggregates

Season	Land use	Depth (cm)				
		(0-5)	(5-15)	(15-30)	(30-60)	(60-100)
Kharif	Rice-wheat (RW)	50.24	47.29	38.55	31.62	21.64
	Forest land (FL)	71.02	69.41	65.50	52.52	48.38
	Maize-wheat (MW)	50.58	45.93	43.14	37.87	30.29
	Barren land (BL)	40.00	36.52	29.91	27.22	22.93
Rabi	Rice-wheat (RW)	51.62	48.42	40.98	35.73	28.02
	Forest land (FL)	72.48	70.75	67.36	55.40	49.82
	Maize-wheat (MW)	51.82	47.04	44.17	38.80	32.05
	Barren land (BL)	41.07	37.81	33.95	28.27	25.28
Factor Means	Depth	(0-5)	(5-15)	(15-30)	(30-60)	(60-100)
		53.60	50.39	45.44	38.42	32.30
	Land use	RW	FL	MW	BL	
		39.41	62.26	42.16	32.29	
	Season	*Kharif*	*Rabi*			
		43.03	45.04			
LSD (p≤0.05)	Seasons (S) = 0.59 Land use (L) = N/S Depth (D) = N/S SxL = N/S SxD = N/S LxD = 1.87 SxLxD = N/S					

Note: Dry-stable macro-aggregates (%)

From the data of table 4.8, it was revealed that the mean value of dry-stable macro-aggregates (>0.25 mm) was highest in forest land (62.26%) followed by maize-wheat (42.16%), rice-wheat (39.41%) and lowest in barren land (32.29%). With increasing soil depth, the dry-stable macro-aggregates of all land use systems decreased. The value of dry-stable macro-aggregates was highest in the 0-5 cm depth (53.60%), followed by 5-15 cm depth (50.39%) and was lowest in the 60-100 cm depth (32.30%). The sub-surface layer (15-30 cm) of forest-land showed significantly higher dry-stable macro-aggregates (65.50% and 67.36%) than the other land-use systems at the same depth in both the seasons. The soils of *Rabi* season showed higher dry-stable macro-aggregates (45.04%) as compared to the soils of *Kharif* season (43.03%). The effect of season and interactive effect of land use and depth were found to be significant.

4.1.9 Effect of different land use systems and seasonal variations on water-stable micro- aggregates at different depths.

Table 4.9: Water- stable micro-aggregates

Season	Land use	Depth (cm)				
		(0-5)	(5-15)	(15-30)	(30-60)	(60-100)
Kharif	Rice-wheat (RW)	20.57	25.82	31.48	34.58	35.18
	Forest land (FL)	9.68	12.08	15.34	15.91	16.72
	Maize-wheat (MW)	20.17	24.68	34.44	36.21	36.25
	Barren land (BL)	15.94	15.03	14.78	13.39	12.37
Rabi	Rice-wheat (RW)	19.53	24.00	29.67	33.00	34.78
	Forest land (FL)	9.30	10.70	13.4	14.93	16.03
	Maize-wheat (MW)	19.51	23.49	33.71	34.95	37.68
	Barren land (BL)	15.34	14.44	14.18	13.05	11.40
Factor Means	Depth	(0-5)	(5-15)	(15-30)	(30-60)	(60-100)
		16.25	18.78	23.37	24.50	25.05
	Land use	RW	FL	MW	BL	
		28.86	13.40	30.10	13.99	
	Season	*Kharif*	*Rabi*			
		22.03	21.15			
LSD (p≤0.05)	Seasons (S) = 0.37 Land use (L) = N/S Depth (D) = N/S SxL = N/S SxD = N/S LxD = 1.18 SxLxD = N/S					

Note: Water- stable micro-aggregates (%)

From the data presented in table 4.9, it was revealed that the mean value of water-stable micro-aggregates (<0.25 mm) was highest in maize-wheat (30.10%) followed by rice-wheat (28.86%), barren land (13.99%) and lowest in forest land (13.40%). With increasing soil depth, the water-stable micro-aggregates of all land use systems increased .The value of water-stable micro-aggregates was lowest in the 0-5 cm depth (16.25%), followed by 5-15 cm depth (18.78%) and was highest in the 60-100 cm depth (25.05%). The soils of *Kharif* season showed higher water-stable micro-aggregates (22.03%) as compared to the soils of *Rabi* season (21.15%). The effect of season and interactive effect of land use and depth were found to be significant.

4.1.10 Effect of different land use systems and seasonal variations on dry-stable micro- aggregates at different depths.

Table 4.10: Dry-stable micro-aggregates

Season	Land use	Depth (cm)				
		(0-5)	(5-15)	(15-30)	(30-60)	(60-100)
Kharif	Rice-wheat (RW)	22.57	24.65	28.70	35.63	36.02
	Forest land (FL)	9.16	8.78	8.67	8.67	8.05
	Maize-wheat (MW)	21.18	24.04	28.06	32.28	34.6
	Barren land (BL)	13.88	14.03	10.56	10.45	9.67
Rabi	Rice-wheat (RW)	21.68	23.84	29.66	34.05	35.40
	Forest land (FL)	8.80	8.43	8.09	7.87	7.40
	Maize-wheat (MW)	20.85	23.41	26.81	31.43	33.60
	Barren land (BL)	13.53	13.32	10.26	10.05	9.19
Factor Means	Depth	(0-5)	(5-15)	(15-30)	(30-60)	(60-100)
		16.45	17.56	18.85	21.30	21.74
	Land use	RW	FL	MW	BL	
		29.22	8.39	27.62	11.49	
	Season	*Kharif*	*Rabi*			
		19.48	18.88			
LSD (p≤0.05)	Seasons (S) = 0.42 Land use (L) = N/S Depth (D) = N/S SxL = N/S SxD = N/S LxD = 1.33 SxLxD = N/S					

Note: Dry-stable micro-aggregates (%)

From the data presented in table 4.10, it was revealed that the mean value of dry-stable micro-aggregates (<0.25 mm) was highest in rice-wheat (29.22%) followed by maize-wheat (27.62%), barren land (11.49%) and lowest in forest land (8.39%). With increasing soil depth, the dry-stable micro-aggregates of all land use systems increased .The value of dry-stable micro-aggregates was lowest in the 0-5 cm depth (16.45%), followed by 5-15 cm depth (17.56%) and was highest in the 60-100 cm depth (21.74%). The soils of *Kharif* season showed higher dry-stable micro-aggregates (19.48%) as compared to the soils of *Rabi* season (18.88%). The effect of season and interactive effect of land use and depth were found to be significant.

4.1.11 Effect of different land use systems and seasonal variations on mean-weight diameter at different depths.

Table 4.11: Mean weight diameter

Season	Land use	Depth (cm)				
		(0-5)	(5-15)	(15-30)	(30-60)	(60-100)
Kharif	Rice-wheat (RW)	2.57	2.41	2.17	1.99	1.66
	Forest land (FL)	3.71	3.52	3.85	3.83	3.97
	Maize-wheat (MW)	2.80	2.51	2.28	1.90	1.71
	Barren land (BL)	2.59	2.24	1.96	1.77	1.60
Rabi	Rice-wheat (RW)	2.45	2.27	1.95	1.72	1.35
	Forest land (FL)	3.57	3.39	3.70	3.68	3.92
	Maize-wheat (MW)	2.60	2.37	2.11	1.72	1.45
	Barren land (BL)	2.42	2.11	1.73	1.62	1.32
Factor Means	Depth	(0-5)	(5-15)	(15-30)	(30-60)	(60-100)
		2.83	2.60	2.46	2.27	2.12
	Land use	RW	FL	MW	BL	
		2.05	3.71	2.14	1.93	
	Season	*Kharif*	*Rabi*			
		2.55	2.37			
LSD (p≤0.05)	Seasons (S) = 0.05 Land use (L) = N/S Depth (D) = N/S SxL = N/S SxD = N/S LxD = 0.17 SxLxD = N/S					

Note: Mean weight diameter (mm)

From the perusal of table 4.11, it was revealed that the mean value of mean weight diameter was highest in forest land (3.71 mm) followed by maize-wheat (2.14 mm), rice-wheat (2.05 mm) and was found to be lowest in barren land (1.93 mm). The mean weight diameter values decreased with increasing soil depth in all land use systems. The mean value of mean weight diameter was highest in the 0-5 cm depth (2.83 mm), followed by 5-15 cm depth (2.60 mm) and was lowest in the 60-100 cm depth (2.12 mm). The soils of *Kharif* season showed higher mean weight diameter (2.55 mm) as compared to the soils of *Rabi* season (2.37 mm). The effect of season and interactive effect of land use and depth were significant.

4.2 Effect of Different Land Use Systems and Seasonal Variations on Carbon Pools and Stocks at Different Depths.

4.2.1 Effect of different land use systems and seasonal variations on total organic carbon at different depths.

Table 4.12: Total organic carbon (g kg^{-1})

Season	Land use	Depth (cm)				
		(0-5)	(5-15)	(15-30)	(30-60)	(60-100)
Kharif	Rice-wheat (RW)	18.88	18.61	16.74	15.23	10.78
	Forest land (FL)	26.90	26.41	24.52	25.61	25.68
	Maize-wheat (MW)	18.87	18.62	16.39	15.60	10.71
	Barren land (BL)	13.52	12.58	11.43	11.10	9.72
Rabi	Rice-wheat (RW)	19.24	18.83	17.08	15.81	11.77
	Forest land (FL)	27.88	26.59	25.35	25.90	25.48
	Maize-wheat (MW)	19.44	18.66	16.77	15.77	12.04
	Barren land (BL)	15.44	14.29	13.59	12.89	10.99
Factor Means	Depth	(0-5)	(5-15)	(15-30)	(30-60)	(60-100)
		20.02	19.32	17.73	17.23	14.64
	Land use	RW	FL	MW	BL	
		16.29	26.03	16.28	12.55	
	Season	*Kharif*	*Rabi*			
		17.39	18.19			
LSD (p≤0.05)	Seasons (S) = N/S Land use (L) = N/S Depth (D) = N/S SxL = 0.36 SxD = N/S LxD = 0.57 SxLxD = N/S					

Note: Total organic carbon (g kg^{-1})

From the data presented in table 4.12, it was concluded that the mean value of total organic carbon was highest in forest land (26.03 g kg^{-1}) followed by rice-wheat (16.29 g kg^{-1}), maize-wheat (16.28 g kg^{-1}) and was found to be lowest in barren land (12.55 g kg^{-1}). The total organic carbon values decreased with increasing soil depth in all land use systems except for the forest land which showed significantly higher values in (30-60) and (60-100) cm depth as compared to the upper layers in both the seasons. The mean value of total organic carbon was highest in the 0-5 cm depth (20.02 g kg^{-1}), followed by 5-15 cm depth (19.32 g kg^{-1}) and was lowest in the 60-100 cm depth (14.64 g kg^{-1}). The soils of *Rabi* season showed higher values of total organic carbon (18.19 g kg^{-1}) as compared to the soils of *Kharif* season (17.39 g kg^{-1}). The interactive effect of season and land use and interactive effect of land use and depth were significant. The effect of different land use systems and seasonal variations on total organic carbon at different depths is depicted in fig 4.1.

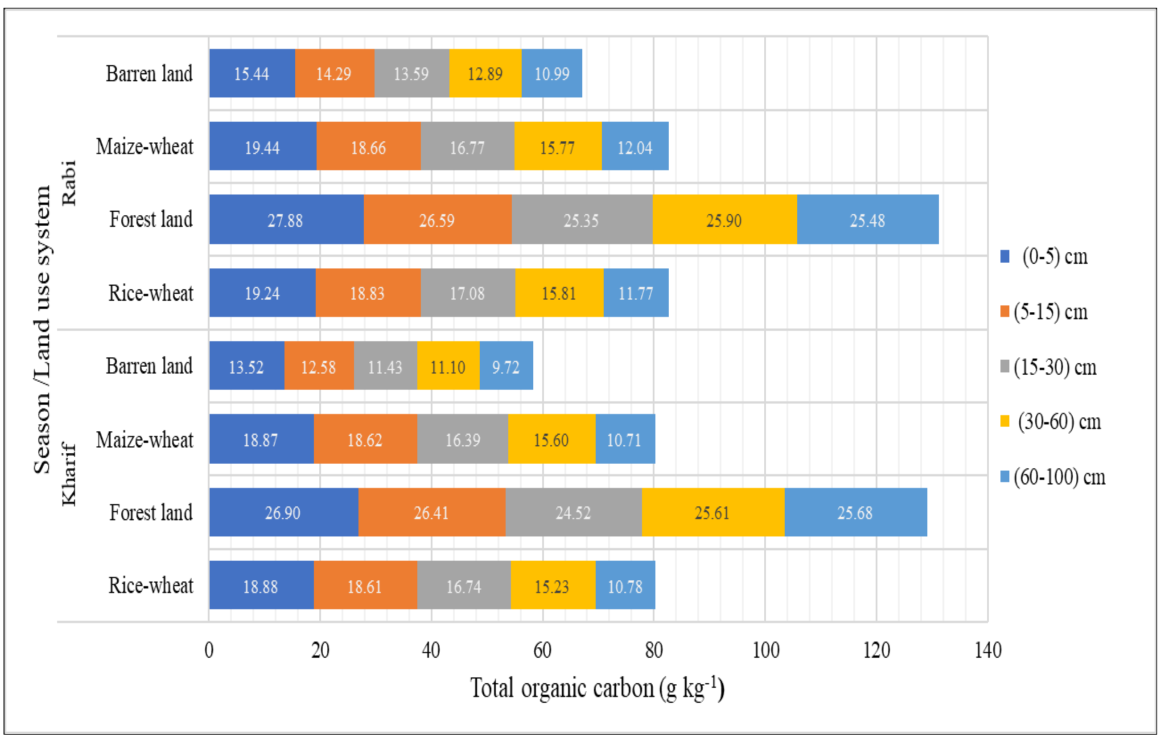

Fig. 4.1: Effect of different land use systems and seasonal variations on total organic carbon at different depths.

4.2.2 Effect of different land use systems and seasonal variations on soil oxidizable organic carbon at different depths.

Table 4.13: Soil oxidizable organic carbon (g kg^{-1})

Season	Land use	Depth (cm)				
		(0-5)	(5-15)	(15-30)	(30-60)	(60-100)
Kharif	Rice-wheat (RW)	5.87	5.73	3.39	2.41	1.47
	Forest land (FL)	7.47	7.12	5.55	3.16	1.49
	Maize-wheat (MW)	5.86	5.78	3.27	2.6	1.76
	Barren land (BL)	4.42	3.76	3.26	2.21	1.27
Rabi	Rice-wheat (RW)	5.46	5.15	3.15	2.26	1.46
	Forest land (FL)	7.23	6.86	5.27	2.82	1.27
	Maize-wheat (MW)	5.71	5.43	2.98	2.48	1.56
	Barren land (BL)	3.99	3.74	3.23	2.50	1.29
Factor Means	Depth	(0-5)	(5-15)	(15-30)	(30-60)	(60-100)
		5.75	5.40	3.76	2.55	1.44
	Land use	RW	FL	MW	BL	
		3.63	4.82	3.74	2.96	
	Season	*Kharif*	*Rabi*			
		3.89	3.69			
LSD ($p \leq 0.05$)	Seasons (S) = N/S Land use (L) = N/S Depth (D) = 0.08 SxL = N/S SxD = N/S LxD = 0.25 SxLxD = N/S					

Note: Soil oxidizable organic carbon (g kg^{-1})

It was revealed from the data presented in table 4.13, that the mean value of soil oxidizable organic carbon was highest in forest land (4.82 g kg^{-1}) followed by maize-wheat (3.74 g kg^{-1}), rice-wheat (3.63 g kg^{-1}) and was found to be lowest in barren land (2.96 g kg^{-1}). The soil oxidizable organic carbon values decreased with increasing soil depth in all land use systems. The mean value of soil oxidizable organic carbon was highest in the 0-5 cm depth (5.75 g kg^{-1}), followed by 5-15 cm depth (5.40 g kg^{-1}) and was lowest in the 60-100 cm depth (1.44 g kg^{-1}). The soils of *Rabi* season showed lower values of soil oxidizable organic carbon (3.69 g kg^{-1}) as compared to the soils of *Kharif* season (3.89 g kg^{-1}). The effect of depth and interactive effect of land use and depth were significant. The effect of different land use system and seasonal variations on soil oxidizable organic carbon at different depths is depicted in fig. 4.2.

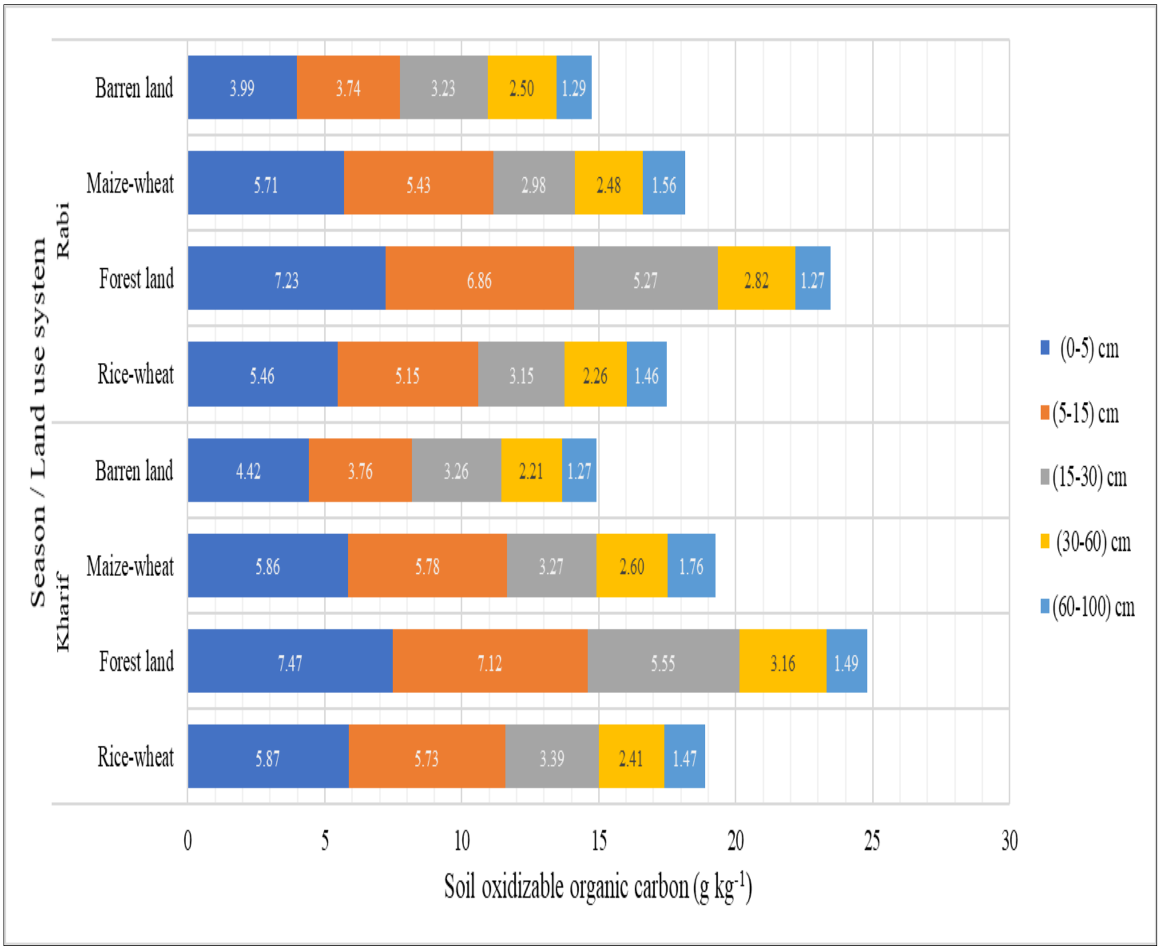

Fig. 4.2: Effect of different land use systems and seasonal variations on soil oxidizable organic carbon at different depths.

4.2.3 Effect of different land use systems and seasonal variations on aggregate associated organic carbon at different depths.

Table 4.14a: Aggregate associated organic carbon {macro-aggregates}

Season	Land use	Depth (cm)				
		(0-5)	(5-15)	(15-30)	(30-60)	(60-100)
Kharif	Rice-wheat (RW)	7.26	7.18	5.59	3.75	2.54
	Forest land (FL)	8.39	8.28	6.29	4.22	3.30
	Maize-wheat (MW)	7.49	7.08	5.40	3.72	3.18
	Barren land (BL)	6.63	6.25	5.31	3.64	2.53
Rabi	Rice-wheat (RW)	8.42	7.84	6.81	4.94	3.38
	Forest land (FL)	8.85	8.52	6.87	5.27	3.68
	Maize-wheat (MW)	7.98	7.36	5.8	4.74	3.46
	Barren land (BL)	6.86	6.41	5.57	4.03	2.85
Factor Means	Depth	(0-5)	(5-15)	(15-30)	(30-60)	(60-100)
		7.73	7.36	5.95	4.28	3.11
	Land use	RW	FL	MW	BL	
		5.77	6.36	5.62	5.00	
	Season	*Kharif*	*Rabi*			
		5.40	5.98			
LSD ($p \leq 0.05$)	Seasons (S) = N/S Land use (L) = N/S Depth (D) = N/S SxL = 0.24 SxD = 0.26 LxD = 0.37 SxLxD = N/S					

Note: Aggregate associated organic carbon {macro-aggregates} (g kg^{-1})

It was concluded from the data presented in table 4.14a, that the mean value of aggregate associated organic carbon (macro-aggregates) was highest in forest land (6.36 g kg^{-1}) followed by rice-wheat (5.77 g kg^{-1}), maize-wheat (5.62 g kg^{-1}) and was found to be lowest in barren land (5.00 g kg^{-1}). The aggregate associated organic carbon (macro-aggregates) values decreased with increasing soil depth in all land use systems. The mean value of aggregate associated organic carbon (macro-aggregates) was highest in the 0-5 cm depth (7.73 g kg^{-1}), followed by 5-15 cm depth (7.36 g kg^{-1}) and was lowest in the 60-100 cm depth (3.11 g kg^{-1}). The soils of *Rabi* season showed greater values of aggregate associated organic carbon (macro-aggregates) (5.98 g kg^{-1}) as compared to the soils of *Kharif* season (5.40 g kg^{-1}). The interactive effect of season and land use, season and depth, land use and depth were significant. The effect of different land use systems and seasonal variations on aggregate associated organic (macro-aggregates) carbon at different depths is depicted in fig. 4.3a.

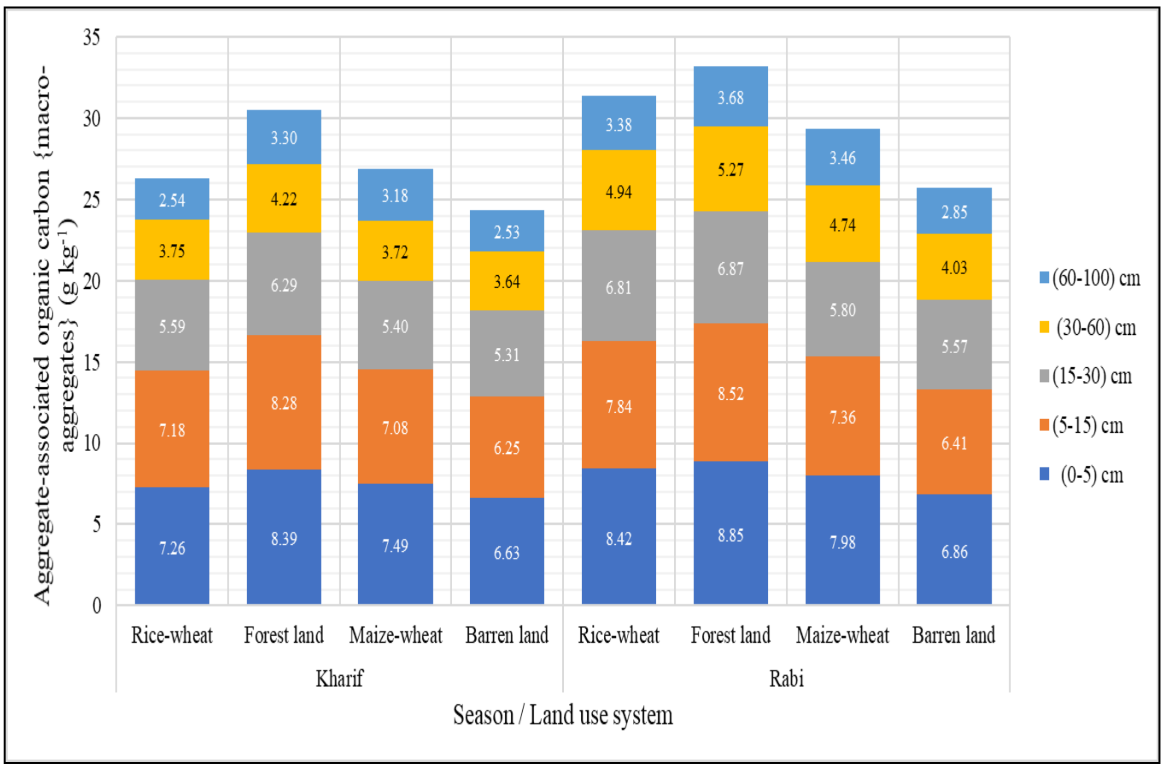

Fig. 4.3a: Effect of different land use systems and seasonal variations on aggregate associated organic carbon (macro-aggregates) at different depths

Table 4.14b: Aggregate associated organic carbon {micro-aggregates} (g kg^{-1})

Season	Land use	Depth (cm)				
		(0-5)	(5-15)	(15-30)	(30-60)	(60-100)
Kharif	Rice-wheat (RW)	7.24	6.52	5.53	3.69	3.49
	Forest land (FL)	8.01	7.78	6.50	4.56	3.40
	Maize-wheat (MW)	7.45	6.96	5.32	3.81	2.83
	Barren land (BL)	6.38	6.00	5.06	4.52	2.66
Rabi	Rice-wheat (RW)	7.30	7.03	5.64	3.80	3.65
	Forest land (FL)	8.10	7.79	6.68	4.65	3.55
	Maize-wheat (MW)	7.48	7.03	5.46	3.93	2.96
	Barren land (BL)	6.40	6.09	5.15	4.68	2.58
Factor Means	Depth	(0-5)	(5-15)	(15-30)	(30-60)	(60-100)
		7.30	6.90	5.67	4.21	3.14
	Land use	RW	FL	MW	BL	
		5.39	6.10	5.32	4.95	
	Season	*Kharif*	*Rabi*			
		5.39	5.50			
LSD ($p \leq 0.05$)	Seasons (S) = N/S Land use (L) = N/S Depth (D) = N/S SxL = 0.21 SxD = 0.25 LxD = 0.33 SxLxD = N/S					

Note: Aggregate associated organic carbon {micro-aggregates} (g kg^{-1})

It was concluded from the data presented in table 4.14b, that the mean value of aggregate associated organic carbon (micro-aggregates) was highest in forest land (6.10 g kg^{-1}) followed by rice-wheat (5.39 g kg^{-1}), maize-wheat (5.32 g kg^{-1}) and was found to be lowest in barren land (4.95 g kg^{-1}). The aggregate associated organic carbon (micro-aggregates) values decreased with increasing soil depth in all land use systems. The mean value of aggregate associated organic carbon (micro-aggregates) was highest in the 0-5 cm depth (7.30 g kg^{-1}), followed by 5-15 cm depth (6.90 g kg^{-1}) and was lowest in the 60-100 cm depth (3.14 g kg^{-1}). The soils of *Rabi* season showed greater values of aggregate associated organic carbon (micro-aggregates) (5.50 g kg^{-1}) as compared to the soils of *Kharif* season (5.39 g kg^{-1}). The interactive effect of season and land use, season and depth, land use and depth were significant. The effect of different land use systems and seasonal variations on aggregate associated organic carbon (micro-aggregates) at different depths is depicted in fig. 4.3b.

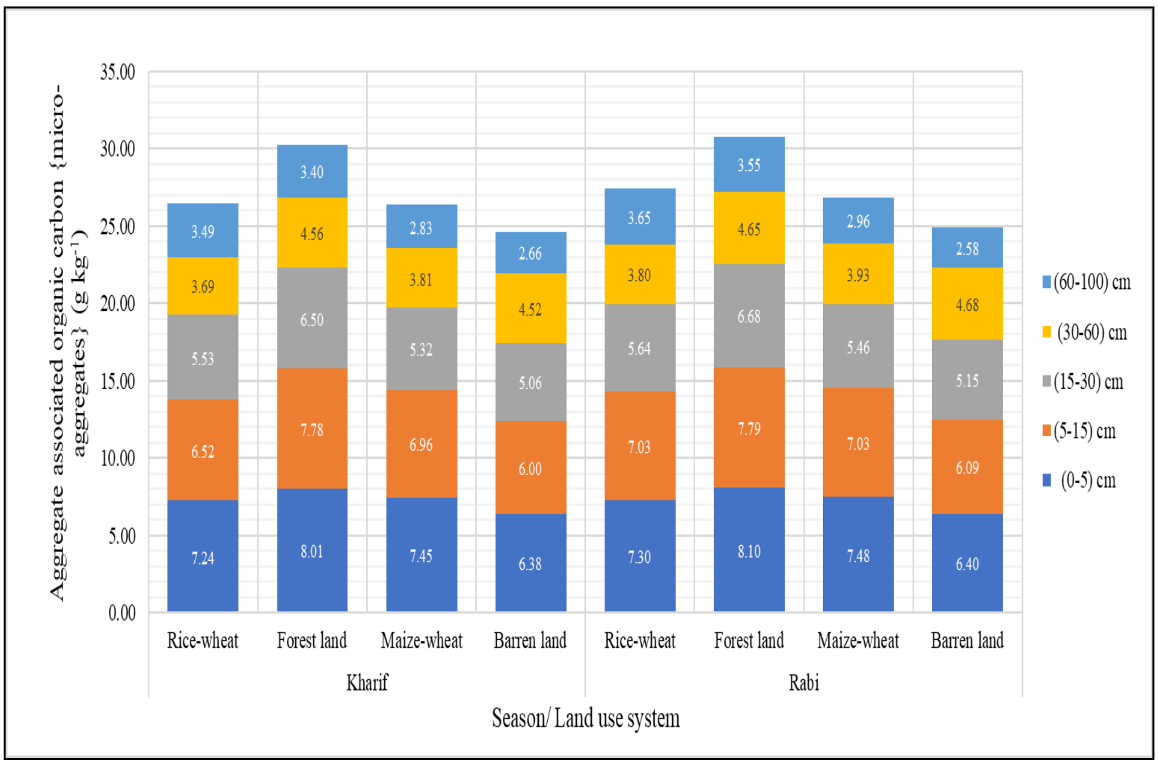

Fig. 4.3b: Effect of different land use systems and seasonal variations on aggregate associated organic carbon (micro-aggregates) at different depths

4.2.4 Effect of different land use systems and seasonal variations on hot water soluble carbon at different depths.

Table 4.15: Hot water-soluble carbon

Season	Land use	Depth (cm)				
		(0-5)	(5-15)	(15-30)	(30-60)	(60-100)
Kharif	Rice-wheat (RW)	0.57	0.52	0.36	0.25	0.10
	Forest land (FL)	0.79	0.74	0.58	0.30	0.14
	Maize-wheat (MW)	0.56	0.51	0.38	0.26	0.11
	Barren land (BL)	0.27	0.23	0.18	0.17	0.10
Rabi	Rice-wheat (RW)	0.35	0.28	0.23	0.19	0.13
	Forest land (FL)	0.49	0.55	0.46	0.34	0.21
	Maize-wheat (MW)	0.40	0.35	0.29	0.21	0.10
	Barren land (BL)	0.23	0.21	0.21	0.16	0.10
Factor Means	Depth	(0-5)	(5-15)	(15-30)	(30-60)	(60-100)
		0.45	0.42	0.33	0.23	0.12
	Land use	RW	FL	MW	BL	
		0.29	0.46	0.31	0.18	
	Season	*Kharif*	*Rabi*			
		0.35	0.27			
LSD (p≤0.05)	Seasons (S) = N/S Land use (L) = N/S Depth (D) = N/S SxL = N/S SxD = N/S LxD = N/S SxLxD = 0.06					

Note: Hot water-soluble carbon (g kg^{-1})

From the perusal of Table 4.15, it was concluded that the mean value of hot water-soluble carbon was highest in forest land (0.46 g kg^{-1}) followed by maize-wheat (0.31 g kg^{-1}), rice-wheat (0.29 g kg^{-1}) and was found to be lowest in barren land (0.18 g kg^{-1}). The hot water-soluble carbon values decreased with increasing soil depth in all land use systems. The mean value of hot water-soluble carbon was highest in the 0-5 cm depth (0.45 g kg^{-1}), followed by 5-15 cm depth (0.42 g kg^{-1}) and was lowest in the 60-100 cm depth (0.12 g kg^{-1}). The soils of *Kharif* season showed higher values of hot water-soluble carbon (0.35 g kg^{-1}) as compared to the soils of *Rabi* season (0.27 g kg^{-1}). The interactive effect of season, land use and depth were significant. The effect of different land use systems and seasonal variations on hot water-soluble carbon at different depths is depicted in fig. 4.4.

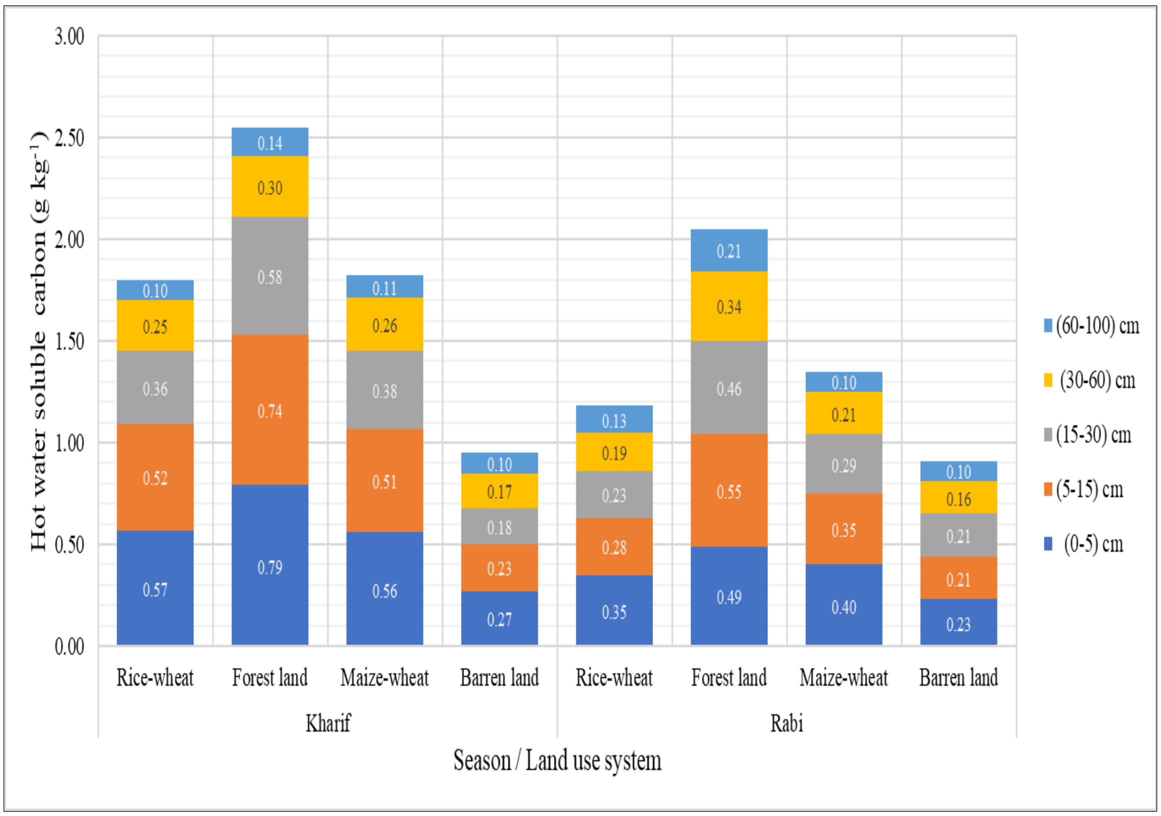

Fig. 4.4: **Effect of different land use systems and seasonal variations on hot water-soluble carbon at different depths**

4.2.5 Effect of different land use systems and seasonal variations on particulate organic carbon at different depths.

Table 4.16: Particulate organic carbon

<table>
<tr><th rowspan="2">Season</th><th rowspan="2">Land use</th><th colspan="5">Depth (cm)</th></tr>
<tr><th>(0-5)</th><th>(5-15)</th><th>(15-30)</th><th>(30-60)</th><th>(60-100)</th></tr>
<tr><td rowspan="4">Kharif</td><td>Rice-wheat (RW)</td><td>4.81</td><td>4.58</td><td>2.42</td><td>1.47</td><td>0.80</td></tr>
<tr><td>Forest land (FL)</td><td>6.32</td><td>5.99</td><td>4.87</td><td>2.16</td><td>1.84</td></tr>
<tr><td>Maize-wheat (MW)</td><td>4.78</td><td>4.64</td><td>2.80</td><td>1.54</td><td>0.66</td></tr>
<tr><td>Barren land (BL)</td><td>2.87</td><td>2.61</td><td>2.96</td><td>0.93</td><td>0.59</td></tr>
<tr><td rowspan="4">Rabi</td><td>Rice-wheat (RW)</td><td>5.07</td><td>4.80</td><td>2.58</td><td>1.53</td><td>1.00</td></tr>
<tr><td>Forest land (FL)</td><td>6.38</td><td>6.06</td><td>5.30</td><td>2.49</td><td>1.97</td></tr>
<tr><td>Maize-wheat (MW)</td><td>4.93</td><td>4.67</td><td>3.09</td><td>1.89</td><td>0.80</td></tr>
<tr><td>Barren land (BL)</td><td>5.96</td><td>5.51</td><td>3.57</td><td>3.13</td><td>1.95</td></tr>
<tr><td rowspan="6">Factor Means</td><td rowspan="2">Depth</td><td>(0-5)</td><td>(5-15)</td><td>(15-30)</td><td>(30-60)</td><td>(60-100)</td></tr>
<tr><td>5.14</td><td>4.85</td><td>3.44</td><td>1.89</td><td>1.20</td></tr>
<tr><td rowspan="2">Land use</td><td>RW</td><td>FL</td><td>MW</td><td>BL</td><td rowspan="2"></td></tr>
<tr><td>2.90</td><td>4.33</td><td>2.98</td><td>3.00</td></tr>
<tr><td rowspan="2">Season</td><td>Kharif</td><td>Rabi</td><td colspan="3" rowspan="2"></td></tr>
<tr><td>2.98</td><td>3.63</td></tr>
<tr><td>LSD (p≤0.05)</td><td colspan="6">Seasons (S) = N/S
Land use (L) = N/S
Depth (D) = N/S
SxL = N/S
SxD = N/S
LxD = N/S
SxLxD = 0.44</td></tr>
</table>

Note: Particulate organic carbon (g kg^{-1})

It was revealed from the data presented in table 4.2.5, mean value of particulate organic carbon was highest in forest land (4.33 g kg^{-1}) followed by maize-wheat (2.98 g kg^{-1}), rice-wheat (2.90 g kg^{-1}) and was found to be lowest in barren land (3.00 g kg^{-1}). The particulate organic carbon values decreased with increasing soil depth in all land use systems. The mean value of particulate organic carbon was highest in the 0-5 cm depth (5.14 g kg^{-1}), followed by 5-15 cm depth (4.85 g kg^{-1}) and was lowest in the 60-100 cm depth (1.20 g kg^{-1}). The soils of *Rabi* season showed higher values of particulate organic carbon (3.63 g kg^{-1}) as compared to the soils of *Kharif* season (2.98 g kg^{-1}). The interactive effect of season, land use and depth were significant. The effect of different land use systems and seasonal variations on particulate organic carbon at different depths is depicted in fig 4.5.

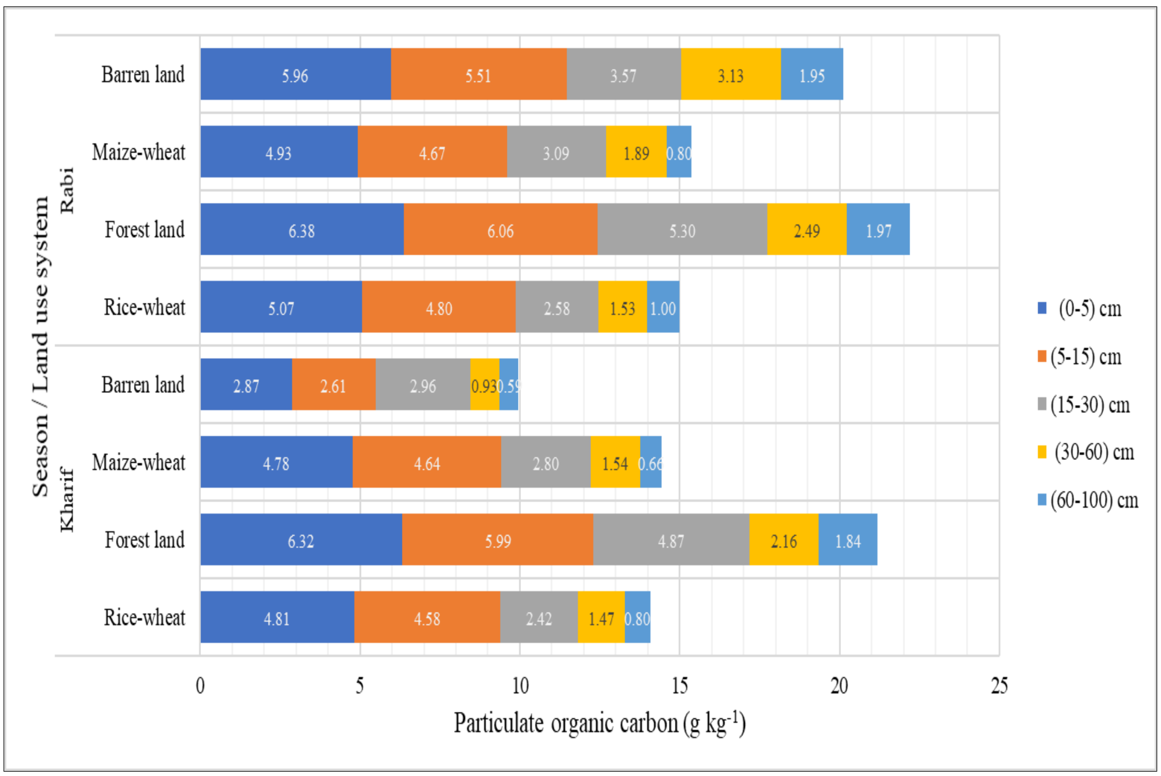

Fig. 4.5: Effect of different land use systems and seasonal variations on particulate organic carbon at different depths

4.2.6 Effect of different land use systems and seasonal variations on microbial biomass carbon at different depths.

Table 4.17: Microbial biomass carbon (mg kg^{-1})

Season	Land use	Depth **(cm)**				
		(0-5)	(5-15)	(15-30)	(30-60)	(60-100)
Kharif	Rice-wheat (RW)	93.12	83.59	73.87	52.13	38.15
	Forest land (FL)	100.73	94.17	81.83	65.33	46.97
	Maize-wheat (MW)	94.98	86.98	69.03	50.74	36.74
	Barren land (BL)	76.93	70.01	52.16	38.60	29.97
Rabi	Rice-wheat (RW)	88.83	79.51	71.91	49.35	37.05
	Forest land (FL)	96.92	92.77	79.31	63.94	45.56
	Maize-wheat (MW)	91.80	82.05	67.38	47.17	36.28
	Barren land (BL)	73.93	68.42	51.29	37.35	29.86
Factor Means	Depth	(0-5)	(5-15)	(15-30)	(30-60)	(60-100)
		89.65	82.18	68.34	50.57	37.57
	Land use	RW	FL	MW	BL	
		66.75	76.75	66.31	52.85	
	Season	*Kharif*	*Rabi*			
		66.80	64.53			
LSD ($p \leq 0.05$)	Seasons (S) = 1.43 Land use (L) = N/S Depth (D) = N/S SxL = N/S SxD = N/S LxD = 4.53 SxLxD = N/S					

Note: Microbial biomass carbon (mg kg^{-1})

From the perusal of table 4.17, it was revealed that the mean value of microbial biomass carbon was highest in forest land (76.75 mg kg^{-1}) followed by rice-wheat (66.75 mg kg^{-1}), maize-wheat (66.31 mg kg^{-1}) and was found to be lowest in barren land (52.85 mg kg^{-1}). The microbial biomass carbon values decreased with increasing soil depth in all land use systems. The mean value of microbial biomass carbon was highest in the 0-5 cm depth (89.65 mg kg^{-1}), followed by 5-15 cm depth (82.18 mg kg^{-1}) and was lowest in the 60-100 cm depth (37.57 mg kg^{-1}). The soils of *Rabi* season showed lower values of microbial biomass carbon (64.53 mg kg^{-1}) as compared to the soils of *Kharif* season (66.80 mg kg^{-1}). The effect of season, and interactive effect of land use and depth were significant. The effect of different land use systems and seasonal variations on microbial biomass carbon at different depths is depicted in fig 4.6.

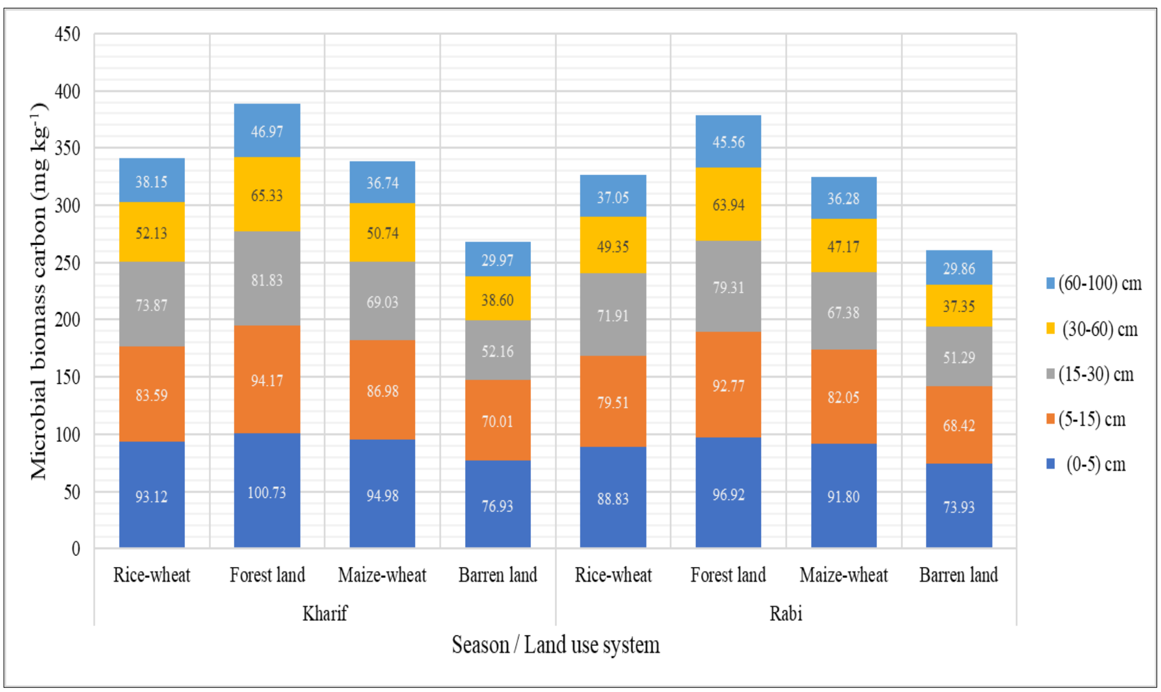

Fig. 4.6: Effect of different land use systems and seasonal variations on microbial biomass carbon at different depths

4.3 Coefficient of Correlation between Different Soil Properties in *Kharif* Season

Table 4.18: Coefficient of correlation between different soil properties in *Kharif* season

	pH	EC	BD	PD	MWHC	MacroAW	MacroAD	MicroAW	MicroAD	MWD	TOC	SOC	AAOC	HWC	POC	MBC	Sand	Silt	Clay
pH	1.00	-0.36	0.59*	0.54*	-0.30	-0.54*	-0.48	0.11	-0.02	-0.22	-0.13	-0.66*	-0.66*	-0.61*	-0.61*	-0.66*	-0.09	0.23	-0.10
EC		1.00	-0.47	-0.44	0.21	0.61*	0.52*	-0.53*	-0.45	0.44	0.46	0.69*	0.68*	0.64*	0.66*	0.62*	0.06	0.13	-0.15
BD			1.00	0.93*	-0.49*	-0.65*	-0.59*	0.19	0.07	-0.42	-0.23	-0.73*	-0.76*	-0.68*	-0.69*	-0.78*	-0.11	0.23	-0.09
PD				1.00	-0.51*	-0.68*	-0.61*	0.22	0.10	-0.41	-0.28	-0.73*	-0.78*	-0.72*	-0.72*	-0.78*	-0.12	0.27	-0.11
MWHC					1.00	0.78*	0.81*	-0.13	-0.15	0.73*	0.41	0.54*	0.52*	0.60*	0.54*	0.63*	-0.11	-0.30	0.33
MacroAW						1.00	0.94*	-0.39	-0.35	0.76*	0.59*	0.86*	0.81*	0.87*	0.83*	0.86*	0.03	-0.18	0.12
MacroAD							1.00	-0.38	-0.39	0.85*	0.64*	0.77*	0.73*	0.81*	0.78*	0.79*	0.02	-0.19	0.13
MicroAW								1.00	0.94*	-0.48	-0.85*	-0.40	-0.35	-0.38	-0.50*	-0.25	0.15	-0.45	0.23
MicroAD									1.00	-0.56*	-0.89*	-0.27	-0.23	-0.29	-0.40	-0.15	0.19	-0.45	0.19
MWD										1.00	0.75*	0.48	0.44	0.52*	0.52*	0.54*	-0.04	-0.02	0.05
TOC											1.00	0.42	0.36	0.47	0.51*	0.36	-0.21	0.28	0.78*
SOC												1.00	0.95*	0.93*	0.94*	0.92*	0.09	-0.18	0.57*
AAOC													1.00	0.90*	0.92*	0.93*	0.08	-0.23	0.61*
HWC														1.00	0.94*	0.89*	0.03	-0.18	0.59*
POC															1.00	0.87*	0.07	-0.16	0.67*
MBC																1.00	0.10	-0.30	0.80*
Sand																	1.00	-0.27	-0.64*
Silt																		1.00	-0.56*
Clay																			1.00

Note: *correlation is significant at 5% level.

EC (Electrical conductivity), BD (Bulk density), PD (Particle density), MWHC (Maximum water holding capacity), MacroAW (Water-stable macro-aggregates), MacroAD (Dry-stable macro-aggregates), MicroAW (Water-stable micro-aggregates), MicroAD (Dry-stable micro-aggregates), MWD (Mean weight diameter), TOC (Total organic carbon), SOC (Soil oxidizable organic carbon), AAOC (Aggregate-associated organic carbon), HWC (Hot water- soluble carbon), POC (Particulate organic carbon), MBC (Microbial biomass carbon)

Data from the above table 4.18, revealed that in *Kharif* season, clay was positively significantly correlated with TOC (r = 0.78*), SOC (r = 0.57*), AAOC (r = 0.61*), HWC (r = 0.59*), POC (r = 0.67*) and MBC (r = 0.80*). MacroAW were found to be positively significantly correlated with TOC (r = 0.59*), SOC (r = 0.86*), AAOC (r = 0.81*), HWC (r = 0.87*), POC (r = 0.83*) and MBC (r = 0.86*). MacroAD were also found to be positively significantly correlated with TOC (r = 0.64*), SOC (r = 0.77*), AAOC (r = 0.73*), HWC (r = 0.81*), POC (r = 0.78*) and MBC (r = 0.79*).

4.4 Coefficient of Correlation between Different Soil Properties in *Rabi* Season

Table 4.19: Coefficient of correlation between the different soil properties in *Rabi* season

	pH	EC	BD	PD	MWHC	MacroAW	MacroAD	MicroAW	MicroAD	MWD	TOC	SOC	AAOC	HWC	POC	MBC	Sand	Silt	Clay
pH	1.00	-0.49	0.59*	0.61*	-0.44	-0.64*	-0.63*	0.29	0.20	-0.46	-0.35	-0.69*	-0.69*	-0.61*	-0.69*	-0.68*	-0.07	0.17	-0.09
EC		1.00	-0.54*	-0.56*	0.26	0.59*	0.52*	-0.57*	-0.47	0.43	0.50*	0.76*	0.67*	0.53*	0.71*	0.69*	0.03	0.11	-0.13
BD			1.00	0.99*	-0.56*	-0.65*	-0.60*	0.24	0.12	-0.44	-0.27	-0.74*	-0.81*	-0.57*	-0.73*	-0.81*	-0.12	0.26	-0.11
PD				1.00	-0.57*	-0.66*	-0.61*	0.29	0.16	-0.45	-0.31	-0.75*	-0.82*	-0.58*	-0.74*	-0.81*	-0.13	0.26	-0.10
MWHC					1.00	0.82*	0.84*	-0.20	-0.19	0.71*	0.46	0.57*	0.60*	0.74*	0.60*	0.66*	-0.05	-0.30	0.32
MacroAW						1.00	0.95*	-0.44	-0.38	0.78*	0.64*	0.82*	0.78*	0.87*	0.82*	0.84*	0.03	-0.16	0.11
MacroAD							1.00	-0.42	-0.41	0.85*	0.67*	0.75*	0.71*	0.86*	0.77*	0.78*	0.02	-0.16	0.12
MicroAW								1.00	0.94*	-0.52*	-0.87*	-0.46	-0.32	-0.40	-0.55*	-0.33	0.15	-0.36	0.17
MicroAD									1.00	-0.59*	-0.90*	-0.30	-0.17	-0.35*	-0.43	-0.20	0.18	-0.38	0.16
MWD										1.00	0.78*	0.48	0.44	0.67*	0.55*	0.55*	-0.05	-0.05	0.09
TOC											1.00	0.46	0.35	0.57*	0.54*	0.41	-0.21	0.26	0.70*
SOC												1.00	0.92*	0.78*	0.94*	0.91*	0.10	-0.15	0.59*
AAOC													1.00	0.74*	0.89*	0.94*	0.07	-0.25	0.71*
HWC														1.00	0.79*	0.77*	0.11	-0.16	0.63*
POC															1.00	0.88*	0.08	-0.14	0.58*
MBC																1.00	0.06	-0.24	0.78*
Sand																	1.00	-0.43	-0.60*
Silt																		1.00	-0.46
Clay																			1.00

Note: *correlation is significant at 5% level.

EC (Electrical conductivity), BD (Bulk density), PD (Particle density), MWHC (Maximum water holding capacity), MacroAW (Water-stable macro-aggregates), MacroAD (Dry-stable macro-aggregates), MicroAW (Water-stable micro-aggregates), MicroAD (Dry-stable micro-aggregates), MWD (Mean weight diameter), TOC (Total organic carbon), SOC (Soil oxidizable organic carbon), AAOC (Aggregate-associated organic carbon), HWC (Hot water- soluble carbon), POC (Particulate organic carbon), MBC (Microbial biomass carbon)

From the perusal of the above table 4.19, it was revealed that in *Rabi* season, clay was positively significantly correlated with TOC (r = 0.70*), SOC (r = 0.59*), AAOC (r = 0.71*), HWC (r = 0.63*), POC (r = 0.58*) and MBC (r = 0.78*). MacroAW were found to be positively significantly correlated with TOC (r = 0.64*), SOC (r = 0.82*), AAOC (r = 0.78*), HWC (r = 0.87*), POC (r = 0.82*) and MBC (r = 0.84*). MacroAD were also found to be positively significantly correlated with TOC (r = 0.67*), SOC (r = 0.75*), AAOC (r = 0.71*), HWC (r = 0.86*), POC (r = 0.77*) and MBC (r = 0.78*).

Chapter-5

Discussion

Chapter-5

Discussion

The results of the investigation entitled 'Impact of land use system and seasonal variations on aggregate associated soil carbon in outer Himalayas' are presented in the foregoing chapter and have been discussed under following sub-headings:

5.1 Effect of Different Land-Use Systems and Seasonal Variations on Physical Properties of Soil at Different Depths.

5.1.1 pH

5.1.2 Electrical conductivity (EC)

5.1.3 Bulk density

5.1.4 Particle density

5.1.5 Soil texture

5.1.6 Maximum water holding capacity

5.1.7 Water-stable macro-aggregates

5.1.8 Dry-stable macro-aggregates

5.1.9 Water-stable micro-aggregates

5.1.10 Dry-stable micro-aggregates

5.1.11 Mean weight diameter

5.2 Effect of Different Land-Use Systems and Seasonal Variations on Carbon Pools and Stocks at Different Depths.

5.2.1 Total organic carbon

5.2.2 Soil oxidizable organic carbon

5.2.3 Aggregate associated organic carbon

5.2.4 Hot water-soluble carbon

5.2.5 Particulate organic carbon

5.2.6 Microbial biomass carbon

5.3 Coefficient of Correlation between Different Soil Properties in *Kharif* Season

5.4 Coefficient of Correlation between Different Soil Properties in *Rabi* Season

5.1 Effect of Different Land Use Systems and Seasonal Variations on Physical Properties of Soil at Different Depths.

5.1.1 pH

The mean value of pH was found to be lowest in forest-land and was highest in barren-land. This may be due to the presence of high organic acids, viz. humin, humic and fulvic acids in forest land. However, there is negligible presence of organic matter in barren land. There is depletion of cations in soils of barren land due to over-exposure to over-grazing, wind and water. As far as rice-wheat and maize-wheat land use systems are concerned, the mean value of pH was found to be statistically significant. However, the trend was following a linear pattern. Similar values were observed by Kukal *et al.* (2014) and Bhowmik *et al.* (2019). The average value of pH in all land use systems showed an increasing trend with increase in depth because of the deposition of anions in lower depths due to rainfall and irrigation. The present study is in conformity with the findings of Gupta (1994) and Bessah *et al.* (2016). The mean value of pH was lower in *Kharif* season as compared to the *Rabi* season. It is evident that there is an increase in degree of ionization due to rainfall that releases more H^+ ions in the soil and are responsible for causing acidity in *Kharif* season. Similar trend was observed by Ndukwu *et al.* (2010), Patel *et al.* (2015) and Osobamiro *et al.* (2018).

5.1.2 Electrical conductivity (EC)

The mean value of EC was found to be highest in barren land, followed by maize-wheat, rice-wheat and was lowest in forest land. The electrical conductivity in all land use systems of the study area was below the safe limit of 1 dS m^{-1} for growing any crop, with the lowest mean value in the forest. It may be due to salt accumulation in barren lands and a high amount of decomposing litter in forests. Similar trend was observed by Kiflu and Beyene (2013). A slightly decreasing trend in EC with increasing depth was observed among all the land use systems, which could be due to the slow mobility of various ion salts (Cl, SO_4^{2-}, HCO_3^-, CO_3^{2-}, Na^+, Ca^{2+}, Mg^{2+}, and K^+) towards lower horizons or low concentration of soluble salts due to rapid water movement through the soil profile (Sondhi 1992; Nazir 1993). The high EC value in the surface layer compared to the subsurface layers could also be attributed to the upward movement of soluble salts to the surface via capillary rise of water in submontane soil under the current "hyperthermic" temperature regime (Sondhi, 1992). The value of EC was lowest in *Kharif* season as compared to *Rabi* because before the onset of *Kharif* season, the soils were exposed to less rainfall and climatic vagaries. The present work is in conformity with the findings of Mirza and Patil, (2020).

5.1.3 Bulk density

The mean value of bulk density was found to be lowest in case of forest land and highest value was observed in case of barren land followed by rice-wheat and maize-wheat land use systems. Litter decomposition and microbial activity in the forest area resulted in an increase in organic matter content, thus lowering bulk density. The results are in conformity with the findings of Agbeshie *et al.* (2020). Paltineanu *et al.* (2019) also reported increased soil bulk density in agricultural and barren lands, due to tillage, management, and cultivation operations. A significantly higher bulk density was observed in the (60-100) cm depth and least was found in the (0-5) cm depth in all land use systems. This may be attributed to the fact that with an increase in depth, soil compaction increases and organic matter decreases. Similar results were reported by Sharma *et al.* (2014), Bessah *et al*. (2016) and Hussain *et al.* (2019). The higher bulk density observed during the *Kharif* season could be due to increased soil management practices and field equipment operation at this time of year. The results are in conformity with the observations of Omer *et al.* (2018).

5.1.4 Particle density

The mean value of particle density was found to be lowest in case of forest land and highest value was observed in case of barren land followed by rice-wheat and maize-wheat land use systems. Barren soils being more prone to soil erosion, showed significantly higher particle density due to removal of silt particles, low soil organic carbon and due to the impact of falling raindrops. A significantly higher particle density was observed in the (60-100) cm depth and least was found in the (0-5) cm depth in all land use systems because of decrease in organic matter and reduced aggregation in sub-surface layers. However, due to the presence of more clay content and organic matter in forest soils, forest soils showed significantly lower particle density. Similar results were obtained by Sharma *et al.* (2014), Paltineanu *et al.* (2019) and Agbeshie *et al.* (2020).

5.1.5 Soil texture

The forest land showed the highest percentage of clay content amongst all the land use systems because of the presence of root and microbial biomass in forest land which acts as a binding agent for the finer particles, thus becoming less prone to erosion. When compared to forest land, both cultivated and barren land contained significantly less clay content. This could be due to the reason that the finer particles get washed away by excessive overland flow of water during the rainy season which is further aggravated by decrease or less vegetation cover in barren land. The results are in conformity with the findings of Agbeshie *et al.* (2020). As far as rice-wheat and maize-wheat systems are concerned, a higher percentage of clay content was found in rice-wheat system, as compared to the maize-wheat land use system, this is attributed to the fact that land remains under submergence for a larger time span due to paddy cultivation. Similar results were reported by Kukal *et al.* (2014). In all land uses, the soil followed a consistent pattern of clay content present in lower depths. The increased clay concentration in the subsurface depth (60-100) cm can be attributed to the process of soil formation process viz. illuviation. Gupta and Tripathi (1992) in North-West Himalayan soils and Gupta and Verma (1992) in *Kandi* soils of Jammu district made similar observations. Gupta (1994) reported that Sandy loam was the major textural class, followed by sandy clay loam in Shiwaliks of Jammu.

5.1.6 Maximum water holding capacity

The highest maximum water holding capacity values were found in the forest, while the lowest were found in the barren land use system. The variation in clay and organic carbon content, as well as the heterogeneity of parent material, could explain the difference in water holding capacity under different land uses. Sathyavathi and Reddy (2004) found similar results in the soils of the Sivagiri micro-watershed in the Chittoor district of Andhra Pradesh's Telangana region. Gol (2009) found a similar pattern in maximum water retention capacity in forest and agriculture land use. The maximum values were found in forest soils, which could be attributable to higher soil organic matter and finer clay content. A significantly higher maximum water holding capacity was found in the surface layer (0-5) cm, while the minimum value was found in the lowest subsurface depth (60-100) cm in all land use systems, which may be due to presence of high organic matter and low bulk density in the surface layer. Similar observations were made by Khan and Kamalkar (2012) and Kumar *et al.* (2019). The *Kharif* season showed higher mean value of maximum water holding capacity as compared to *Rabi* season because during the *Kharif* season the soil pores get filled with water due to rainfall. In case of *Rabi* season, which is drier and as the rainfall is negligible and evaporation losses are more, the value of maximum water holding capacity is on the lower side. Similar trend was obtained by Patel *et al.* (2015).

5.1.7 Water-stable macro-aggregates

The mean value of water-stable macro-aggregates (>0.25 mm) was found to be significantly higher in case of forest land, followed by rice-wheat, maize-wheat and was lowest in barren land. The increased percentage of water-stable macro-aggregates in forest soils as compared to cultivated soils showed an increase in macro-aggregate turnover caused by disturbance. Similar trend was obtained by Saha *et al.* (2011). The labile fraction of soil organic matter (SOM) that binds micro-aggregates to form macro-aggregates is extremely sensitive to land use change and cultivation (Ashagire *et al.* 2007). In case of barren land, the shearing force of runoff water, along with the kinetic energy of striking raindrops, disperses the aggregates and exposes the organic content. Soil organic matter is preferentially removed by surface runoff and blowing winds because it is concentrated in the surface soil and has a low density (Lal 2003). The decrease in water-stable macro-aggregates with soil depth could be attributed to the less organic carbon in lower layers. Gupta *et al.* (2009) also reported higher water-stable macro-aggregate values at lower depths under all land uses could be attributable to deep roots with minimal disturbance in the subsurface layer. The *Rabi* season showed significantly greater percentage of water-stable macro-aggregates as compared to *Kharif* season as it is evident from the fact that higher temperature during *Kharif* season induces disruption of macro-aggregates into micro-aggregates as temperature has a negative impact on soil aggregation especially when temperature is above 30℃. The present finding is in conformity with the study of Omer *et al.* (2018).

5.1.8 Dry-stable macro-aggregates

The mean value of dry-stable macro-aggregates (>0.25 mm) was found to be significantly higher in case of forest land, followed by rice-wheat, maize-wheat and was lowest in barren land which is attributable to less disturbance and presence of organic matter in forest soils and vice-versa in case of rice-wheat, maize-wheat, and barren land. Organic matter in the soil, especially humic compounds, has been shown to play a crucial influence in the stability of soil aggregates (Piccolo *et al.* 1997; Bronick and Lal 2005). The decrease in dry-stable macro-aggregates with soil depth could be attributed to the lower layers containing less organic carbon. The results are in conformity with the findings of Gupta *et al.* (2009). The *Rabi* season showed significantly higher percentage of dry-stable macro-aggregates as compared to *Kharif* season because high temperature during *Kharif* season induces disruption of macro-aggregates into micro-aggregates as temperature has a negative impact on soil aggregation especially when temperature is more than 30^0. Similar results were obtained by Wang *et al.* (2016) and Omer *et al.* (2018).

5.1.9 Water-stable micro-aggregates

The mean value of water-stable micro-aggregates (<0.25 mm) was found to be significantly higher in case of maize-wheat and rice-wheat land use systems, followed by barren land and was lowest in forest land. The mechanical breakdown of macro-aggregates into micro-aggregates in cultivated land use systems is mainly due to tillage and harvest traffic (Lal 1993). The higher percentage of water-stable micro-aggregates in soils of barren land is due to raindrop impact and loss of vegetative cover (Holeplass *et al.* 2004). The increase in water-stable micro-aggregates with soil depth could be attributed to the lower layers containing less organic carbon. The results are similar with the findings of Gupta *et al.* (2009). Because high temperatures during the *Kharif* season cause disruption of macro-aggregates into micro-aggregates and temperature has a negative impact on soil aggregation, especially when temperatures exceed 30°C, the *Kharif* season showed a significantly higher percentage of water-stable micro-aggregates than the *Rabi* season. The results are in conformity with the findings of Wang *et al.* (2016) and Omer *et al.* (2018).

5.1.10 Dry-stable micro-aggregates

The mean value of dry-stable micro-aggregates (<0.25 mm) was found to be significantly higher in case of rice-wheat and maize-wheat land use systems, followed by barren land and was lowest in forest land. In conventionally cultivated areas, due to tillage-induced mechanical breakdown of macro-aggregates (>0.25 mm) into micro-aggregates (<0.25 mm) and their subsequent soil C loss are observed. Similar findings are reported by Gajic *et al.* (2006) and Saha *et al.* (2011). The lower layers of the soil contain less organic carbon, which could explain the increase in dry-stable micro-aggregates with depth. The findings are familiar to those of Gupta *et al.* (2009). The *Kharif* season showed higher percentage of dry-stable micro-aggregates as compared to *Rabi* season as it is evident from the fact that the disintegration of macroaggregates into microaggregates is caused by an increase in temperature, which has a negative impact on soil aggregation and aggregate stability, especially in the high temperature range (30-50 °C). Due to the temperature rise from 4 to 28 °C, soil aggregate stability diminishes, which is similar with the findings of Annabi *et al.* (2004).

5.1.11 Mean weight diameter

The greater the mean weight diameter of a soil sample, the more stable the soil is against erosion agents and degradation. Because of the vegetation cover, which reduces raindrop impact, forest land had the largest mean weight diameter. The lowest mean weight diameter, on the other hand, was found in barren land due to a lack of vegetation cover, low SOC content, and the impact of rainfall. Because of soil disturbance, rice-wheat and maize-wheat land use systems had lower mean weight diameter than forest land. In all land use systems, the mean weight diameter decreased as depth increased. Because of the abundance of leaf litter, microbial biomass, and other organic matter, the uppermost layer (0-5) cm had the largest mean weight diameter. The results agree with those of Gupta *et al.* (2009) and Saha *et al.* (2011). The mean weight diameter was higher in *Kharif* season as compared to the *Rabi* season because of higher temperature in *Kharif* season. Increased temperature and microbial-plant root activity could be causing these temporal changes. Mycorrhizae fungi and their hyphae have a symbiotic interaction with plant roots that could help with aggregation. These results are in conformity with those of Omer *et al.* (2018).

5.2 Effect of Different Land-Use Systems and Seasonal Variations on Carbon Pools and Stocks at Different Depths.

5.2.1 Total organic carbon

The mean value of total organic carbon was found to be highest in case of forest land followed by rice-wheat, maize-wheat, and barren land use systems. Because of higher humus, litter fall, residue assimilation, and external application of organic matter, total organic carbon was highest in forest land as compared to other land use systems. Because of the canopy provided by the trees found in forest land use, litter deposition supports turnover as well as a greater soil moisture content. Also, the forest floors are normally covered with canopy; hence direct impact of sunlight is reduced due to which the oxidation is also reduced. On the other hand, due to low surface cover and tillage practices, total organic carbon is low in barren, rice-wheat, and maize-wheat systems. Also, a decreasing trend with increase in depth was observed in all land use systems due to decrease in organic matter. The observations are in conformity with the study of Mganga *et al.* (2011), Sainepo *et al.* (2018) and Hussain *et al.* (2019). In the *Rabi* season, total organic carbon values were significantly greater, which could be attributable to a significant drop in temperature, which inhibits microbial activity in the soil, organic matter decomposition and therefore is responsible for high organic matter. Li *et al.* (2014b) found that the ideal temperature range for soil microbial activity is 25 to 35 °C. Similar results were obtained by Wang *et al.* (2016).

5.2.2 Soil oxidizable organic carbon

The mean value of soil oxidizable organic carbon was found to be highest in case of forest land followed by maize-wheat, rice-wheat, and barren land use systems. The plantations and forests include high amounts of dead and decomposing litter, which contributes to soil oxidizable organic carbon, whereas agricultural lands have biomass removed repeatedly. Biomass inputs are also lacking in barren lands (Hu *et al.* 2013). Also, a decreasing trend with increase in depth was observed in all land use systems i.e., the upper most depth (0-5) cm showed significantly higher value of soil oxidizable organic carbon as compared to the lower depths in all land use systems. Organic materials are generally added to surface soils by litter fall, external applications, and other means (Sharma *et al.* 2014).

5.2.3 Aggregate associated organic carbon

Because of the abundant litter and biomass returns to the soil, which combine with the decay of roots to contribute to the formation of aggregates, forest land had the highest amount of aggregate associated organic carbon, followed by rice-wheat, maize-wheat, and barren land. Lower aggregate associated organic carbon in barren lands, on the other hand, is due to a lack of vegetation. The aggregate associated organic carbon decreased with increasing depth in all land use systems. This is also due to the continuous addition of leaf litter in the uppermost layer, which causes aggregate formation. Similar results were obtained by Saha *et al.* (2011). In comparison to the *Kharif* season, *Rabi* season had a significantly greater value of aggregate associated organic carbon. However, the macro-aggregates (>0.25 mm) show a greater increase in aggregate-associated organic carbon as compared to the micro-aggregates (<0.25 mm) with decrease in temperature. Temperature rise has a negative effect on soil organic carbon content, soil aggregation, and aggregate stability. Furthermore, as temperature rises, humic acid and humin molecules become less aliphatic and more decomposed (Wang *et al.* 2016).

5.2.4 Hot water-soluble carbon

The mean value of hot water-soluble carbon was found to be highest in case of forest land followed by maize-wheat, rice-wheat and barren land use systems. Because forest lands have more vegetation cover, they have significantly higher hot water-soluble carbon than other land use systems. One thing to keep in mind is that the lower depths of forest land also had a high amount of hot water-soluble carbon due to their deeper root systems. In all land use systems, the hot water-soluble carbon decreased with increasing depth. Organic materials are usually added to surface soils through litter fall, external applications, and other methods. Similar results were obtained by Saha *et al*. (2011). *Kharif* season showed significantly higher value of hot water-soluble carbon as compared to *Rabi* season. The factor contributing to the rapid decline in *Rabi* is the high amount of rain that fell during the *Kharif* season, which had a significant impact on hot water-soluble carbon due to leaching. The present findings are in concurrence with the findings of Jiang *et al.* (2006). Precipitation is the primary control of hot water-soluble carbon content (Guo *et al.* 2018).

5.2.5 Particulate organic carbon

Particulate organic carbon was highest in forest land, followed by maize-wheat and rice-wheat, and was lowest in barren land due to the continuous addition of organic matter in the form of leaf litter, root residues, and root biomass, which is lower in cultivated land use and almost non-existent in barren lands. The value of particulate organic carbon was discovered to be highest in (0-5 cm), as evidenced by the fact that particulate organic carbon is strongly related to root carbon inputs and other organic residues, which are most often concentrated in the surface layers. Similar results were obtained by Saha *et al*. (2011). There is a negative linear relationship between particulate organic carbon and temperature, which explains why the *Rabi* season had significantly higher particulate organic carbon values than the *Kharif* season. Particulate organic carbon is primarily made up of litter residues and microbial debris, and their contents are high when the temperature is low. The low temperature fragments the microbial cells and increases the content of particulate organic carbon. However, higher temperatures and greater precipitation increases leaching, resulting in a decrease in particulate organic carbon. The findings are consistent with those of Wu *et al.* (2021).

5.2.6 Microbial biomass carbon

The mean value of microbial biomass carbon was found to be highest in case of forest land followed by rice-wheat, maize-wheat and barren land use systems. Tillage practises are responsible for the low concentration of microbial biomass carbon in agricultural land use systems. Cultivation has a negative impact on labile carbon (Shrestha *et al.* 2006). Low value of microbial biomass carbon in barren soils may be due to poor vegetation, which results in low microbial activity, as microbial biomass carbon decreases rapidly with distance from the rhizosphere and adding litter to soil improves soil microbial biomass (Paul and Clark, 1996 and Jin *et al.* 2010). The value of microbial biomass carbon was discovered to be highest in (0-5 cm) in all land use systems, as it is evident that the organic materials are generally added to surface soils by litter fall, external applications, and other means (Sharma *et al.* 2014). The *Rabi* season had significantly lower values of microbial biomass carbon, which is because soil microbes are extremely sensitive to temperature changes. When temperature and humidity are optimal, the value of microbial biomass carbon increases. Low moisture and temperature, on the other hand, reduces the proliferation and activity of soil microbes. Similar results were reported by Guo *et al.* (2018), Evangelou *et al.* (2021) and Wu *et al.* (2021).

5.3 Coefficient of Correlation between Different Soil Properties in *Kharif* Season

In *Kharif* season clay was found to be positively significantly correlated with TOC, SOC, AAOC, HWC, POC and MBC. Tisdall and Oades (1982) discovered that the amount of soil organic carbon (SOC) in any given environment increases as soil texture becomes finer. Because fine-textured soils are more fertile than coarse-textured counterparts, Franzluebbers *et al.* (1996) hypothesised that higher SOC content in fine-textured soils may be due to variable C input rather than long-term decomposition dynamics. The water-stable and dry-stable macro-aggregates were also found to be positively significantly correlated with TOC, SOC, AAOC, HWC, POC and MBC. Sodhi *et al.* (2009) discovered that macro-aggregates have higher carbon concentrations than micro-aggregates. Six *et al.* (1998) found a link between the proportion of carbon lost due to disturbance (e.g., tillage, trampling, etc.) and an increase in macro-aggregate turnover.

5.4 Coefficient of Correlation between Different Soil Properties in *Rabi* Season

Clay was found to be positively significantly correlated with TOC, SOC, AAOC, HWC, POC and MBC in *Rabi* season. Tisdall and Oades (1982) discovered that the amount of soil organic carbon (SOC) in any given environment increases as soil texture becomes finer. Because fine-textured soils are more fertile than coarse-textured counterparts, Franzluebbers *et al.* (1996) hypothesised that higher SOC content in fine-textured soils may be due to variable C input rather than long-term decomposition dynamics. The water-stable and dry-stable macro-aggregates were also found to be positively significantly correlated with TOC, SOC, AAOC, HWC, POC and MBC. Sodhi *et al.* (2009) discovered that macro-aggregates have higher carbon concentrations than micro-aggregates. Six *et al.* (1998) found a link between the proportion of carbon lost due to disturbance (e.g., tillage, trampling, etc.) and an increase in macro-aggregate turnover.

Summary and Conclusions

Chapter-6

Summary and Conclusions

A study was conducted to assess the "Impact of land use system and seasonal variations on aggregate associated soil carbon in outer Himalayas." Four land use systems viz. rice-wheat, forest land, maize-wheat and barren land were randomly selected for present investigation, keeping in mind the diversity of flora and fauna of the systems. Samples were taken in two different seasons i.e., *Kharif* and *Rabi* at five different depths (0-5, 5-15, 15-30, 30-60 and 60-100 cm). Out of various soil properties, soil clay and macro-aggregates showed positive and significant impact on all soil carbon pools. A detailed study in terms of soil analysis was done for aggregate associated soil carbon pools and stocks. The present investigation was conducted with the following objectives.

1. To study the effects of different land-use systems on aggregate associated soil carbon pools and carbon stocks.
2. To study the effect of seasonal variations on aggregate associated soil carbon pools and carbon stocks.

The results of the present study are summarized as under:

6.1 Effect of Different Land Use Systems and Seasonal Variations on Physical Properties of Soil at Different Depths

The soils of all land use systems varied from slightly acidic to slightly alkaline in nature. The mean value of pH was highest in barren land (7.46) at 60-100 cm depth (7.74) in *Rabi* season (7.36) and lowest in forest land (7.22) at 0-5 cm depth (6.93) in *Kharif* season (7.28). The mean value of electrical conductivity was highest in barren land (0.24 dS m^{-1}) in *Rabi* season (0.18 dS m^{-1}) at 0-5 cm depth (0.26 dS m^{-1}) and was lowest in forest land (0.14 dS m^{-1}) in *Kharif* season (0.17 dS m^{-1}) at 60-100 cm depth (0.10 dS m^{-1}). The mean value of bulk density was highest in barren land (1.50 Mg m^{-3}) at 60-100 cm depth (1.44 Mg m^{-3}) in *Kharif* season (1.42 Mg m^{-3}) and lowest in forest land (1.32 Mg m^{-3}) at 0-5 cm depth (1.39 Mg m^{-3}) in *Rabi* season (1.41 Mg m^{-3}). The mean value of particle density was lowest in forest land (2.53 Mg m^{-3}) at 0-5 cm depth (2.43 Mg m^{-3}) and highest in barren land (2.63 Mg m^{-3}). at 60-100 cm depth (2.69 Mg m^{-3}). The mean value of clay content was highest in forest land (21.49%) at 60-100 cm depth (18.52%) and lowest in barren land (15.80 %) at 0-5 cm depth (17.68%). The mean value of maximum water holding capacity was highest in forest land (38.70%) at the 0-5 cm depth (35.09%) in *Kharif* season (33.40%) and lowest in barren land (27.04%) at 60-100 cm depth (30.22%) in *Rabi* season (32.43%). The mean value of water-stable macro-aggregates was highest in forest land (57.29%) in *Rabi* season (42.33%) at 0-5 cm depth (51.62 %) and lowest in barren land (30.57) in *Kharif* season (32.43%) at 60-100 cm depth (27.46%). The mean value of dry-stable macro-aggregates was highest in forest land (62.26%) at 0-5 cm depth (53.60 %) in *Rabi* season (45.04%) and lowest in barren land (32.29%) at 60-100 cm depth (32.30%) in *Kharif* season (43.03%). The mean value of water-stable micro-aggregates was highest in maize-wheat (30.10%) at 60-100 cm depth (25.05%) in *Kharif* season (22.03%) and lowest in forest land (13.40%) at 0-5 cm depth (16.25%) in *Rabi* season (21.15%). The mean value of dry-stable micro-aggregates was highest in rice-wheat (29.22%) at 60-100 cm depth (21.74%) in *Kharif* season (19.48%) and lowest in forest land (8.39%) at 0-5 cm depth (16.45%) in *Rabi* season (18.88%). The mean value of mean weight diameter was highest in forest land (3.71 mm) at the 0-5 cm depth (2.83 mm) in *Kharif* season (2.55 mm) and lowest in barren land (1.93 mm) at in the 60-100 cm depth (2.12 mm) in *Rabi* season (2.37 mm).

6.2 Effect of Different Land Use Systems and Seasonal Variations on Carbon Pools and Stocks at Different Depths

The mean value of total organic carbon was highest in forest land (26.03 g kg^{-1}) at 0-5 cm depth (20.02 g kg^{-1}) in *Rabi* season (18.19 g kg^{-1}) and was found to be lowest in barren land (12.55 g kg^{-1}) at 60-100 cm depth (14.64 g kg^{-1}) in *Kharif* season (17.39 g kg^{-1}). The mean value of soil oxidizable organic carbon was highest in forest land (4.82 g kg^{-1}) in *Kharif* season (3.89 g kg^{-1}) at 0-5 cm depth (5.75 g kg^{-1}) and was lowest in barren land (2.96 g kg^{-1}) in *Rabi* season (3.69 g kg^{-1}) at 60-100 cm depth (1.44 g kg^{-1}). The mean value of aggregate associated organic carbon (macro-aggregates) was highest in forest land (6.36 g kg^{-1}) at 0-5 cm depth (7.73 g kg^{-1}) in *Rabi* season (5.98 g kg^{-1}) and was found to be lowest in barren land (5.00 g kg^{-1}) at 60-100 cm depth (3.11 g kg^{-1}) in *Kharif* season (5.40 g kg^{-1}). The mean value of aggregate associated organic carbon (micro-aggregates) was highest in forest land (6.10 g kg^{-1}) at 0-5 cm depth (7.30 g kg^{-1}) in *Rabi* season (5.50 g kg^{-1}) and was found to be lowest in barren land (4.95 g kg^{-1}) at 60-100 cm depth (3.14 g kg^{-1}) in *Kharif* season (5.39 g kg^{-1}). The mean value of hot water-soluble carbon was highest in forest land (0.46 g kg^{-1}) at 0-5 cm depth (0.45 g kg^{-1}) in *Kharif* season (0.35 g kg^{-1}) and was found to be lowest in barren land (0.18 g kg^{-1}) at 60-100 cm depth (0.12 g kg^{-1}) in *Rabi* season (0.27 g kg^{-1}). The mean value of particulate organic carbon was highest in forest land (4.33 g kg^{-1}) in *Rabi* season (3.63 g kg^{-1}) at 0-5 cm depth (5.14 g kg^{-1}) and was lowest in barren land (3.00 g kg^{-1}) in *Kharif* season. The mean value of particulate organic carbon was highest in the and was lowest in (2.98 g kg^{-1}) at 60-100 cm depth (1.20 g kg^{-1}). The mean value of microbial biomass carbon was highest in forest land (76.75 mg kg^{-1}) at 0-5 cm depth (89.65 mg kg^{-1}) in *Kharif* season (66.80 mg kg^{-1}) and was lowest in barren land (52.85 mg kg^{-1}) at 60-100 cm depth (37.57 mg kg^{-1}) in *Rabi* season (64.53 mg kg^{-1}).

The present study clearly revealed that there is an impact of land use systems on aggregate associated soil carbon pools and stocks. The amount of carbon varied in all land use systems and followed the trend, Forest-land > Rice-wheat > Maize-wheat > Barren land. Soil depths also played a vital role, as far as carbon storage is concerned. All carbon pools were found to be highest in surface layers (0-5 and 5-15) cm, whereas least was found in the sub-surface layer (60-100) cm. In case of seasonal variations, most of the higher values of carbon were found in *Kharif* season mainly due to erosion which is a causal agent of erosion in Himalayas.

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CERTIFICATE-IV

Certified that all necessary corrections as suggested by the external examiner and advisory committee have been duly incorporated in the thesis entitled "**Impact of Land Use System and Seasonal Variations on Aggregate Associated Soil Carbon in Outer Himalayas**" submitted by **Ms. Japneet Kour Kukal**, Registration No. **J-19-M-689.**

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