Effect of different land use systems on soil erodibility, aggregation and organic carbon dynamics in soils of Eastern Haryana

By

Koushik Bhattacharyya

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CERTIFICATE–I

This is to certify that the dissertation entitled, **“Effect of different land use systems on soil erodibility, aggregation and organic carbon dynamics in soils of Eastern Haryana”** submitted for the degree of **Master of Science** in the subject of **Soil Science** of the Chaudhary Charan Singh Haryana Agricultural University, Hisar, is a bonafide research work carried out by **Mr. Koushik Bhattacharyya (2019A125M)** under my supervision and that no part of this thesis has been submitted for any other degree.

The assistance and help received during the course of investigation have been duly acknowledged.

(Dr. Hardeep Singh Sheoran)
Major Advisor
Assistant Professor,
Department of Soil Science,
CCS Haryana Agricultural University
Hisar – 125004

CERTIFICATE – II

This is to certify that the dissertation entitled **“Effect of different land use systems on soil erodibility, aggregation and organic carbon dynamics in soils of Eastern Haryana”** submitted by **Mr. Koushik Bhattacharyya (2019A125M)** to the **Chaudhary Charan Singh Haryana Agricultural University, Hisar**, in partial fulfillment of the requirements for the degree of **Master of Science** in the subject of **Soil Science**, has been approved by the Student’s Advisory Committee after an oral examination on the same.

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Place: Hisar

Dated: ***Koushik Bhattacharyya***

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CHAPTER-I

INTRODUCTION

Soil is considered to be an important constituent of any ecosystem, where it plays a key role in deciding the agricultural productivity of a particular land use system. Soil being not only the medium for crop growth, also sustains the crop productivity while maintaining or enhancing the environmental as well as soil quality (Lal, 2008). Decline in soil quality as a segment of anthropogenic activities has become a major challenge for the entire global scientific community during the 20th century and has remained high on the international agenda in the 21st century as well. Soil erosion is considered to be the one of major cause of poor soil quality resulting in low productivity as the available macro- and micronutrients along with the organic matter are washed away from the soils. Consequently, the soil organic carbon also moves out of the local carbon cycle further depleting the soil fertility (Sharma *et al.*, 2014). Balota and Matos (2011) reported that there is an immense need to improve the soil aggregation along with capturing of carbon within these aggregates and thereby enhancing the process of carbon sequestration and can be adopted as useful strategy in mitigating the adverse impact of climate change as result of increased concentration of atmospheric CO_2 on crop productivity (Lal, 2001). Moreover, distribution of aggregates within the soil also represents a balance between forces of disruption to those that favours the aggregation.

Land use change not only affects the soil organic carbon accumulation but it also affects other nutrient contents in soil such as; nitrogen, phosphorus, potassium and their distribution and storage in soils which influences the composition and quality of organic matter (Six *et al.*, 2000; John *et al.*, 2005; Helfrich *et al.*, 2006). In addition it stimulates the biological changes in the rooting zone and the beneficial rhizospheric microorganisms can help in maintaining the ecosystem balance by decaying organic matter and cycling of nutrients that serves as an indicator of land use changes and ecosystem sustainability (Ros *et al.*, 2006; Balser *et al.*, 2010). Hence, it is important to study the effect of different land uses on the rhizosphere communities for maintaining the soil quality to regenerate the soil’s ability to provide ecosystem services (Van Leeuwen *et al.*, 2017). Now a days, the practice of land use conversion, for instance from natural ecosystems to cultivated ecosystems is very common throughout the world (Vagen *et al.*, 2006; Khormali and Nabiollahy, 2009) which contributed to the historical rise in global levels of atmospheric CO_2 and combined with conventional tillage and lack of biomass return to soil, it is reported to reduce the degree of soil organic matter humification. Both land use and soil management practices influence the soil properties and processes, such as soil organic carbon dynamics, aggregation, bulk density, erosion, oxidation, mineralization and leaching etc. (Celik, 2005; Liu *et al.*, 2010). Faulty agricultural practices have led to the significant reductions in soil organic matter and deterioration of soil fertility, causing lower crop yields and quality of soils (Korschens, 2002). Assessing land-use-induced changes in soil properties is essential for addressing the issue of agro ecosystem transformation and sustainable land productivity (Yao *et al.*, 2010). Therefore, sustainable land use systems are much needed to lower down the risk of soil degradation while maintaining soil fertility. Adoption of different land use systems results in alteration of soil characteristics which in turn affects the soil fertility in terms of available macro- and micronutrients (Onwudike *et al.*, 2015), alteration of soil reaction, soil organic matter, soil physical condition and microbial activity in the rhizosphere (Karlen *et al.*, 2003; Sarawathy *et al.*, 2007). Land use changes may also affect many natural resources and ecological processes such as surface runoff and erosion and changes soil resilience to environmental impacts (Fu *et al.*, 2000; Hacisalihoglu, 2007). The increasing intensity of land use may cause erosion and soil compaction through changes in soil physical and chemical properties (Misir *et al.*, 2007). The direct measurement of soil erodibility is costly and time consuming (Singh and Khera, 2007), therefore certain erodibility indices of soil are also considered to be efficient in predicting the extent of erosion. Percent-weight of water stable aggregates (WSA) >3 mm, percent-weight of WSA >0.5 mm, erosion ratio, surface-aggregation ratio, modified surface-aggregation ratio, clay ratio, dispersion ratio, modified clay ratio and erosion ratio have become an imperative parameters for assessing and predicting impact of a particular land use systems on soil quality (Wang *et al.*, 2013).

Soils are considered to be the largest terrestrial pool of organic carbon and are potentate in sequestering carbon in soil mainly depends upon the physico-chemical characteristics and stabilization of organic carbon within the aggregates (Debashis-saha *et al.*, 2011) and several studies had focused on establishing relationship between organic carbon, soil erosion and the role of soil aggregation in organic carbon protection under different land use systems (Berhe *et al.*, 2007; Yadav and Malanson, 2007). Moreover, differences in soil organic carbon fractions under different land use systems can provide crucial information about carbon sequestration processes (Six *et al.*, 2002).

In recent times, there are growing concerns among the scientific community about this alarming situation where time has come for a shift in our conservation concepts and programms to get away from the stable approach of not only managing the soil erosion, but also managing the soil carbon through adoption of suitable land use systems for a particular piece of land. Moreover, the assessment of potential carbon sequestration in soils requires the estimation of carbon pools under existing land use system and their spatial distribution in the soil profile. For this estimation, knowledge about the impact exerted by different land use systems on soil properties is pre-requisite. Keeping the above facts in view, the present study was planned with the following objectives:

1. To study the effect of different land use systems on physico-chemical properties of soil
2. To quantify the soil organic carbon stocks and establish a relationship among soil properties and erodibility indices under different land use systems

CHAPTER-II

REVIEW OF LITERATURE

To have a clear understanding of the present investigation entitled "Effect of different land use systems on soil erodibility, aggregation and organic carbon dynamics in soils of Eastern Haryana", the literature has been reviewed under the following heads:

2.1 Effect of different land use systems on soil physical properties

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2.1 Soil physical Properties

2.1.1 Soil texture

Soil texture is a basic property of soil which governs the soil aggregation, structure, nutrient retention and their availability. Fine textured soils are having higher proportion of clay particles, higher surface area and molecular linkage potential and therefore, can behave as nuclei with ability to generate macro and micro-aggregates, resulting in a better soil structure (Bronick and Lal, 2005). Kong *et al.* (2009) reported that from 1982 to 2006, the sequence of rise in the soil organic carbon level for different textured soils among the different land use system was fine sand < sandy loam < light loam < middle loam soil, suggesting that the soil having higher proportion of fine particles has the higher ability and rate of soil organic carbon build up. Tivet *et al.* (2012) reported that the impact of soil textural gradation is directly related to silt content, whereas clay content or the relationship between land use system and clay was significant in clay and sand textured soils. Saglam and Dengiz (2012) reported that clay and clay loam soils, when compared with loamy soils, can retain more amount of moisture and found better in terms of soil fertility status under sub-humid climatic conditions. Kaur and Bhat (2017) reported that more clay and silt was found in the soil from agricultural and forestry land at Takarla, and similar results were reported in grassland soil at Mukerian in Punjab. Addition of large amounts of plant material leads to enhancement in soil properties which results in higher soil organic matter content in clay soils as compared to loamy soils. Such findings also demonstrated that aggregate formation was influenced by soil texture and organic matter content. Soil texture has rarely been examined in terms of its effects on nutrient utilization between soil aggregates in case of multiple use of a particular land (Ge *et al.*, 2019). Role of land use systems with respect to the impact on texture and in turn on nutrient availability and other soil properties have been rarely evident that limits our way to estimate natural cycles under different land use conditions.

2.1.2 Bulk density

Bulk density (BD) is an important physical property of soil which depends upon the pore space present in the soil and the variations in BD occurs due to difference in soil textural class as well as organic matter content of the soil (Oguike *et al.*, 2018). Selassie and Ayanna (2013) reported that the forest land use system was observed to have the lowest bulk density, while the agriculture land use system had the maximum values for bulk density. Mengiste *et al.* (2015) reported that land under pasture management had the higher value of bulk density (1.39 Mg m^{-3}) in comparison to agriculture (1.24 Mg m^{-3}) as compaction by farmed animals may have led to the rise in bulk density of soils. Neha *et al.* (2020) reported that with the regular addition of organic material in the soil through litter fall under forest and horticultural land use systems, the bulk density of surface soils of forest was observed to be 7.6 % lower as compared to the agriculture type of land use, whereas it was only 2.1 % lower under horticulture system. Gorems and Goshal (2020) studied that bulk density differed significantly over the different land use categories and reported that notable changes in bulk density of forest soils (1.22 Mg m^{-3}) were observed as compared to agriculture (1.37 Mg m^{-3}) and deteriorated forest (1.25 Mg m^{-3}) type of land use systems (Tripathi *et al.*, 2007). Agbeshie *et al.* (2020) reported that under different land use systems, highest soil bulk density (BD) was observed in degraded mine land (1.43 Mg m^{-3}), followed by crop land (1.22 Mg m^{-3}), while the forestlands recording the least value of BD (1.10 Mg m^{-3}). Siyabulela *et al.* (2019) reported that soils from the communal lands had significantly higher bulk density values when compared with soils from game reserves in semi-arid South African rangelands. Tumayro and Tesgaye (2021) observed that the bulk density was significantly affected by different land use systems and reported that the highest (1.33 Mg m^{-3}) and the lowest (1.20 Mg m^{-3}) bulk density was recorded in the cultivated land and grassland, respectively.

2.1.3 Moisture retention characteristics

Pore space that exists between the soil particles allows the moisture retention within the soil and is strongly related to soil aggregates. As water molecules stuck more tightly to the fine particles of clay soils than to the coarser particles of sandy soils, clays tends to retain more water (Leeper and Uren, 1993). The nature and the amount of clay, organic matter content and the soil structure are supposed to affect the water retention by different soil types under different land use systems. Bormann and Klaassen (2008) reported that land use system had a significant impact on soil water conduction and water storage capabilities of soils where forest soils shows significantly higher water retention, followed by grassland and cropland. The differences in moisture content at saturation percentage and field capacity were studied between forest and cassava cropland type of land use systems and no significant differences were observed between two types of land use systems, but significant variations exists at permanent wilting point and in plant available water content between the two systems (Oguike and Mbagwu, 2009). Wen-zhong *et al.* (2010) studied the variations in soil moisture under three types of agroforestry boundaries and reported that moisture content in forest-grassland landscape boundary was the highest in dry season, while no significant differences in soil moisture content were observed under the forest-wheat and shelterbelt-wheat agro-forestry systems. Ayoubi *et al.* (2011) also reported that natural forest soils have higher water availability than the reforested and agricultural soils. Mukhopadhay *et al.* (2012) studied the soil moisture characteristics under different physiographic and land use situation and reported the pattern of forest > vegetables > cereals > fallow in terms of available plant water content. Yu *et al.* (2015) reported that conversion of land from cropland to forest land tends to increase the soil water-retention capacity of soils as forest soils tend to promote the formation of mesopores. Soil water distribution and its retention depends on physical properties of soil and a higher soil moisture content under orchard land use was reported by Fang *et al.* (2016), while Oguike *et al.* (2018) reported that soil moisture features varied markedly under forest type of land use system as compared to other types of land use. Gabriela de Queiroz *et al.* (2020) evaluated that the spatial - temporal variations in moisture content of soils and reported that forest soils holds more moisture content with low vertical and periodic fluctuations than the other types of land use systems. According to the Dlapa *et al.* (2020), the moisture retention characteristics of soils under the different land use systems obeyed the hierarchical pore size distribution and followed the order; orchard > forestland > grassland > agricultural land, where, orchard and forest soils were found to be superior in terms of porous structure and moisture retention characteristics. Oliveira *et al.* (2021) also reported that preserved forest soils retain more water at field capacity, permanent wilting point and plant available water content as compared to other types of land use systems.

2.1.4 Aggregate size distribution

Soil aggregates represents a group of soil particles attached to each other and are formed through a dynamic process involving the interaction of many abiotic and biotic factors and processes, such as soil mineralogical composition, texture, microbial and agricultural activities (Bronick and Lal, 2005). Changes in land use system from forest to agriculture usually results in substantial reductions in silt content, aggregate stability and organic material content which had the adverse effect on soil aggregation (Abad *et al.*, 2014). Celik (2005) studied the impact of different land use systems on soil characteristics and reported that forest soils are having the higher values of mean weight diameter (MWD) and water-stable aggregates (WSA) than in croplands. Gajic *et al.* (2006) reported that the conversion of forests to conventional cultivating land significantly reduced the water stable aggregates in soils and the water stability was observed to be lowest in aggregates more than 3 mm in size. Kukal *et al.* (2007) studied the impact of four different land use systems, namely; eroded, agricultural, forest and grazing land on aggregate stability and reported that aggregates from grazing land are less erodible soil fractions, accompanied by forest soils, agricultural and eroded land soils. Kumar *et al.* (2000) carried out a study on effect of land use and soil depth on water stable aggregates and the results of their study revealed that aggregates with diameters greater than 0.25 mm were more prevalent in surface soils under forest (89.1-92.8 %) and orchard (66.2-79.3 %) land use systems. Soils from various land use act differently to the beating action of raindrops with same kinetic energy (Lehrsch and Kincaid, 2006) and the stability of soil aggregates is the connecting link between biological, chemical, and physical properties in the soil for the stabilization of organic material in soils (Kukal *et al.*, 2008). Lawal *et al.* (2009) also observed that forest soils had a higher mean weight diameter (MWD) than native vegetation and arable cropping. Singh *et al.* (2017) studied the impact of land use change on soil aggregate dynamics under natural forest (NF), degraded forest (DF), cropland (CL) and Jatropha plantation (JP) in the dry tropical region of India. The trend of macro- and microaggregate fractions through the soil profile was NF > JP > DF > CL whereas that of meso-aggregates was CL > DF < JP > NF. Zhao *et al.* (2017) reported that under different types of land use the average mean weight diameter (MWD) and water stable aggregates (WSA) appeared to be highest in paddy grown soils, followed by forest and the lowest MWD was observed upland type of land use. Zhong *et al.* (2018) reported that with the conversion of land from agricultural land to vegetated land, the proportions of macro-aggregates (>2 mm) and meso-aggregates (2–0.25 mm) increased while that of micro-aggregates (0.25–0.053 mm) decreased significantly. Jiao *et al.* (2020) reported that stable soil aggregates (> 0.25 mm) and mean weight diameter were significantly higher in grassland soils as compared to the arable and forest soils. Duan *et al.* (2021) also reported that land use change from natural forest to orchard and cropland significantly decreased the aggregate stability and thereby increasing the soil erodibility.

2.1.5 Soil erodibility indices (Dispersion ratio, Clay ratio, Modified clay ratio, Erosion ratio, Suspension percentage, Suspension ratio)

The change in land use type and soil management practices has a profound impact on the physical and chemical environments, thereby affecting the fertility and productivity of soils (George *et al.*, 2013; Gonnety *et al.*, 2013). Soil properties such as textural class (sand, loam and clay), organic matter content, existence of binding agent (sesquioxides, lime), nature and type of clay minerals, and the cationic composition on the exchangeable sites affect the rate of water entry into the soil, dispersion, runoff and ultimately the soil fertility.

Singh and Khera (2008) studied the impact of four land-uses namely; barren, cultivated, grassland and forest land use systems on various soil erodibility indices and reported that values of dispersion ratio (DR), clay ratio (CR) and modified clay ratio (MCR) were found in the order: barren = cultivated > grassland > forest. Saha *et al.* (2011) studied the soil erodibility characteristics under modified land use systems against shifting cultivation in Meghalaya, India and reported that natural forest soils had the lower values of erodibility indices (suspension percentage, dispersion ratio, clay ratio, erosion ratio, erosion index) as compared to agriculture, agri-horti-silvi-pastoral, livestock-based type of land use system. Yilmaz *et al.* (2015) reported that soils from different land use systems (grassland, cultivated land, coniferous forest land and broadleaf forest land) were observed to have the values higher than the dispersion ratio (DR) limit of 15 and the erosion ratio (ER) limit of 10 and thus, regarded as susceptible to erosion, where the highest ER and DR values were found in the soils of broadleaf forests. Dutta *et al.* (2016) studied the soil aggregation and erodibility indices under different land uses in Jorhat district of Assam and reported that susceptibility of soils to erosion in terms of dispersion ratio and erosion ratio was observed to follow the order: rice soil > vegetable soil > tea soil > forest soil and soils under forest land use were found to be more stable as compared to the soils under cultivation. Maqbool *et al.* (2017) reported that the dispersion ratio in different land use systems varied from 0.49-0.85 with trend of wasteland = agriculture unirrigated > agriculture irrigated > agri-horticulture > horticulture > pastures > forests with mean values of 0.82, 0.82, 0.78, 0.76, 0.65 and 0.61 percent, respectively. Kusre *et al.* (2018) studied several erodibility indices which are used to describe the intensity of the soil erosion and reported that the dispersion ratio values in most of the soils were >15%, indicating high vulnerability to erosion, while the values of clay ratio (3.44-

9), modified clay ratio (mean value of 6.9) indicated higher susceptibility to erosion. Obiechefu *et al.* (2020) studied the effect of land use changes on erodibility indices of soil and reported that dispersion ratio (DR) increases in the order: continuous cultivation > fallow land > grass land > forest land. They concluded that though all the soils under study were considered to be susceptible to erosion, however, the soil under continuous cultivation was observed to be the most susceptible (DR = 107), and the soil under forest land was least susceptible to erosion (DR = 32). Vashisht *et al.* (2020) reported that the erosion indices among different land use followed the sequence: barren land (0.97) > cultivated land (0.84) > grassland (0.74) > forest land (0.63). The soils under barren land were observed to be more susceptible as compared to other land use systems. Babur *et al.* (2021) studied the three types of land-use practices *i.e.*, forestland, pastoral land and riparian site and reported that silt content were maximum in forestland as compared to their counterparts (pastoral and riparian sites). The dispersion percentage (80%) and the erosion ratio (11%) were remarkably higher under riparian sites than in pastoral region. Therefore, the pasture soils are less erodible than the riparian areas as they are having higher amount of clay (95%) and aggregation rate (38%).

2.2 Soil chemical Properties

2.2.1 Soil pH, electrical conductivity (EC) and calcium carbonate ($CaCO_3$)

Duguma *et al.* (2010) studied on soil chemical properties of central highland Ethiopia and reported that lowest pH was observed in woodlot soils while, the pH of homestead soils were highest. Rezaei *et al.* (2012) studied the effect of land use change on soil properties and clay mineralogy of forest soils and found that with conversion of woodland to tea plantation, the pH of the soils reduced significantly. Research findings of Afshari *et al.* (2019) showed that grassland had a higher pH value than agricultural soils (wheat, maize) which in turn adversely affect the nutrient supply, their mobility and microbial activity in soil. Moreover, the electrical conductivity of range land was higher than the agricultural land. Alaie and Gupta (2019) reported that highest soil pH was recorded under barren land (7.90), followed by agriculture (7.55), horticulture (7.30) and least under forest (7.21) while the electrical conductivity ranged from 0.08-0.31 dS m^{-1} under forest, 0.18-0.77 dS m^{-1} under barren land, 0.11-0.45 dS m^{-1} under agriculture and 0.10-0.35 dS m^{-1} under horticulture land use systems. Tufa *et al.* (2019) studied the effects of land use types (grass, cultivated, forest and grazing land) on soil chemical properties and observed that EC was highest (0.53 dS m^{-1}) and lowest (0.26 dS m^{-1}) in the forest and the grassland soils, respectively whereas the highest (11.50%) and the lowest (5.10%) $CaCO_3$ values were observed with forest and grazing lands, respectively. Devi *et al.* (2020) studied the effect of agri-silvi-horticultural system (kinnow + eucalyptus + wheat, kinnow + wheat and control) on soil chemical properties and reported that the average soil pH ranged from 8.15 to 8.28 under various tree based system. However, the electrical conductivity of soil was significantly reduced under tree based system by 25% and 15.9% under kinnow + eucalyptus + wheat and kinnow + wheat system, respectively over control and the calcium carbonate content in soil varied from 0.69% to 0.76% under agri-silvi-horticultural system and control land, respectively.

2.2.2 Cation exchange capacity (CEC)

CEC is an inherent soil characteristic and influences the soil's ability to hold the essential nutrients and acts as a buffering agent. Rudramurthy *et al.* (2007) reported that tobacco plantation soils had a higher exchangeable Al^{+3} (0.27 cmol (p+) kg^{-1}), however, the highest CEC (48.5 cmol (p+) kg^{-1}), overall potential acidity (18.7 cmol (p+) kg^{-1}) and buffering capacity (0.76 cmol (p+) kg^{-1}) was observed in mixed forest soils and had a greater capacity to fix potassium and phosphorus than soils in croplands. Hazelton and Murphy (2007) reported that among the different land use systems, forestland had higher CEC while moderate CEC was observed with pasture and farmlands. Chimdi *et al.* (2012) observed that cation exchange capacity (CEC) for agricultural soils were lower than natural forest and ranged from 19.2 cmol (p+) kg^{-1} in agricultural soils to 28.2 cmol (p+) kg^{-1} in natural forests. Kiflu and Beyene (2013) observed that the highest cation exchange capacity (CEC) values were observed under grassland (27.53 cmol (p+) kg^{-1}) while, lowest in maize (21.80 cmol (p+) kg^{-1}). Yitbarek *et al.* (2013) observed that CEC of agricultural soils differed significantly from the other types of land use systems. Kaur and Bhat (2017) reported that agriculture and forest land-use systems recorded higher values of CEC as compared to agro-forestry and grassland. Olorunfemi *et al.* (2018) reported that under different land use systems such as: natural forest (NF), plantations (PA) and cropland (CP), the CEC of soils varied from 3.43 cmol (p+) kg^{-1} to 11.97 cmol (p+) kg^{-1} with plantations having the highest value of CEC among the different land use systems.

2.2.3 Organic carbon and its fractions

Soil organic carbon affects the soil physical, chemical and biological properties of soil and if the SOC content in soil is low, it may not be possible to obtain potential yield (Kay and Angers, 1999). Kizilkaya and Dengiz (2010) also reported that conversion of the natural forest into agricultural land had resulted in significant reductions in concentration of organic matter. Reza *et al.* (2018) studied the effect of different land use systems on soil properties and reported that organic carbon (2.17%) was observed to be the highest in forest soil, followed by soil under horticultural system, tea plantation and agriculture land use systems. Olorunfemi *et al.* (2018) reported that among the different land uses (natural forest, plantations and cropland) natural forest accumulated more organic carbon as compared to plantations sites and cultivated land. Tufa *et al.* (2019) studied four different types of land use systems (grass, cultivated, forest and grazing land) and revealed that the soil organic carbon content was significantly affected by the land use types, where highest (5.60%) soil organic carbon content was recorded in forest land and the lowest (3.5%) was observed under grazing land. Sahoo *et al.* (2019) reported that the average total organic carbon content (%) in the different land use types decreased in the following order: Forest > Current Jhum > Agroforestry > Wet Rice Cultivation > Jhum Fallow > Plantation > Grassland and in contrast active carbon pool was highest in wet rice cultivation (61.64%) while the lowest was observed in forest (58.71%). Tiwari *et al.* (2019) also reported that the soil organic carbon was highest in the natural forest or mixed forest soil and lowest in agricultural soils. Cholbe *et al.* (2020) reported that among the different land use systems in wolaita zone, Southern Ethiopia the highest amount of organic carbon was found in enset-coffee and grazing land while, lowest cropland. Similar findings were also reported by Reza *et al.* (2020) where the total organic carbon was observed to be highest in forest (20.8 g kg^{-1}) followed by rubber plantation (14.4 g kg^{-1}), mixed (12.7 g kg^{-1}) and cultivated (10.1 g kg^{-1}) land. Tumayro and Tesgaye (2021) also reported the highest soil organic carbon (4.86%) in surface layer of forest soil while the lowest (1.36%) was recorded in cultivated soil among the different land use systems (cultivated, grazing and forest land). Marcos and Juan (2006) also reported that prolonged cultivation reduces the level of soil organic carbon fractions such as particulate organic carbon, protein and humic-falvic acid. Yong (2007) also observed that conversion of cultivated land to pasture has the ability to improve particulate organic carbon in the upper 5 cm layer. Gmach *et al.* (2018) studied the soil organic carbon dynamics under different land uses and found that particulate and mineral associated fractions were higher under native vegetation as compared to other land use systems. Jiao *et al.* (2020) reported that the SOC in forest soil was significantly higher than arable land and grassland in the top 5 cm soil layer and the concentration of soil labile carbon in arable land was significant lower than both grassland and forest land. Luo *et al.* (2020) reported that conversion of native vegetation to cultivated land significantly decreased particulate organic carbon and the change of mineral associated organic carbon increased significantly in case of agricultural soils, while it decreased under native vegetation.

2.2.4 Available N, P, K and DTPA extractable micronutrients (Zn, Cu, Fe, Mn)

Panwar *et al.* (2011) reported that nitrogen was highest (386 kg ha^{-1}) in forest soils and lowest (248 kg ha^{-1}) in the agricultural land and similar trend was observed for available P, where P content was 22.54 kg ha^{-1} in the forest system and it was 13.10 kg ha^{-1} in home gardens. Pal *et al.* (2015) observed that available NPK of forest, farming and tea garden soils were higher from that of uncultivated land. Miheretua and Yimer (2017) reported that mean values of total nitrogen decreased with the conversion of land from forest (0.21%) to cultivated land

(0.09%). In contrast, available P under cultivated land was significantly higher as compared to grazing and forest land. According to the study of Mandal *et al.* (2018), available nitrogen followed a pattern of horticulture > agricultural land > uncultivated land, however, available phosphorus and potassium content in soil showed a different trend of agricultural land > horticultural land > uncultivated land. Shivakumar *et al.* (2020) reported that available nitrogen content in coffee plantations was markedly higher (435.82 kg ha^{-1}) as compared banana soils (404.40 kg ha^{-1}). Likewise, the available nitrogen content in natural systems ranged from 294.97 to 376.55 kg ha^{-1}, where the grasslands are having the lowest and semi-evergreen forests soils are having the highest content of available N. Dhaliwal *et al.* (2008) reported that horticultural land had the higher availability of micronutrients, while uncultivated land had the lowest among the different land use types. Pal *et al.* (2013) studied the micronutrient concentration under different land use systems and reported that all the micronutrients had the highest concentration in forest land while their lowest concentration was observed in wasteland. Cholbe *et al.* (2020) evaluated the three land use systems (enset-coffee, crop land and grazing land) and reported the higher availability of Fe, Mn, Zn and Cu under the enset-coffee and grazing land uses, while the lower contents of Fe, Mn, Zn and Cu were observed in agricultural soils. Choudhury *et al.* (2021) evaluated the soil micronutrient status in the mountain ecosystem of Indian (Eastern) Himalaya and reported that with the conversion of land from evergreen forest to upland agriculture and plantation, available Mn, Cu, and Zn contents decreased significantly from 30.5, 1.74 and 2.13 mg kg^{-1} under forest to 12.3, 0.74 and 1.24 mg kg^{-1} in agriculture, respectively.

2.3 Soil biological properties

2.3.1 Microbial biomass carbon

The soil microbial biomass acts as a labile reservoir of plant available nutrients and is considered to be the more sensitive indicator of change in soil conditions than the total organic matter content (Garcìa-Gil *et al.*, 2000). Francaviglia *et al.* (2017) reported that microbial biomass carbon was significantly higher (193.8 mg kg^{-1} soil) in cork oak forest ecosystem, followed by no tilled grassed vineyard (156.3 mg kg^{-1} soil). Reza *et al.* (2018) reported that microbial biomass carbon (MBC) was observed to be the highest levels had been highest in forest soil (237.6 mg kg^{-1}) as compared to agricultural soil (52.6 mg kg^{-1}). Qi *et al.* (2018) studied the response of microbial biomass carbon to land use changes in fixed desertified land in China and reported that the MBC content was 520.33 mg kg^{-1} for shrub land, 404.15 mg kg^{-1} for arboreal land, 219 mg kg^{-1} for arable land and 181 mg kg^{-1} for nursery garden. Bargali *et al.* (2019) observed that soil MBC (16-397 g/g) was markedly higher in agricultural soils with several trees while it was considerably lower in open cropland. Tiwari *et al.* (2019) reported that among the different land use systems (natural forest, mixed forest, savanna and agriculture land) soil microbial biomass carbon was observed to be the highest in natural forest soil (768.25 μg g^{-1} soil) and followed the decreasing trend in terms of its content as mixed forest, savanna and agricultural land. Meena and Rao (2020) studied the soil microbial and enzyme activity in the rhizosphere zone under different land use systems such as; mixed forest cover (MFC), *Prosopis juliora* dominated forest cover (PFC) and cultivated viz. agriculture field (AF), vegetable field (VF) and reported that higher soil microbial biomass carbon was found under forest as compared to cultivated land and followed the trend as: MFC > PFC > VF > AF. Jiao *et al.* (2020) also reported that among the different land use systems the concentration of soil microbial biomass carbon (MBC) followed the order as forest land > grassland > arable land.

2.3.2 Dehydrogenase and alkaline phosphatase activity

The enzyme activities in soil have often been observed as an indicator of microbial activity and soil fertility (Kennedy and Papendick, 1995). Balota *et al.* (2013) observed that there was a substantial difference in alkaline phosphatase activity between the natural forests, coffee plantations, and traditionally cultivated cropping lands. While comparing traditionally cultivated soils to forest soils, alkaline phosphatase activity was nearly 34% in traditionally cultivated soils and 37% in coffee plantations to the forest site. Kuwano *et al.* (2014) measured the DHA levels under different land use systems and reported the highest activity in sugarcane, peach-palm, and secondary forest soils. Mganga *et al.* (2016) reported that montane forest had the highest phosphatase activity while lowest activity was observed in savannah (mixed woodland-grassland). While, agricultural practices increased phosphatase activity in arable soils as compared to soils under natural vegetation located at the same elevation. Blonska *et al.* (2017) studied the soils from agricultural land, grasslands, deciduous and coniferous vegetation for their enzymatic activity and reported that soils under agricultural use had the minimum DHA activity while forest soils showed higher activity of dehydrogenase. Brkljaca *et al.* (2019) reported that dehydrogenase activity (DHA) had increased in grasslands and unused vineyards soils as compared to conventionally ploughed agricultural soils. Sarto *et al.* (2020) observed higher alkaline phosphatase activity under no tillage maize system than in the native savanna (mixed forest-grassland) and pasture land, but alkaline phosphatase activity in soil was higher in the pasture soils as compared to the other land use systems. Reddy *et al.* (2020) reported that the alkaline phosphatase activities was found higher in forests (natural and manmade) and coffee plantations while the lower value recorded under agricultural soil. Maini *et al.* (2020) reported that the DHA content was found to be highest in agri-horticulture soils while the lowest was observed in barren lands and higher alkaline phosphatase enzyme activity was found under forest soil as compared other land use systems.

CHAPTER-III

MATERIALS AND METHODS

The materials and methods used to study the effect of different land use systems on soil erodibility, aggregation and organic carbon dynamics in soils of Eastern Haryana have been described and presented here as per the details given below:

3.1 Location

Soil samples were collected from the four types of land use systems; agriculture, horticulture, agro-forestry and forestry at various locations in the districts namely; Ambala, Panchkula and Yamunanagar of Eastern Haryana and their soil properties were studied. Locations of sampling sites and their coordinates are given in Table 3.1.

3.2 Collection and processing of soil samples

A total of 180 surface soil samples (0-15 cm) in triplicates were collected from four types of land use systems (agriculture, horticulture, agro-forestry and forestry) at different locations and analyzed for the various physical, chemical and biological properties as mentioned below:

3.2.1 Physical properties

Soil texture, bulk density, moisture retention characteristic, aggregate size distribution, soil erodibility indices (clay ratio, modified clay ratio, dispersion ratio, erosion ratio, suspension percentage, suspension ratio).

3.2.2 Chemical properties

Soil pH, electrical conductivity (EC), calcium carbonate ($CaCO_3$), cation exchange capacity (CEC), available macronutrients (N, P, K) and DTPA extractable micronutrients (Zn, Cu, Fe, Mn), organic carbon and its fractions *i.e.*, particulate (53-2000 µm) and mineral associated carbon fraction (< 53 µm) and finally carbon stocks were estimated for each type of land use system.

3.2.3 Biological properties

Microbial biomass carbon, dehydrogenase and alkaline phosphatase activity were measured under different type of land use system.

Soil samples were collected randomly from different locations (Fig: 3.1) in polythene bags and labeled properly, indicating the location and the type of land use system. One portion of the representative samples collected from each site was air dried, grounded, crushed lightly with help of mortar and pestle and finally passed through 2 mm sieve and was kept under shade in laboratory for the analysis of physico-chemical properties of soil. Another portion of the soil samples was stored in moist condition in the fridge at 4°C for microbial and enzymatic activity analysis.

Table 3.1: Locations and coordinates of sampling sites in selected districts of Eastern Haryana

Sr. No.	Location	Village	Block	District	Latitude	Longitude	Soil texture
1	**L_1**	Adhoi	Barara	Ambala	30.1909°N	77.0176°E	Clay loam
2	**L_2**	Taprian	Barara	Ambala	30.3274°N	77.1073°E	Clay loam
3	**L_3**	Burj Sahid	Naraingarh	Ambala	30.4179°N	77.0754°E	Clay loam
4	**L_4**	Bari Bassi	Naraingarh	Ambala	30.4629°N	77.0733°E	Clay loam
5	**L_5**	Rataur	Naraingarh	Ambala	30.5054°N	77.0607°E	Clay loam
6	**L_6**	Garian	Pinjore	Panchkula	30.8271°N	76.8804°E	Loamy sand
7	**L_7**	Chandi Mandir	Pinjore	Panchkula	30.7352°N	76.8949°E	Loamy sand
8	**L_8**	Mauli	Raipur Rani	Panchkula	30.5321°N	76.9813°E	Sandy loam
9	**L_9**	Golpura	Raipur Rani	Panchkula	30.5127°N	76.9876°E	Sandy loam
10	**L_{10}**	Kakar Majra	Raipur Rani	Panchkula	30.4921°N	77.0090°E	Sandy loam
11	**L_{11}**	Rattangarh	Jagadhari	Yamunanagar	30.0725°N	77.1972°E	Loam
12	**L_{12}**	Aurangabad	Jagadhari	Yamunanagar	30.1022°N	77.2327°E	Loam
13	**L_{13}**	Udhamgarh	Jagadhari	Yamunanagar	30.1760°N	77.3215°E	Sandy loam
14	**L_{14}**	Sherpur	Chhachhrauli	Yamunanagar	30.2465°N	77.3819°E	Sandy loam
15	**L_{15}**	Bhilpura	Chhachhrauli	Yamunanagar	30.2508°N	77.4249°E	Loam

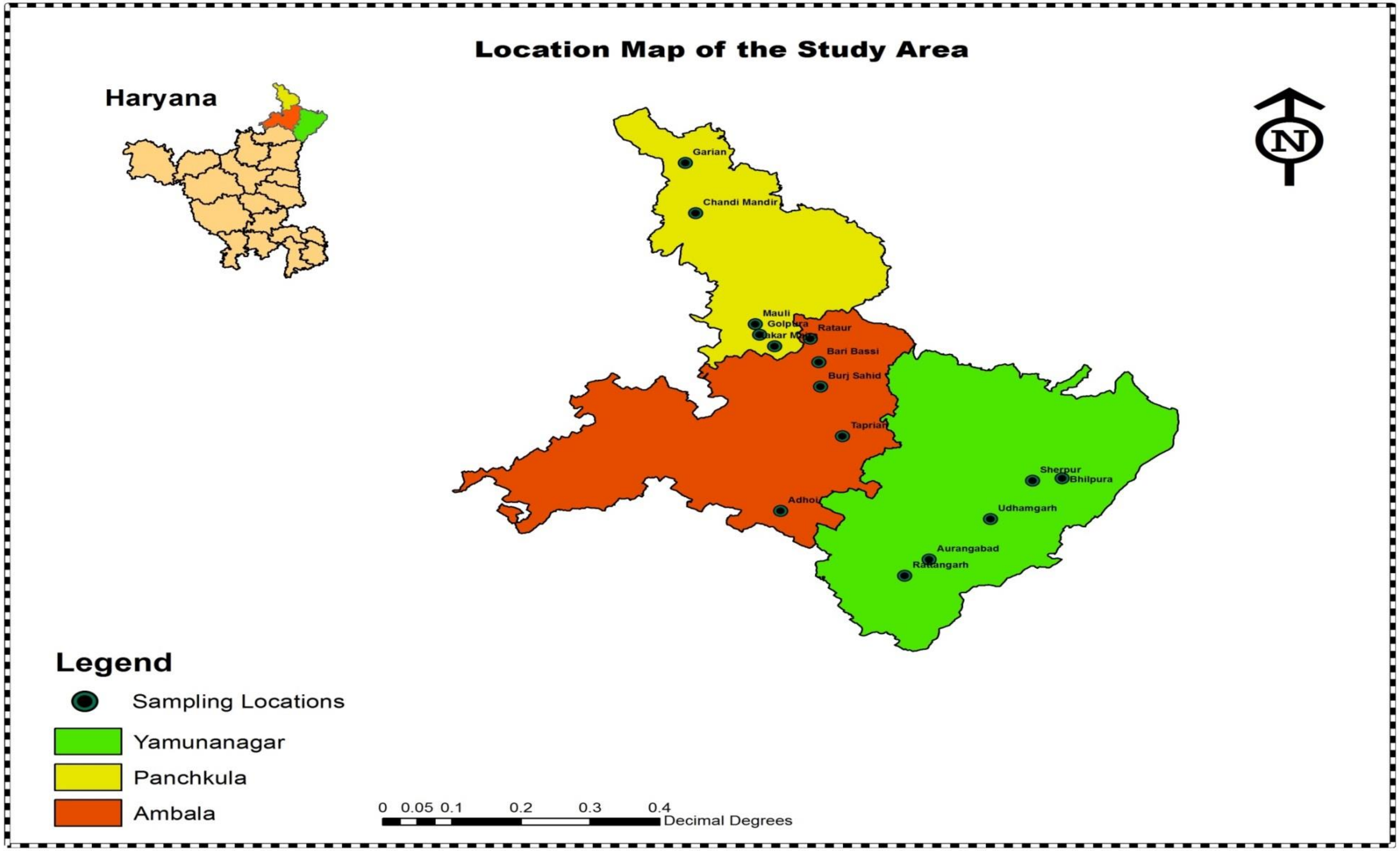

Figure 3.1: Sampling sites in selected districts of Eastern Haryana

3.3 Analysis of physical, chemical and microbiological properties

Collected soil samples were analyzed for the physical, chemical and microbiological parameters by using standard methods as given below:

3.3.1 Soil Texture

The particle size analysis (mechanical analysis) was carried out by using International Pipette Method of Robinson, as mentioned by Piper, 1966. The textural class of each sample was assigned on the basis of relative proportions of sand, silt and clay in the sample using the textural triangle provided by the International Society of Soil Sciences (ISSS).

3.3.2 Bulk density (BD)

The Core method was used to evaluate the bulk density of undisturbed soil samples (Bodman, 1942). The soil samples inside the metallic core were oven dried for 24 hours at 105^0C. The bulk density (Mg m^{-3}) of oven dried soil samples was determined using the volume-mass relationship.

3.3.3 Moisture retention characteristics

The moisture retained by the soil in equilibration at 0.1, 0.3, 0.5, 1, 3, 5 and 15 bar suction were used to derive the soil moisture retention characteristic of soil samples using pressure plate apparatus (Richards, 1947).

3.3.4 Aggregation size distribution and Mean Weight Diameter (MWD)

The aggregate size distribution of soil samples was determined by employing Yoder's standard wet sieving method (1936). The equation given by Yonker and McGuiness (1957) was used to calculate the mean weight diameter (mm) as given below:

$$MWD = \sum_{i=1}^{n} d_i w_i$$

Where, n = number of size fraction,

d_i = mean diameter of each size range,

w_i = fraction weight of aggregate in that size range of total dry weight of the sample analyzed.

3.3.5 Soil erodibility indices (dispersion ratio, clay ratio, modified clay ratio, erosion ratio, suspension percentage, suspension ratio):

Soil erodibility indices are mathematical parameters and were calculated using the following equations as mentioned in the table given below:

Table 3.2: Equations of various erodibility indices

Erodibility indices	Equations
Dispersion Ratio	$[\frac{\%\text{ (silt +clay) in an undispersed soil sample}}{\%\text{ (silt +clay) in an dispersed soil sample}} \times 100]$, (Middleton, 1930)
Erosion Ratio	$[\frac{\text{Dispersion ratio}}{\%\text{ Clay/Moisture equivalent}}]$, (Middleton, 1930)
Clay Ratio	$[\frac{\%\text{ (Sand+Silt)}}{\%\text{ (Clay)}}]$, (Bouyoucos, 1935)
Modified Clay Ratio	$[\frac{(\%(Silt+Sand))}{\%(Clay+Organic\ Matter)}]$, (Robinson and Page, 1950; Bryan, 1968)
Suspension Percentage	$\%\ (Silt + Clay)\ in\ undispersed\ soil\ sample$, (Middleton, 1930)
Suspension ratio	$\frac{\text{Dispersion ratio}}{\text{Clay / maximum water holding capacity}}$, (Bhardwaj, 1979)

3.3.6 pH$_{(1:2)}$

The pH of the soil samples were measured in 1:2 soil-water suspension by using glass electrode (Jackson, 1967).

3.3.7 Electrical Conductivity$_{(1:2)}$ (dS m^{-1})

Electrical conductivity was determined in 1:2 soil-water suspensions by using systronics conductivity bridge (Richards, 1954).

3.3.8 Calcium carbonate ($CaCO_3$)

The calcium carbonate content (%) of soils was determined by using Puri's (1930) method, where the soil suspension was titrated with 0.5N H_2SO_4 in presence of bromothymol blue and bromocresol green indicators.

3.3.9 Cation exchange capacity (CEC)

Cation exchange capacity [cmol (p+) kg^{-1}] was determined by using 1N ammonium acetate method as suggested by Jackson (1967).

3.3.10 Available nitrogen

Available nitrogen (kg ha^{-1}) in soil samples were determined by micro-kjeldahl method as suggested by Subbiah and Asija (1956). A known amount of soil was distilled with alkaline $KMnO_4$ solution and finally the absorbed ammonia in boric acid was titrated against the standard sulphuric acid.

3.3.11 Available phosphorus

Under alkaline conditions, available phosphorus (kg ha^{-1}) was extracted with 0.5M $NaHCO_3$ (pH 8.5) and was determined colorimetrically (Olsen *et al.*, 1954). The reduced phosphomolybdate complexes by $SnCl_2$ of the soil filtrate provides blue colour complex whose intensity was measured with the help of spectrophotometer at 660 nm wavelength.

3.3.12 Available potassium

Available potassium (kg ha^{-1}) was extracted with 1N ammonium acetate and potassium concentration was determined by flame-photometer (Jackson, 1967).

3.3.13 Available (DTPA extractable) zinc, manganese, copper and iron

Lindsay and Norvell's (1978) method was used to determine the DTPA extractable iron, manganese, copper and zinc (ppm). With the formation of soluble complexes, DTPA extracts the easily soluble Fe, Mn, Cu and Zn. Triethanolamine (TEA) buffers the extracting solution at pH 7.3 and $CaCl_2$ is added to avoid $CaCO_3$ dissolution. These conditions allow the correct amount of Fe, Mn, Cu and Zn to be extracted, as well as $CaCl_2$ to stabilize the extractant's pH. An atomic absorption spectrophotometer (AAS) was used to determine the elements in the DTPA extract.

3.3.14 Organic carbon

Organic carbon (%) was determined by following the rapid titration method as suggested by Walkley and Black (1934).

3.3.15: 3.3.16 Particulate and mineral associated carbon fractions

Particulate organic carbon (POC) was determined using the method described by Cambardella and Elliott (1992) and Hassink (1995). Fifty gram soil from each sample was dispersed in 150 ml of 0.5% sodium hexametaphosphate solution by shaking for 15 hours on a reciprocal shaker. The dispersed soil sample was passed through 53 µm sieve and after rinsing several times with water; the material that was retained on the sieve was dried at 50°C overnight. The soil slurry passing through the sieve contained the mineral-associated carbon (< 53 µm) and was dried at 50°C. The dried mineral matter was ground with mortar and pestle and analyzed for total organic carbon (Snyder and Trofymow, 1984).

3.3.16 Soil organic carbon stocks

The soil organic carbon stocks were calculated using the following equation.

$$\text{Soil organic carbon stocks (Mg ha}^{-1}\text{)} = \text{Organic carbon (\%)} \times \text{bulk density (Mg m}^{-3}\text{)} \times \text{Depth (m)} \times 100$$

3.3.17 Microbial biomass carbon (soil fumigation-extraction method)

The soil fumigation-extraction method (Vance *et al.*, 1987) was used to determine the microbial biomass carbon (MBC). Ten gram of soil was fumigated with 20 ml of chloroform in vacuum desiccator for 24 hours. Samples were then extracted with 0.5 M K_2SO_4 and similar extraction method was employed for non-fumigated samples. Finally microbial biomass carbon (µg g^{-1} of soil) was calculated by subtracting the value of extracted carbon in fumigated from non-fumigated soil sample.

3.3.18 Dehydrogenase activity

The procedure used for DHA (µg TPF g^{-1} soil d^{-1}) determination was developed by Casida *et al.* (1964). Activity of dehydrogenase was measured in terms of the amount of triphenyltetrazolium chloride (TTC) which was reduced by dehydrogenase present in the soil. The red methanolic solution of triphenylformazan-TPF was filtered through Whatman No. 1 filter paper and finally absorbance was measured at 485 nm by using spectrophotometer.

3.3.19 Alkaline phosphatase activity

Tabatabai and Bremner's (1969) method was used for the determination of alkaline phosphatase activity in soil. One gram of soil of each samples were stirred with toluene, modified universal buffer (MUB) and p-nitrophenyl phosphate solution. The calcium chloride and sodium hydroxide solution was added to it after one hour of incubation at 37 ºC and filtered it properly. Finally the absorbance of the filtrate was measured colorimetrically at 420 nm.

3.4 Statistical analysis

The statistical analysis of the results was carried out by two factorial RBD analysis using OP Stat, CCS HAU Hisar, software.

CHAPTER-IV

EXPERIMENTAL RESULTS

The results obtained from the present study entitled “Effect of different land use systems on soil erodibility, aggregation and organic carbon dynamics in soils of Eastern Haryana”, are presented under following heads:

4.1. Effect of different land use systems on soil physical properties

4.1.1 Soil texture

4.1.2 Bulk density

4.1.3 Moisture retention characteristic

4.1.4 Aggregate size distribution

4.1.5 Soil erodibility indices (Dispersion ratio, Clay ratio, Modified clay ratio, Erosion ratio, Suspension percentage, Suspension ratio)

4.2 Effect of different land use systems on soil chemical properties

4.2.1 Soil pH, electrical conductivity (EC) and calcium carbonate ($CaCO_3$)

4.2.2 Cation exchange capacity (CEC)

4.2.3 Soil organic carbon and organic carbon stocks

4.2.4 Carbon fractions- particulate organic carbon and mineral associated organic carbon

4.2.5 Available N, P, K and DTPA extractable micronutrients (Zn, Cu, Fe, Mn)

4.3 Effect of different land use systems on soil biological properties

4.3.1 Microbial biomass carbon

4.3.2 Dehydrogenase and alkaline phosphatase activity.

4.1. Soil physical Properties

4.1.1 Soil texture

The data pertaining to soil textural class under different land use systems at different locations is presented in Table 4.1.1. The sampling locations details along with their coordinates are given in Appendix A. Data on mechanical composition of soils revealed that wide variations exists in percent sand, silt and clay content of soils under different land use systems at different locations. The soils were observed to belong four textural classes *i.e.* loamy sand, sandy loam, loam and clay loam. The percent sand content varied from 42.8-81.8 %, 39.8-

80.3 %, 42.6-82.1 % and 42.8-81.7 % under agriculture, horticulture, agro-forestry and forestry land use systems, respectively, while the silt content varied from 8.1-33.3 %, 10.1-33.9 %, 7.8-33.8 % and 7.4-35.1 % under four types of land use systems (agriculture, horticulture, agro-forestry and forestry), respectively. The clay content in soil at different locations ranged from 8.9-36.8 % under agriculture, 9.4-35.7 % under horticulture, 10.1-37.2 % under agro-forestry and 10.9-38.6 % under forest land use system. The result obtained from the study indicated that different land use systems at different locations did not influence the textural class of the soil.

4.1.2 Bulk density

A perusal of data on bulk density (BD) at different locations (Table 4.1.2) showed significant variations among the different land use systems. The mean BD values of all locations was observed to be highest (1.41 Mg m^{-3}) under agriculture while the lowest value of 1.34 Mg m^{-3} of BD was found under forest land use system. In case of the locations, the lowest average value of BD *i.e.* observed at L_1 (1.26 Mg m^{-3}) while it was highest at L_6 (1.55 Mg m^{-3}) among the different locations. Overall, the values of BD followed the order: agriculture > horticulture > agro-forestry > forestry. The interaction effect of location and land use systems was found to be non-significant.

4.1.3 Soil moisture retention characteristics

For the easy interpretation of results obtained for moisture retention characteristics of soils, the moisture retained by the soils at different locations among the four types of land use systems were averaged for each suction (kPa) and are plotted for loamy sand, sandy loam, loam and clay loam textured soils individually in figure 4.1.1 and 4.1.2. The amount of moisture retained by soils at field capacity (33 kPa suction) and plant available water content for different textured soils under four types of land use systems are represented in Fig. 4.1.3. Data revealed that among all the textural classes (loamy sand, sandy loam, loam and clay loam) of soil, forest land use systems showed an increase in the amount of moisture content retained by soils at field capacity (FC) and plant available water content (AWC) as compared to other land use systems. However, the significant increase in moisture content was observed only with clay loam soils. The moisture content in clay loam soils at FC and AWC were 32.63 % and 23.8 %, respectively under forest land use systems, while it was 30 % and 21.6 %, respectively in case of agriculture land use system. Overall, the moisture content in different textured soils at all the levels of suctions was observed to be superior in forest soils as compared to the other types of land use systems and followed the trend as: forest > agro-forest > horticulture > agriculture.

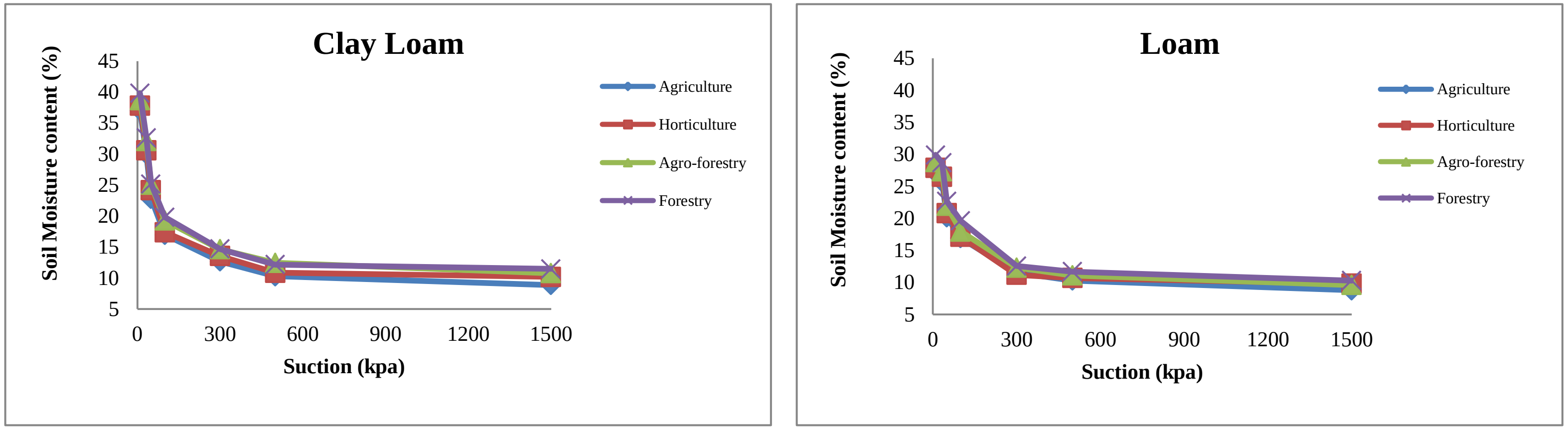

Fig: 4.1.1 Soil moisture retention curves of clay loam and loam soils under different land use systems

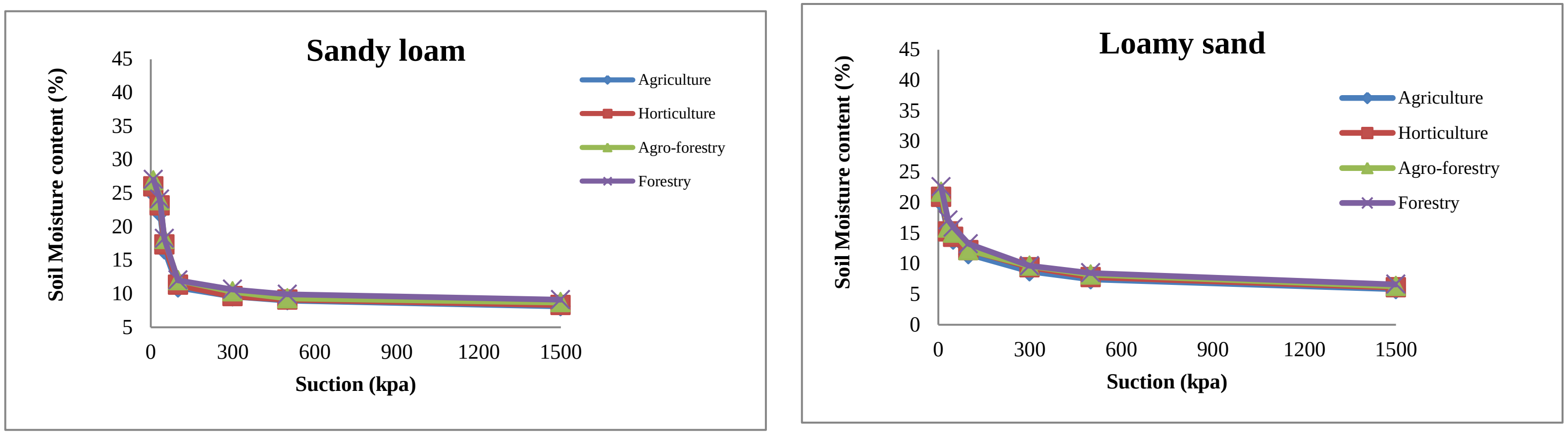

Fig 4.1.2: Soil moisture retention curves of sandy loam and loamy sand soils under different land use systems

Table 4.1.1: Mechanical composition of soils under different land use systems at different locations

District	**Location (L)**	**Agriculture**			**Texture**	**Horticulture**			**Texture**	**Agro-forestry**			**Texture**	**Forestry**			**Texture**
		Sand (%)	Silt (%)	Clay (%)		Sand (%)	Silt (%)	Clay (%)		Sand (%)	Silt (%)	Clay (%)		Sand (%)	Silt (%)	Clay (%)	
Ambala	L_1	44.6	22.3	33.1	CL	43.8	22.6	33.6	CL	42.7	23.1	34.2	CL	44.7	19.5	35.8	CL
	L_2	42.8	22.3	34.9	CL	44.6	21.5	33.9	CL	43.9	20.4	35.7	CL	42.8	20.6	36.6	CL
	L_3	44.9	18.3	36.8	CL	44.7	19.6	35.7	CL	44.7	18.1	37.2	CL	44.9	16.5	38.6	CL
	L_4	43.5	25.1	31.4	CL	44.4	23.4	32.2	CL	42.6	24.6	32.8	CL	43.7	23.1	33.2	CL
	L_5	43.8	24.4	31.8	CL	39.8	29.1	31.1	CL	44.6	23.3	32.1	CL	43.9	22.3	33.8	CL
Panchkula	L_6	81.8	8.1	10.1	LS	79.2	11.2	9.6	LS	80.3	9.1	10.6	LS	78.8	10.1	11.1	LS
	L_7	81.3	9.8	8.9	LS	80.3	10.3	9.4	LS	82.1	7.8	10.1	LS	81.7	7.4	10.9	LS
	L_8	74.4	8.1	17.5	SL	73.1	10.1	16.8	SL	71.7	10.2	18.1	SL	72.3	8.8	18.9	SL
	L_9	71.9	11.6	16.5	SL	70.3	12.6	17.1	SL	69.2	12.9	17.9	SL	70.6	10.8	18.6	SL
	L_{10}	68.5	14.7	16.8	SL	69.8	12.9	17.3	SL	68.4	13.5	18.1	SL	69.1	12.1	18.8	SL
Yamunanagar	L_{11}	47.6	32.6	19.8	L	48.6	32.1	19.3	L	46.8	33.1	20.1	L	47.1	32.1	20.8	L
	L_{12}	47.2	33.3	19.5	L	46.4	33.9	19.7	L	45.8	33.8	20.4	L	44.1	35.1	20.8	L
	L_{13}	71.7	11.5	16.8	SL	70.1	12.6	17.3	SL	68.6	13.3	18.1	SL	70.4	10.8	18.8	SL
	L_{14}	68.4	15.5	16.1	SL	68.8	14.7	16.5	SL	69.8	13.1	17.1	SL	68.5	13.6	17.9	SL
	L_{15}	49.3	30.9	19.8	L	49.7	30.2	20.1	L	48.1	31.5	20.4	L	49.5	29.8	20.7	L

*** CL = Clay loam, SL = Sandy loam, L = Loam, LS = Loamy sand**

Table 4.1.2: Bulk density (Mg m^{-3}) of soils under different land use systems at different locations

District	**Location (L)**	**Bulk density (Mg m^{-3})**				
		Agriculture	**Horticulture**	**Agro-forestry**	**Forestry**	**Mean**
Ambala	**L_1**	1.24	1.30	1.28	1.21	**1.26**
	L_2	1.28	1.32	1.25	1.23	**1.27**
	L_3	1.36	1.39	1.28	1.30	**1.33**
	L_4	1.34	1.35	1.30	1.18	**1.29**
	L_5	1.30	1.32	1.29	1.28	**1.30**
Panchkula	**L_6**	1.55	1.56	1.59	1.48	**1.55**
	L_7	1.58	1.53	1.49	1.50	**1.53**
	L_8	1.51	1.49	1.48	1.43	**1.48**
	L_9	1.48	1.43	1.45	1.40	**1.44**
	L_{10}	1.49	1.45	1.49	1.41	**1.46**
Yamunanagar	**L_{11}**	1.33	1.38	1.34	1.31	**1.34**
	L_{12}	1.37	1.31	1.36	1.31	**1.34**
	L_{13}	1.53	1.45	1.32	1.41	**1.43**
	L_{14}	1.41	1.42	1.37	1.39	**1.40**
	L_{15}	1.39	1.32	1.35	1.32	**1.35**
	Mean	**1.41**	**1.40**	**1.38**	**1.34**	
CD at 5%	Location (L) = 0.02; Land use System (LUS) = 0.01; L×LUS = 0.04					

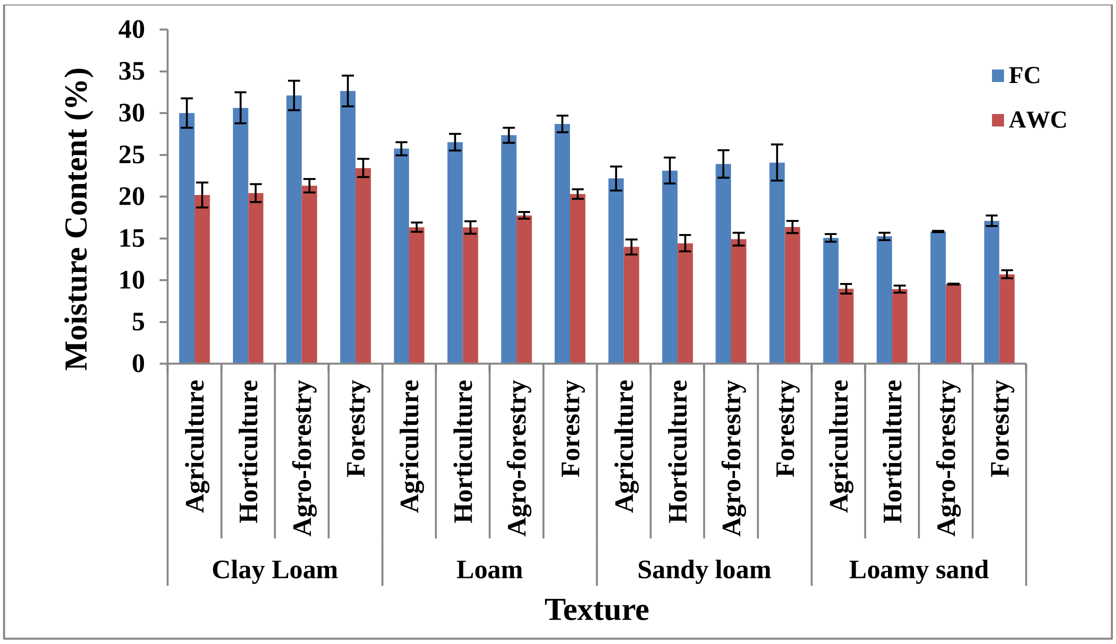

Fig. 4.1.3: Field capacity and available water content in soils under different land use systems in different textured soils

4.1.4 Aggregate size distribution

The data on aggregate size distribution of soil samples collected from different land use system at different locations is presented in Table 4.1.3. The water stable aggregates (WSA) of the size >0.25 mm in diameter of forest soils were higher (43.19 %) as compared to agro-forestry soils (42.48 %), horticultural (41.5 %) and agricultural soils (40.83 %). The amount of water stable aggregates (>0.25 mm) were found to increase with increase in the fineness of soil texture at different locations among the different land use systems. The mean value for water stable aggregates varied from 24.97 % at L_7 (loamy sand) to 61.62 % at L_1 (clay loam) under different land use systems. The aggregate stability expressed in terms of mean weight diameter (MWD) of texturally different soils has been plotted in Fig. 4.1.4. Among the different textured soils, the highest aggregate stability was observed with clay loam soil (0.96 mm) under forest system, followed by loam, sandy loam and loamy sand soil. Significant differences in MWD under different land use systems, where forestry systems had the highest value and followed the order of decrease in MWD: forestry > agro-forestry > horticultural > agricultural land use system.

Table 4.1.3: Water stable aggregates (>0.25 mm) of soils under different land use systems

District	Location (L)	Water stable aggregates (%) (> 0.25 mm)				
		Agriculture	**Horticulture**	**Agro-forestry**	**Forestry**	**Mean**
Ambala	**L_1**	60.49	61.51	62.11	62.37	**61.62**
	L_2	57.83	58.31	58.89	60.28	**58.83**
	L_3	57.94	56.62	57.80	58.71	**57.77**
	L_4	60.00	61.42	62.05	62.08	**61.39**
	L_5	59.00	58.31	60.14	60.73	**59.55**
Panchkula	**L_6**	26.35	27.28	28.44	28.82	**27.72**
	L_7	23.55	24.30	25.42	26.60	**24.97**
	L_8	30.41	31.11	32.10	33.11	**31.68**
	L_9	31.12	32.59	33.84	34.23	**32.95**
	L_{10}	32.84	33.79	33.92	34.04	**33.65**
Yamunanagar	**L_{11}**	36.37	37.70	38.24	39.05	**37.84**
	L_{12}	35.18	36.10	37.55	38.00	**36.71**
	L_{13}	31.43	31.96	32.58	33.90	**32.47**
	L_{14}	30.71	31.37	32.60	33.15	**31.96**
	L_{15}	39.25	40.08	41.51	42.70	**40.89**
	Mean	**40.83**	**41.50**	**42.48**	**43.19**	
CD at 5%	Location (L) = 0.22; Land use System (LUS) = 0.11; L×LUS = 0.43					

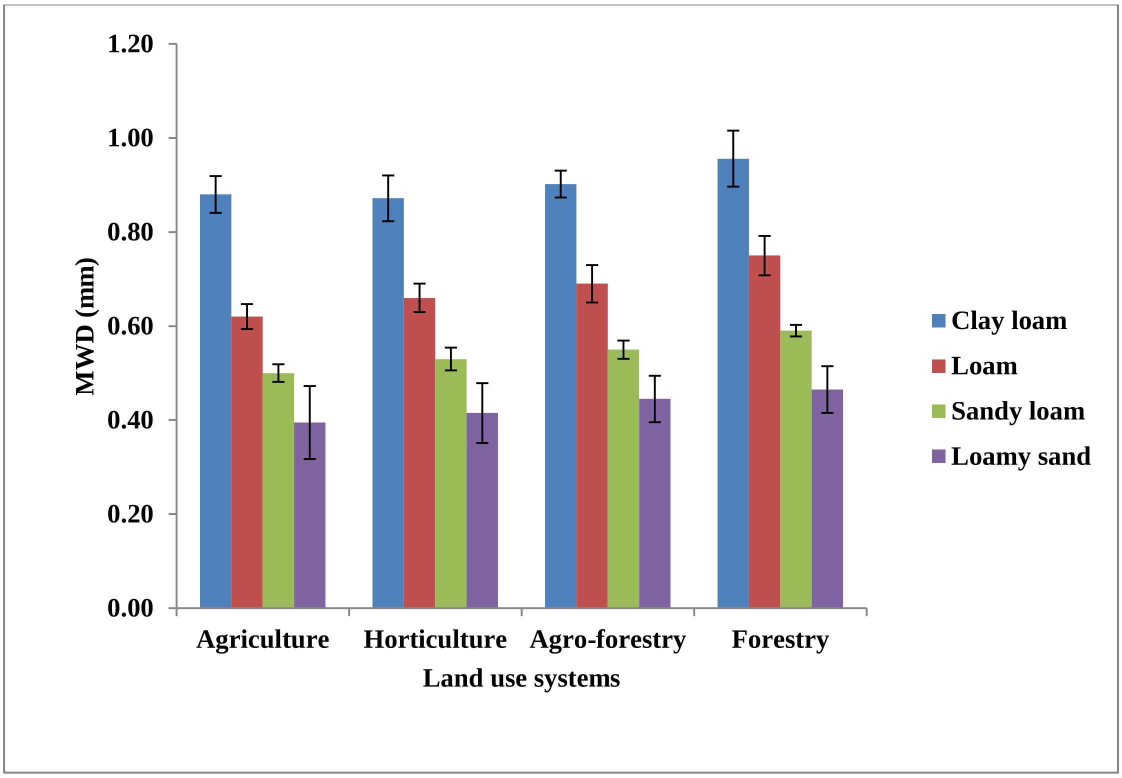

Fig. 4.1.4: Average mean weight diameter (MWD) in mm of different textured soils under different land use systems

4.1.5 Soil erodibility indices (clay ratio, modified clay ratio, dispersion ratio, erosion ratio, suspension percentage, suspension ratio):

To estimate the soil erodibility of a soil under different land use systems, various soil erodibility indices are calculated using different mathematical equations. Further, in order to derive the meaningful influences, soils belonging to same textural class are pooled for each land use system and the results obtained in relation to different erodibility indices are presented below:

Dispersion ratio (DR): The mean values of DR under agriculture, horticulture, agro-forestry and forestry were 64.8, 63.5, 62.3 and 60.8 with loamy sand soils, 57.7, 57, 55 and 53.8 in sandy loam soils, 52.8, 52.3, 51.3 and 50.8 in loam soils and 47.4, 47.3, 45 and 43.2 with clay loam soils respectively as depicted in figure 4.1.5. Irrespective to land use systems, the highest values of dispersion ratio were recorded in loamy sand soils followed by sandy loam, loam and clay loam soils.

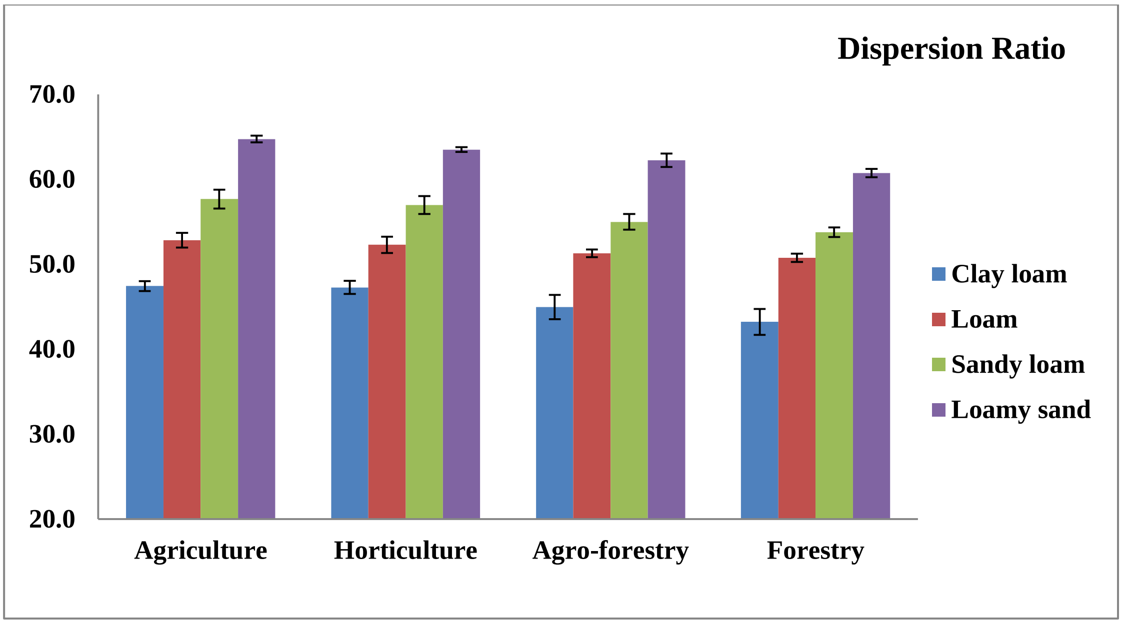

Fig 4.1.5: Effect of different land use systems on dispersion ratio of texturally different soils

Erosion ratio (ER): The erosion ratio of texturally different soils under four types land use systems are presented in Fig 4.1.6. The ER values in agriculture, horticulture, agro-forestry and forestry were observed to be 56.3, 55.1, 52.8 and 51.5 with loamy sand soils, 38.9, 38.1, 37.1 and 35.8 with sandy loam soils, 36.0, 35.4, 35.5 and 34.9 with loam soils and 22.7, 22.3, 22.1 and 21.0 in clay loam soils respectively. Data on ER showed decreasing trend with increase in the clay content of soils under different land use systems.

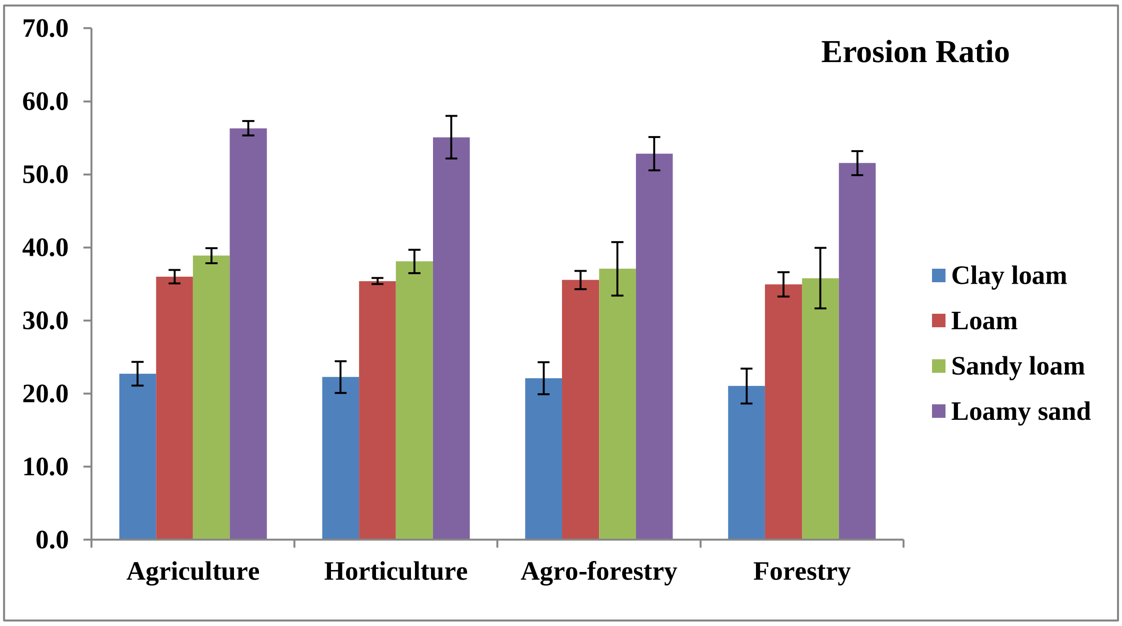

Fig 4.1.6: Effect of different land use systems on erosion ratio of texturally different soils

Clay ratio (CR): The results obtained for clay ratio of different textured soils under different land use systems is depicted in Fig 4.1.7. Among the different textured soils, clay ratio was observed to be highest under loamy sand soil followed by sandy loam, loam and lowest with clay loam soils, irrespective of the land use systems. The CR values for agriculture, horticulture, agro-forestry and forestry were 9.57, 9.53, 8.62 and 8.13 with loamy sand soils, 4.98, 4.88, 4.61 and 4.37 with sandy loam soils and 4.08, 4.09, 3.93 and 3.81 with loam soils while CR values were observed to be 1.99, 2.01, 1.92 and 1.82 with clay loam soil, respectively. With the increase of the fineness in soil texture clay ratio showed a decreasing trend under the four types of land use systems.

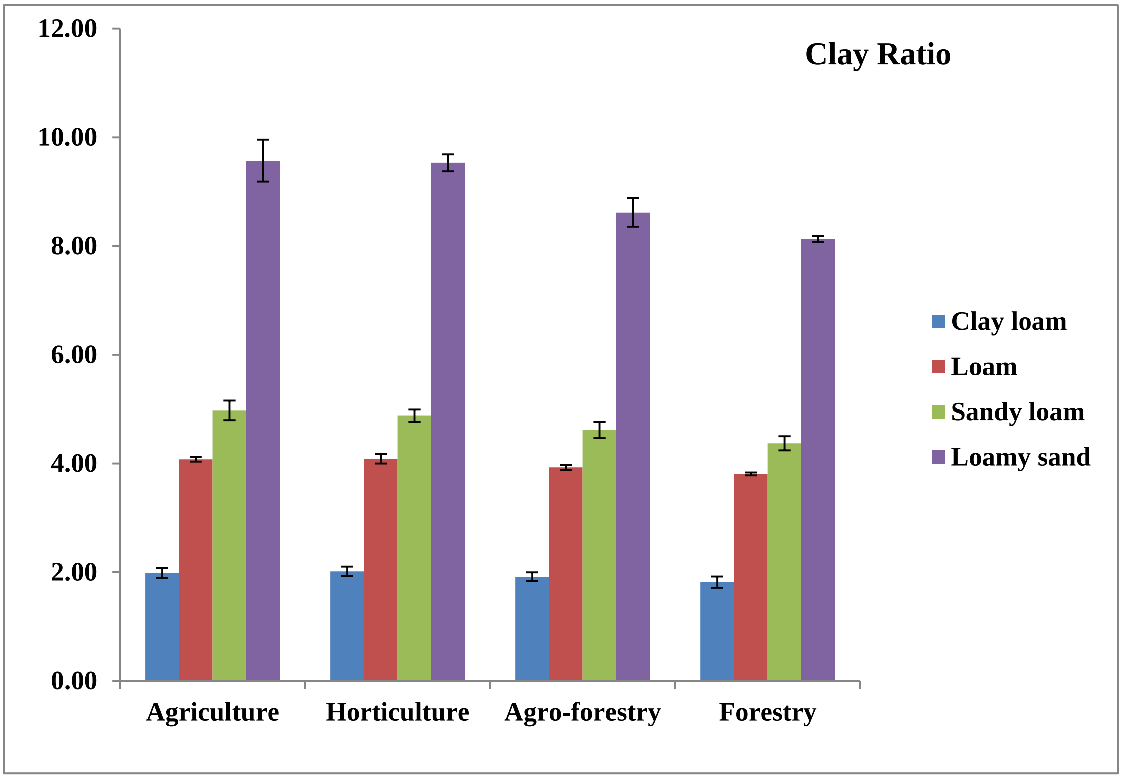

Fig 4.1.7: Effect of different land use systems on clay ratio of texturally different soils

Modified clay ratio (MCR): The modified clay ratio of different textured soils under different land use systems is plotted in Fig 4.1.8. The values of MCR followed the similar trend as that of clay ratio and with the increase in heaviness of texture from loamy sand to clay loam, the values of MCR also decreased. The MCR values for agriculture, horticulture, agro-forestry and forestry were 9.01, 8.88, 8.01 and 7.56 with loamy sand soils, 4.74, 4.62, 4.36 and 4.12 with sandy loam soils and 3.87, 3.86, 3.72 and 3.60 with loam soils while, the MCR values were observed to be 1.92, 1.95, 1.85 and 1.76 under clay loam texture respectively. With the increase of the fineness in soil texture clay ratio showed a decreasing trend under the four types of land use systems.

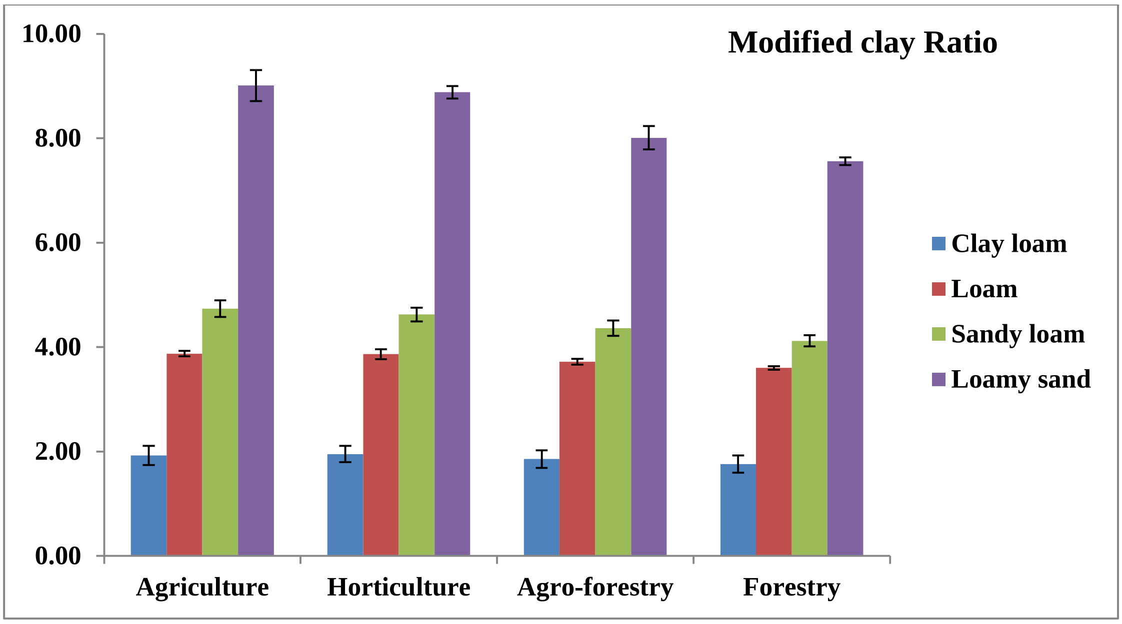

Fig 4.1.8: Effect of different land use systems on modified clay ratio of texturally different soils

Suspension percentage (SP): The values of suspension percentage under four types of land use systems *i.e.* agriculture, horticulture, agro-forestry and forestry were 11.95, 12.85, 11.70 and 11.95 with loamy sand soils, 16.72, 16.86, 16.76 and 16.04 with sandy loam soils and 25.58, 25.76, 24.30 and 23.20 with loam soils while the SP values were 27.47, 27.07, 27.23 and 26.93 with clay loam soils, respectively (Fig 4.1.9). In case of SP of different textured soil, the highest value was obtained from the clay loam soil followed by loam, sandy loam and loamy sand soil texture at different locations.

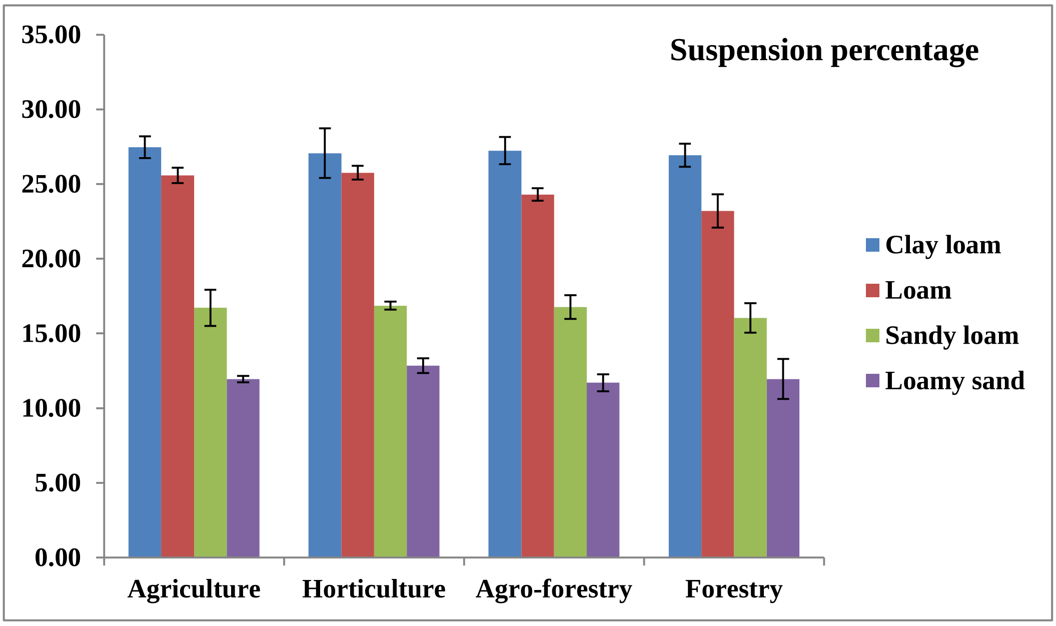

Fig 4.1.9: Effect of different land use systems on suspension percentage of texturally different soils

Suspension ratio (SR): The suspension ratio of different textured soils under four types of land use systems is presented in Fig 4.1.10. The SR values with agriculture, horticulture, agro-forestry and forest land use systems were 112.6, 110.2, 105.7 and 103.1 with loamy sand soils, 77.8, 76.2, 74.2 and 71.6 with sandy loam soils, 72.0, 70.8, 71.1 and 69.9 with loam soils and 45.4, 44.5, 44.2 and 42.1 with clay loam soils, respectively. SR for different textured soils was observed to be highest in loamy sand soils followed by sandy loam, loam while lowest values of SR were recorded in clay loam soils. With the increase in clay proportion of soil, suspension ratio showed a decreasing trend under different land use systems.

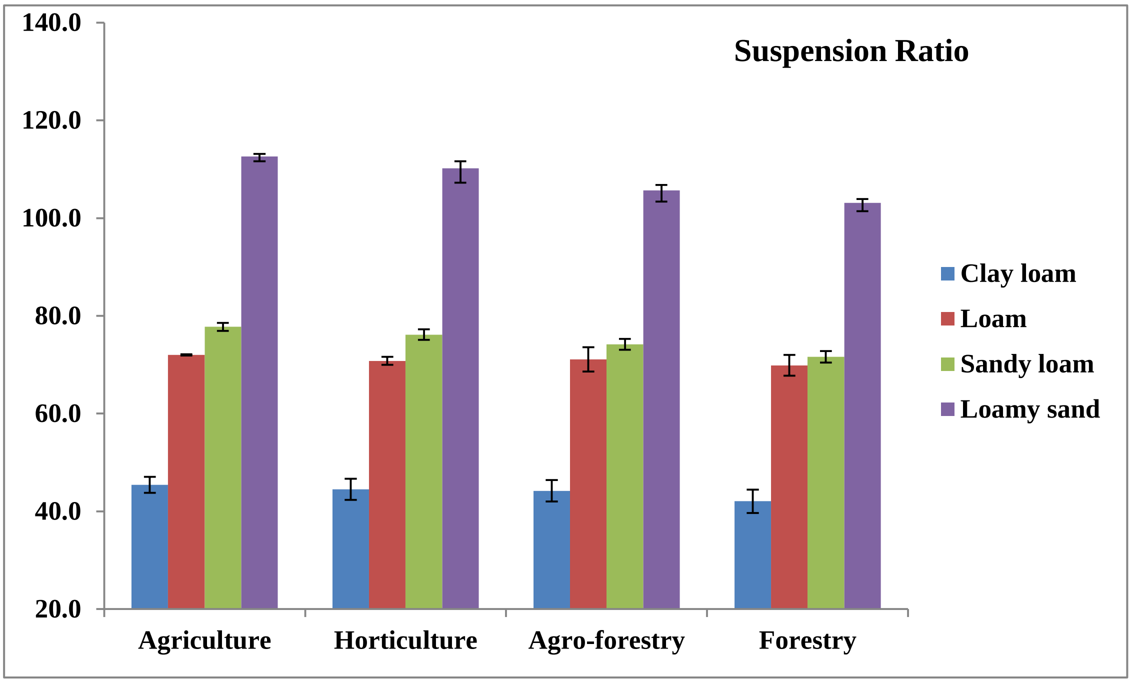

Fig 4.1.10: Effect of different land use systems on suspension ratio of texturally different soils

4.2 Chemical properties

4.2.1 Soil pH, electrical conductivity (EC) and $CaCO_3$ content

Data presented in table 4.2.1 revealed that pH of soils in the study area ranged from neutral to slightly alkaline. Moreover, conversion of land changes from forest to agriculture resulted in an increase of soil pH at different locations. Among the different land use systems, the average soil pH was observed to be lowest (7.46) in forest soils, while highest (7.82) pH was recorded with agriculture land use system. Mean values of soil pH varied from 7.39 to 7.82 at different locations irrespective to the land use systems. Data on EC also showed significant variations under different land use systems at different locations (Table 4.2.1). Among the different land use systems, a reverse trend was observed as that of pH and highest EC (0.45 dS m^{-1}) was observed in forest soils, while lowest (0.35 dS m^{-1}) in agriculture soils.

Table 4.2.1: Soil pH, electrical conductivity (EC) and $CaCO_3$ content (%) under different land use systems at different locations

District	**Location (L)**	**pH $_{(1:2)}$**					**EC$_{(1:2)}$ (dSm^{-1})**					**$CaCO_3$ content (%)**				
		Agriculture	**Horticulture**	**Agro-forestry**	**Forestry**	**Mean**	**Agriculture**	**Horticulture**	**Agro-forestry**	**Forestry**	**Mean**	**Agriculture**	**Horticulture**	**Agro-forestry**	**Forestry**	**Mean**
Ambala	**L_1**	7.68	8.07	7.96	7.47	**7.80**	0.33	0.34	0.41	0.35	**0.36**	0.00	0.00	0.00	1.61	**0.40**
	L_2	8.09	7.83	7.61	7.24	**7.69**	0.34	0.25	0.48	0.43	**0.38**	0.00	0.00	0.00	1.17	**0.29**
	L_3	7.65	7.16	7.58	7.45	**7.46**	0.33	0.37	0.33	0.61	**0.41**	0.00	0.00	0.00	1.05	**0.26**
	L_4	7.43	7.34	7.44	7.36	**7.39**	0.35	0.35	0.29	0.37	**0.34**	0.00	0.00	0.00	0.00	**0.00**
	L_5	7.86	7.49	7.47	7.61	**7.61**	0.13	0.14	0.29	0.38	**0.23**	0.00	0.00	0.00	0.00	**0.00**
Panchkula	**L_6**	7.58	7.42	7.39	7.54	**7.48**	0.47	0.24	0.27	0.41	**0.35**	0.00	0.00	0.00	1.30	**0.32**
	L_7	8.27	7.49	7.84	7.34	**7.74**	0.39	0.25	0.48	0.61	**0.43**	2.50	0.00	3.07	0.00	**1.39**
	L_8	7.79	7.73	7.58	7.46	**7.64**	0.51	0.57	0.92	0.66	**0.67**	0.00	2.67	1.35	0.00	**1.01**
	L_9	7.72	7.48	7.54	7.53	**7.57**	0.35	0.37	0.30	0.38	**0.35**	0.00	0.00	0.00	0.00	**0.00**
	L_{10}	7.56	7.66	7.57	7.45	**7.56**	0.30	0.37	0.27	0.36	**0.33**	0.00	0.00	0.00	0.00	**0.00**
Yamunanagar	**L_{11}**	7.69	7.39	7.69	7.54	**7.58**	0.21	0.25	0.30	0.25	**0.25**	0.00	0.00	0.00	0.00	**0.00**
	L_{12}	8.06	7.61	7.58	7.33	**7.65**	0.42	0.32	0.35	0.44	**0.38**	0.00	0.00	0.00	3.13	**0.78**
	L_{13}	8.07	7.81	7.72	7.68	**7.82**	0.37	0.33	0.39	0.41	**0.37**	0.00	0.00	2.63	0.00	**0.66**
	L_{14}	8.28	7.61	7.62	7.45	**7.74**	0.25	0.42	0.76	0.56	**0.50**	0.00	1.65	0.00	0.00	**0.41**
	L_{15}	7.55	7.31	7.43	7.39	**7.42**	0.41	0.41	0.63	0.49	**0.49**	0.00	0.00	0.00	0.00	**0.00**
	Mean	**7.82**	**7.56**	**7.60**	**7.46**		**0.35**	**0.33**	**0.43**	**0.45**		**0.17**	**0.29**	**0.47**	**0.55**	
CD at 5%	Location (L) = 0.27; Land use System (LUS) = 0.14; L×LUS = NS						Location (L) = 0.03; Land use System (LUS) = 0.01; L×LUS = 0.05					Location (L) = 0.15; Land use System (LUS) = 0.07; L×LUS = 0.29.				

Moreover, in case of different locations, maximum EC of 0.67 dS m^{-1} was recorded at L_8, where it was lowest (0.23 dS m^{-1}) was recorded L_5. The data presented in table 4.2.1 further indicated the mean $CaCO_3$ content which was 0.55 % under forest land use system, was significantly reduced to 0.17 % in agricultural soils. However, the $CaCO_3$ content was also observed to be nil (0 %) at different locations under the four types of land use systems.

4.2.2 Cation exchange capacity (CEC)

Data presented in table 4.2.2 indicated the variations in CEC of soils at different locations under the four types of land use systems. The CEC of soils was significantly enhanced in forest soils as compared to other land use systems and followed the trend as: forestry > agro-forestry > horticulture > agriculture. The mean value of CEC was observed to be higher under forest system (11.79 cmol (P+) kg^{-1}), while it was lowest (9.25 cmol (P+) kg^{-1}) under agriculture land use system. Among the different locations, the average value of CEC varied from 6.79 cmol (P+) kg^{-1} to 14.24 cmol (P+) kg^{-1}, where highest value of CEC was observed at L_3. Moreover, significant interactive effect was observed between location and land use systems.

Table 4.2.2: Effect of different land use systems on cation exchange capacity (cmol P+) kg^{-1}) at different locations

District	Location (L)	Cation exchange capacity [cmol (P+) kg^{-1}]				
		Agriculture	**Horticulture**	**Agro-forestry**	**Forestry**	**Mean**
Ambala	**L_1**	11.72	12.12	16.76	14.77	**13.84**
	L_2	12.89	12.31	13.72	13.95	**13.22**
	L_3	14.98	13.20	14.53	14.26	**14.24**
	L_4	13.56	12.58	10.87	15.78	**13.20**
	L_5	12.15	13.27	14.57	15.19	**13.80**
Panchkula	**L_6**	5.09	6.23	7.82	8.02	**6.79**
	L_7	6.02	6.13	7.71	8.23	**7.02**
	L_8	7.20	6.25	8.91	8.74	**7.78**
	L_9	5.74	6.35	7.29	8.12	**6.88**
	L_{10}	6.03	7.95	6.91	7.93	**7.21**
Yamunanagar	**L_{11}**	7.81	7.22	11.72	12.11	**9.72**
	L_{12}	8.35	9.86	11.28	12.94	**10.61**
	L_{13}	9.08	11.01	11.98	12.57	**11.16**
	L_{14}	10.24	8.23	11.17	12.21	**10.47**
	L_{15}	7.91	7.59	10.27	11.97	**9.43**
	Mean	**9.25**	**9.35**	**11.03**	**11.79**	
CD at 5%	Location (L) = 0.79; Land use System (LUS) = 0.41; L×LUS = 1.58					

4.2.3 Organic carbon and organic carbon stocks:

Soil organic carbon content (SOC) in soils for four types of land use systems at different locations ranged between 0.54 to 0.66% (Table 4.2.3). In addition to land use systems, soil texture also had a significant impact on retaining SOC content of the soils. Forest soils had the highest SOC content (0.66%), followed by agro-forestry (0.61 %), horticulture (0.57 %) and it was lowest in agriculture (0.54%) soils. It was also observed that the organic carbon content had a significant interaction between locations and land use systems. The average SOC content at different locations varied from 0.42 % to 0.68 %, where lowest SOC content in soil was observed at L_7 while, it was highest at L_4.

Table 4.2.3: Soil organic carbon content (%) under different land use systems at different locations

District	**Location (L)**	**Organic carbon (%)**				
		Agriculture	**Horticulture**	**Agro-forestry**	**Forestry**	**Mean**
Ambala	**L_1**	0.62	0.56	0.57	0.69	**0.61**
	L_2	0.67	0.63	0.68	0.72	**0.67**
	L_3	0.59	0.57	0.65	0.82	**0.65**
	L_4	0.65	0.60	0.70	0.77	**0.68**
	L_5	0.57	0.65	0.69	0.68	**0.65**
Panchkula	**L_6**	0.38	0.35	0.46	0.49	**0.42**
	L_7	0.31	0.45	0.46	0.47	**0.42**
	L_8	0.47	0.42	0.51	0.58	**0.49**
	L_9	0.51	0.58	0.61	0.66	**0.59**
	L_{10}	0.53	0.62	0.64	0.63	**0.61**
Yamunanagar	**L_{11}**	0.66	0.59	0.61	0.71	**0.64**
	L_{12}	0.58	0.73	0.72	0.75	**0.70**
	L_{13}	0.46	0.58	0.63	0.68	**0.59**
	L_{14}	0.50	0.53	0.57	0.68	**0.57**
	L_{15}	0.57	0.65	0.69	0.64	**0.64**
	Mean	**0.54**	**0.57**	**0.61**	**0.66**	
CD at 5%	Location (L) = 0.03; Land use System (LUS) = 0.02; L×LUS = 0.06					

Soil organic carbon stocks (SCS): The data presented in table 4.2.4 revealed that both land use systems and location had a significant effect on the soil organic carbon stocks (SCS) in the soil and followed the same trend as that of SOC. Comparison of mean values revealed that the SOC stocks were found to be superior in forest soils (13.29 Mg ha^{-1}), followed by agro-forestry system (12.55 Mg ha^{-1}), horticulture (11.82 Mg ha^{-1}) and lowest value of SCS (11.22

Mg ha^{-1}) were observed with agriculture land use system. SCS under different land use systems also differs with the change in location and ranged from 9.63 Mg ha^{-1} to 13.92 Mg ha^{-1} at different locations. Overall, the SCS followed the order as forestry > agro-forestry > horticulture > agriculture.

Table 4.2.4: Soil organic carbon stocks (Mg ha^{-1}) under different land use systems at different locations

District	Location (L)	Soil organic carbon stocks (Mg ha^{-1})				
		Agriculture	Horticulture	Agro-forestry	Forestry	Mean
Ambala	L_1	11.53	10.92	10.94	12.52	**11.48**
	L_2	12.86	12.47	12.75	13.28	**12.84**
	L_3	12.04	11.88	12.48	15.99	**13.10**
	L_4	12.66	11.95	13.46	13.45	**12.88**
	L_5	11.12	12.87	13.35	13.06	**12.60**
Panchkula	L_6	8.84	8.19	10.97	10.88	**9.72**
	L_7	7.35	10.33	10.28	10.58	**9.63**
	L_8	10.65	9.39	11.32	12.44	**10.95**
	L_9	11.32	12.44	13.27	13.86	**12.72**
	L_{10}	11.85	13.49	14.30	13.32	**13.24**
Yamunanagar	L_{11}	13.17	12.21	12.26	13.95	**12.90**
	L_{12}	11.92	14.34	14.69	14.74	**13.92**
	L_{13}	10.56	12.62	12.47	14.38	**12.51**
	L_{14}	10.58	11.29	11.71	14.18	**11.94**
	L_{15}	11.88	12.87	13.97	12.67	**12.85**
	Mean	**11.22**	**11.82**	**12.55**	**13.29**	
CD at 5%	Location (L) = 0.33; Land use System (LUS) = 0.17; L×LUS = 0.66					

4.2.4 Carbon fractions: particulate organic carbon and mineral associated organic carbon

At all the locations, organic carbon fractions *i.e.* particulate carbon fractions (53-2000 µm) and mineral associate carbon fractions (< 53 µm) were significantly affected by different land use systems (Table 4.2.5). The particulate organic carbon (POC) and mineral associate organic carbon (MOC) were observed to be significantly higher in forest soils (1307 mg kg^{-1} and 2793 mg kg^{-1}, respectively), followed by agro-forestry (1185 mg kg^{-1} and 2522 mg kg^{-1}, respectively), horticulture (1129 mg kg^{-1} and 2507 mg kg^{-1}, respectively) while lowest value was observed under agriculture (1091 mg kg^{-1} and 2382 mg kg^{-1} respectively) land use system. Locations had significant impact on soil organic carbon stocks as it showed an increase from 902 mg kg^{-1} at L_6 to 1440 mg kg^{-1} at L_{12} for POC and from 2094 mg kg^{-1} at L_7 to 3156 mg kg^{-1} at L_{12} for MOC, depending upon the fineness of soil texture.

Table 4.2.5: Soil particulate and mineral associated carbon fractions under different land use systems at different locations

District	**Location (L)**	**Particulate carbon (mg kg^{-1})**					**Mineral associated carbon (mg kg^{-1})**				
		Agriculture	**Horticulture**	**Agro-forestry**	**Forestry**	**Mean**	**Agriculture**	**Horticulture**	**Agro-forestry**	**Forestry**	**Mean**
Ambala	**L_1**	1154	1121	1142	1282	**1175**	2368	2511	2470	2734	**2521**
	L_2	1254	1189	1217	1504	**1291**	2700	2392	2503	3242	**2709**
	L_3	1178	1128	1231	1721	**1315**	2645	2658	2651	3612	**2892**
	L_4	1194	1112	1284	1537	**1282**	2342	2689	2713	3402	**2787**
	L_5	1134	1219	1280	1249	**1221**	2692	2400	2734	2736	**2641**
Panchkula	**L_6**	812	789	980	1028	**902**	2098	1879	2271	2218	**2117**
	L_7	767	943	976	984	**918**	1632	2278	2278	2189	**2094**
	L_8	1219	902	1061	1189	**1093**	2304	2194	2278	2648	**2356**
	L_9	1050	1166	1131	1213	**1140**	2243	2653	2312	2598	**2452**
	L_{10}	1089	1156	1198	1197	**1160**	2254	2389	2412	2537	**2398**
Yamunanagar	**L_{11}**	1229	1194	1123	1489	**1259**	2643	2698	2398	3129	**2717**
	L_{12}	1185	1523	1510	1540	**1440**	2772	3278	3178	3394	**3156**
	L_{13}	956	1192	1198	1223	**1142**	2214	2786	2489	2519	**2502**
	L_{14}	1021	1083	1156	1234	**1124**	2198	2380	2412	2547	**2384**
	L_{15}	1119	1211	1281	1217	**1207**	2631	2413	2734	2397	**2544**
	Mean	**1091**	**1129**	**1185**	**1307**		**2382**	**2507**	**2522**	**2793**	
CD at 5%	Location (L) = 3.98; Land use System (LUS) = 2.06; L×LUS = 7.96						Location (L) = 1.51; Land use System (LUS) = 0.78; L×LUS = 3.02				

4.2.5 Available nitrogen, phosphorus and potassium (NPK) and DTPA extractable micronutrients (Fe, Mn, Cu and Zn)

The available NPK content under different land use systems varied significantly at different locations (Table 4.2.6). Among the different locations, the available nitrogen content in soils ranged from 110 kg ha^{-1} to 268 kg ha^{-1} at L_7 and L_{12} location, respectively under different land use systems. The available nitrogen content in forest land use systems was significantly higher (235 kg ha^{-1}) as compared to agro-forestry (200 kg ha^{-1}), horticulture (192 kg ha^{-1}) and agriculture (183 kg ha^{-1}) land use systems. There was no definite trend observed in available nitrogen content of soils at different location with respect to their texture but in general higher clay content increases the nitrogen availability. Significant differences in available P contents were recorded under different land use systems at different locations. Results from soil analysis indicated that the highest available P content was found in the forest soils with value of 18.3 kg ha^{-1}, followed by agro-forestry (17.9 kg ha^{-1}), horticulture (17.5 kg ha^{-1}) and the lowest available P content was observed in agricultural soils (16.6 kg ha^{-1}). The average value of available P content in soil varied from 10 to 25 kg ha^{-1} at different locations under the different land use systems. The available K content in forest soils reaching a highest value of 254 kg ha^{-1}, which was significantly higher in comparison to agro-forestry (208 kg ha^{-1}), horticulture (191 kg ha^{-1}) and agriculture (153 kg ha^{-1}) land use systems. Moreover, significant differences in available K content at different location were observed varied from 115 to 298 kg ha^{-1} irrespective to different land use systems. The interaction effect between locations and land use system also revealed a significant effect on all the three macronutrients contents in soils.

Micronutrients: The data of available micronutrients (Fe, Mn, Cu and Zn) content in soils of different locations under different land use systems are presented in table 4.2.7; 4.2.8; 4.2.9 and 4.2.10. Among the different land use systems, highest mean value of iron content was observed in horticulture (5.70 ppm) soils while lowest value was obtained with agro-forestry system (5.02 ppm). L_{12} location showed significantly higher value of iron content (7.13 ppm) as compared to the other locations. The available Mn content ranged from 4.56 to 8.21 ppm at different locations in the soils of Eastern Haryana. The highest average value of Mn content was observed under forestry system (6.62 ppm), followed by agriculture (6.44 ppm), horticulture (6.35 ppm), and agroforestry system (6.34 ppm) at different locations. The available Cu content in soils ranged from 0.43 to 0.95 ppm at different locations, while, highest mean value of Cu content was found in agro-forestry soils (0.66 ppm) and lowest value was observed under horticultural (0.58 ppm) land use systems.

Table 4.2.6: Available NPK status of soil under different land use systems at different locations

District	Location (L)	Available N (kg ha^{-1})					Available P (kg ha^{-1})					Available K (kg ha^{-1})				
		Agriculture	**Horticulture**	**Agro-forestry**	**Forestry**	**Mean**	**Agriculture**	**Horticulture**	**Agro-forestry**	**Forestry**	**Mean**	**Agriculture**	**Horticulture**	**Agro-forestry**	**Forestry**	**Mean**
Ambala	**L_1**	249	196	217	291	**238**	22.0	25.0	25.0	28.0	**25.0**	264	345	255	307	**293**
	L_2	227	201	285	260	**243**	25.0	23.0	24.0	22.0	**23.5**	295	238	246	245	**256**
	L_3	207	126	226	209	**192**	16.0	27.0	19.0	26.0	**22.0**	175	356	310	350	**298**
	L_4	254	210	277	283	**256**	17.0	21.0	23.0	25.0	**21.5**	182	200	236	395	**253**
	L_5	218	261	212	254	**236**	24.0	18.0	21.0	20.0	**20.8**	171	228	227	381	**252**
Panchkula	**L_6**	119	126	98	175	**130**	8.0	10.0	11.0	14.0	**10.8**	160	83	128	118	**122**
	L_7	109	103	124	105	**110**	9.0	8.0	13.0	10.0	**10.0**	98	95	107	159	**115**
	L_8	133	168	140	210	**163**	13.0	15.0	14.0	13.0	**13.8**	83	138	227	224	**168**
	L_9	119	182	126	197	**156**	12.0	16.0	15.0	10.0	**13.3**	110	130	184	178	**150**
	L_{10}	178	243	182	206	**202**	16.0	13.0	16.0	14.0	**14.8**	127	160	178	160	**156**
Yamunanagar	**L_{11}**	240	204	220	240	**226**	16.0	18.0	21.0	19.0	**18.5**	136	163	191	266	**189**
	L_{12}	154	288	319	310	**268**	26.0	17.0	19.0	17.0	**19.8**	143	178	228	285	**209**
	L_{13}	197	133	189	291	**203**	15.0	16.0	14.0	21.0	**16.5**	114	197	201	259	**193**
	L_{14}	133	182	212	199	**182**	13.0	17.0	16.0	20.0	**16.5**	116	183	188	234	**180**
	L_{15}	206	263	168	299	**234**	17.0	19.0	17.0	16.0	**17.3**	125	171	221	242	**190**
	Mean	**183**	**192**	**200**	**235**		**16.6**	**17.5**	**17.9**	**18.3**		**153**	**191**	**208**	**254**	
CD at 5%	Location (L) = 3.59; Land use System (LUS) = 1.85; L×LUS = 7.18						Location (L) = 0.62; Land use System (LUS) = 0.32; L×LUS = 1.23					Location (L) = 4.59; Land use System (LUS) = 2.37; L×LUS = 9.19				

Table 4.2.7: Iron (ppm) concentration in soils under different land use systems at different locations

District	**Location (L)**	**Iron (ppm)**				
		Agriculture	**Horticulture**	**Agro-forestry**	**Forestry**	**Mean**
Ambala	**L_1**	7.86	5.64	6.04	7.74	**6.82**
	L_2	4.26	4.15	5.42	8.12	**5.49**
	L_3	5.70	7.24	5.64	5.48	**6.02**
	L_4	5.28	4.84	5.26	5.44	**5.21**
	L_5	4.60	5.38	4.80	5.60	**5.10**
Panchkula	**L_6**	3.80	4.72	4.34	4.24	**4.28**
	L_7	4.12	3.98	4.44	4.19	**4.18**
	L_8	3.24	2.98	2.58	3.14	**2.99**
	L_9	4.78	7.90	6.20	4.45	**5.83**
	L_{10}	4.60	7.04	6.00	4.74	**5.60**
Yamunanagar	**L_{11}**	6.00	5.06	6.30	4.06	**5.36**
	L_{12}	9.00	10.16	4.64	4.72	**7.13**
	L_{13}	6.84	6.92	4.96	6.20	**6.23**
	L_{14}	3.80	4.30	3.20	2.24	**3.39**
	L_{15}	5.62	5.24	5.42	5.28	**5.39**
	Mean	**5.30**	**5.70**	**5.02**	**5.04**	
CD at 5%	Location (L) = 0.25; Land use System (LUS) = 0.13; L×LUS = 0.5					

Table 4.2.8: Manganese (ppm) concentration in soils under different land use systems at different locations

District	**Location (L)**	**Manganese (ppm)**				
		Agriculture	**Horticulture**	**Agro-forestry**	**Forestry**	**Mean**
Ambala	**L_1**	4.00	4.30	4.44	7.86	**5.15**
	L_2	7.12	6.00	6.30	4.94	**6.09**
	L_3	5.70	7.40	7.30	4.84	**6.31**
	L_4	6.08	7.90	6.40	6.64	**6.76**
	L_5	6.92	8.40	6.40	8.42	**7.54**
Panchkula	**L_6**	4.28	6.20	5.88	5.64	**5.50**
	L_7	4.98	4.42	3.24	5.60	**4.56**
	L_8	4.40	3.64	4.00	7.60	**4.91**
	L_9	7.60	7.80	7.50	6.80	**7.43**
	L_{10}	6.64	6.30	6.76	6.90	**6.65**
Yamunanagar	**L_{11}**	7.20	6.30	8.40	9.11	**7.75**
	L_{12}	6.60	8.40	7.60	10.24	**8.21**
	L_{13}	8.40	8.62	8.19	5.80	**7.75**
	L_{14}	9.80	4.30	7.64	2.14	**5.97**
	L_{15}	6.82	5.20	4.98	6.84	**5.96**
	Mean	**6.44**	**6.35**	**6.34**	**6.62**	
CD at 5%	Location (L) = 0.35; Land use System (LUS) = 0.18; L×LUS = 0.7					

Table 4.2.9: Copper (ppm) concentration in soils under different land use systems at different locations

District	**Location (L)**	**Copper (ppm)**				
		Agriculture	**Horticulture**	**Agro-forestry**	**Forestry**	**Mean**
Ambala	L_1	0.72	0.56	0.54	0.52	**0.59**
	L_2	0.77	0.64	0.61	0.54	**0.64**
	L_3	0.49	0.58	0.45	0.71	**0.56**
	L_4	0.80	0.56	0.70	0.68	**0.69**
	L_5	0.66	0.61	0.68	0.58	**0.63**
Panchkula	L_6	0.22	0.45	0.82	0.70	**0.55**
	L_7	0.32	0.36	0.47	0.58	**0.43**
	L_8	0.71	0.82	0.68	0.53	**0.69**
	L_9	0.40	0.55	0.56	0.49	**0.50**
	L_{10}	0.67	0.81	0.58	0.63	**0.67**
Yamunanagar	L_{11}	0.84	0.52	1.12	0.96	**0.86**
	L_{12}	1.02	0.74	1.04	0.98	**0.95**
	L_{13}	0.92	0.60	0.88	0.48	**0.72**
	L_{14}	0.48	0.42	0.36	0.44	**0.43**
	L_{15}	0.72	0.48	0.38	0.68	**0.57**
	Mean	**0.65**	**0.58**	**0.66**	**0.63**	
CD at 5%	Location (L) = 0.07; Land use System (LUS) = 0.03; L×LUS = 0.13					

Table 4.2.10: Zinc (ppm) concentration in soils under different land use systems at different locations

District	**Location (L)**	**Zinc (ppm)**				
		Agriculture	**Horticulture**	**Agro-forestry**	**Forestry**	**Mean**
Ambala	L_1	1.44	1.24	1.12	1.50	**1.33**
	L_2	0.96	1.22	1.98	1.84	**1.50**
	L_3	1.58	1.87	1.53	0.86	**1.46**
	L_4	1.10	1.07	1.27	1.15	**1.15**
	L_5	0.66	0.81	0.56	0.91	**0.74**
Panchkula	L_6	1.04	0.98	0.66	0.54	**0.81**
	L_7	0.82	0.96	0.71	0.92	**0.85**
	L_8	0.70	0.72	0.71	0.66	**0.70**
	L_9	0.86	1.94	0.70	0.84	**1.09**
	L_{10}	0.92	1.22	0.83	0.68	**0.91**
Yamunanagar	L_{11}	1.98	0.88	0.86	0.82	**1.14**
	L_{12}	1.50	1.32	1.01	1.03	**1.22**
	L_{13}	0.92	1.52	0.82	0.78	**1.01**
	L_{14}	1.26	0.70	1.10	0.71	**0.94**
	L_{15}	0.66	0.52	0.68	0.84	**0.68**
	Mean	**1.09**	**1.13**	**0.97**	**0.94**	
CD at 5%	Location (L) = 0.09; Land use System (LUS) = 0.04; L×LUS = 0.17					

Among the different locations, the value of Zn content in soils varied from 0.68 to 1.50 ppm at different locations. The available Zn content in soils under different land use systems was 1.13, 1.09, 0.97 and 0.94 ppm under horticulture, agriculture, agro-forestry and forestry land use system, respectively. There was no specific trend observed in case of micronutrient availability at different locations under different land use systems. However, the interaction effect between location and land use systems was found to be significant in case of micronutrients.

4.3 Soil biological properties

4.3.1 Microbial biomass carbon (MBC)

The microbial biomass carbon (MBC) is one of the most important fraction of SOC, which accounts for a small portion but considered as an important indicator of soil quality and observed to be significantly influenced under different land use systems at various locations in the soils of Eastern Haryana. MBC varied significantly among the different land use systems at different locations (Table 4.3.1).

Table 4.3.1: Soil microbial biomass carbon under different land use systems at different locations

District	Location (L)	Microbial biomass carbon (μg g^{-1} of soil)				
		Agriculture	Horticulture	Agro-forestry	Forestry	Mean
Ambala	L_1	278	280	296	290	**286**
	L_2	283	275	295	289	**285**
	L_3	283	284	292	290	**287**
	L_4	251	257	273	269	**263**
	L_5	254	255	267	261	**259**
Panchkula	L_6	208	202	218	211	**210**
	L_7	199	203	214	209	**206**
	L_8	229	222	241	237	**232**
	L_9	232	224	245	241	**236**
	L_{10}	225	228	242	236	**233**
Yamunanagar	L_{11}	259	253	268	263	**261**
	L_{12}	257	251	263	260	**258**
	L_{13}	230	233	248	243	**238**
	L_{14}	231	232	247	240	**237**
	L_{15}	265	250	276	272	**266**
	Mean	**246**	**243**	**259**	**254**	
CD at 5%	Location (L) = 3.27; Land use System (LUS) = 1.69; L×LUS = 6.55					

The content of MBC was observed to be highest under agro-forestry (259 µg g^{-1}) and lowest in the horticulture (243 µg g^{-1}) land use systems in the surface soils at different locations. Mostly, heavy textured soils have significantly higher amount of MBC in comparison to the light textured soils at different locations. Among the different locations, the highest value of MBC content (287 µg g^{-1}) was observed at L_{12} location, while the lowest (206 µg g^{-1}) was recorded at L_7. The MBC followed the trend: agro-forestry > forestry > agriculture > horticulture land use system. The interaction effect between location and land use system was also found to be significant.

4.3.2 Dehydrogenase and alkaline phosphatase activity

The dehydrogenase activity (DHA) differed from one location to another under different land use systems (Table 4.3.2). The higher dehydrogenase activity was observed at L_{11} location (54.1 µg TPF g^{-1} soil d^{-1}) and lowest was observed in loamy sand soils at L_6 location (24.4 µg TPF g^{-1} soil d^{-1}). The dehydrogenase activity was decreased generally with increase of coarse particles fraction in soil. Among the different land use systems, agro-forestry had maximum dehydrogenase activity (41.6 µg TPF g^{-1} soil d^{-1}) which was at par with the forest soils (39.9 µg TPF g^{-1} soil d^{-1}), followed by agricultural soils (37.7 µg TPF g^{-1} soil d^{-1}) and lowest was observed in horticultural soils (36.9 µg TPF g^{-1} soil d^{-1}) at different locations. The results revealed that the magnitude of alkaline phosphatase activity varies with locations under the four types of land use systems (Table 4.3.2). The alkaline phosphatase activity at different locations was significantly higher under agro-forestry (190.1 µg PNP g^{-1} soil h^{-1}) systems, followed by forest (186.8 µg PNP g^{-1} soil h^{-1}), agriculture (182.7 µg PNP g^{-1} soil h^{-1}) and horticulture (180.9 µg PNP g^{-1} soil h^{-1}) and followed the similar trend as in case of DHA as: agro-forestry > forestry > agriculture > horticulture land use system. The alkaline phosphatase enzyme activity was varied from 167.4 to 200.5 µg PNP g^{-1} soil h^{-1} at L_7 and L_3, respectively. The interaction effect between location and land use system was also found to be significant in case of dehydrogenase and alkaline phosphatase enzymatic activities at different locations.

Table 4.3.2: Dehydrogenase and alkaline phosphatase activities under different land use systems at different locations

District	**Location (L)**	**Dehydrogenase activity (µg TPF/g of soil/d)**					**Alkaline Phosphatase activity (µg PNP/g of soil/h)**				
		Agriculture	**Horticulture**	**Agro-forestry**	**Forestry**	**Mean**	**Agriculture**	**Horticulture**	**Agro-forestry**	**Forestry**	**Mean**
Ambala	**L_1**	48.9	49.1	52.1	50.2	**50.1**	194.1	195.8	203.2	198.4	**197.9**
	L_2	53.2	50.4	57.6	55.3	**54.1**	197.1	190.8	204.3	199.4	**197.9**
	L_3	49.4	50.6	52.9	51.1	**51.0**	196.2	197.3	206.7	201.9	**200.5**
	L_4	38.2	42.8	46.7	44.2	**43.0**	184.3	186.2	192.6	189.3	**188.1**
	L_5	40.3	41.1	44.2	43.7	**42.3**	185.4	188.3	195.6	192.7	**190.5**
Panchkula	**L_6**	23.7	21.2	27.9	24.8	**24.4**	167.5	162.3	173.9	170.2	**168.5**
	L_7	23.1	24.2	28.2	25.7	**25.3**	163.9	165.2	171.2	169.3	**167.4**
	L_8	33.7	29.9	36.1	34.4	**33.5**	180.2	174.8	186.1	182.3	**180.9**
	L_9	33.8	30.2	35.7	34.2	**33.5**	178.2	172.7	184.6	181.1	**179.2**
	L_{10}	34.1	35.2	36.9	35.8	**35.5**	175.2	177.3	181.2	179.9	**178.4**
Yamunanagar	**L_{11}**	43.2	38.2	46.2	45.5	**43.3**	189.4	182.1	194.3	190.1	**189.0**
	L_{12}	41.4	39.1	43.0	42.2	**41.4**	188.2	185.1	193.8	191.2	**189.6**
	L_{13}	29.7	30.6	34.2	33.0	**31.9**	176.9	178.7	183.9	180.5	**180.0**
	L_{14}	28.6	31.1	35.2	34.9	**32.4**	175.1	176.6	184.1	182.7	**179.6**
	L_{15}	43.7	39.5	46.5	44.1	**43.4**	194.1	195.8	203.2	198.4	**197.9**
	Mean	**37.7**	**36.9**	**41.6**	**39.9**		**182.7**	**180.9**	**190.1**	**186.8**	
CD at 5%	Location (L) = 0.84; Land use System (LUS) = 0.43; L×LUS = 1.67						Location (L) = 1.47; Land use System (LUS) = 0.76; L×LUS = 2.93				

CHAPTER-V

DISCUSSION

Results obtained from the present study entitled "Effect of different land use systems (agriculture, horticulture, agro-forestry and forestry) on soil erodibility, aggregation and organic carbon dynamics in soils of Eastern Haryana" are discussed in this chapter under the following heads:

5.1 Effect of different land use systems on soil texture

Soil texture is an inherent property of soil which is used to predict the physical, chemical and biological processes such as water holding capacity, aeration, infiltration, drainage, bulk density, susceptibility to soil erosion, organic matter content, cation exchange capacity, buffering capacity, enzymatic activity, microbial biomass production that occur in soils and ecosystems (Muller and Hoper, 2004). In the present study, four types of soil texture; clay loam, loam, sandy loam and loamy sand were observed to exist under four different types of land use systems *i.e.* agriculture, horticulture, agro-forestry and forestry at soil sampling sites in the districts of Eastern Haryana. It was observed from the data that land use systems had no significant impact on soil texture since texture is an inherent soil property that largely remains unaffected by land use systems and soil management practices (Jha *et al.*, 2010). Similar findings were also reported by Negasa *et al.* (2017) that there was no significant difference in soil textural class among the different land use types. In contrast, Voundi Nkana and Tonye (2018) reported that continuous cropping and intensive land-use systems have significantly affects the soil particle size distribution. Overall, the soil texture was observed to have a significant effect on most of the other soil properties as well as sustaining the organic matter in soil (Burst *et al.*, 2020).

5.2 Effect of different land use systems on soil bulk density (BD)

A perusal of data on bulk density (BD) at different locations (Table 4.1.2) showed significant variations among the different land use systems. The mean BD values of all locations was observed to be highest (1.41 Mg m^{-3}) under agriculture while the lowest value of 1.34 Mg m^{-3} of BD was found under forest land use system. Among the different land use systems (LUS), forest land use system resulted in significant reductions in bulk density of soils followed by agro-forestry and horticulture, while at majority of the locations. The possible reason for decrease in bulk density under forest LUS may be due to accumulation of organic materials in the form of leaf litter and plant biomass (Sepehya *et al.*, 2012; Abbasi and Tahir, 2012). Our results are supported by Tripathi *et al.*, (2007), who reported that forest and mixed forest systems had the higher organic matter content which may be associated with greater soil biological activity, especially earthworms (Kahlon *et al.*, 2012) which reduces the bulk density compared to agricultural land. Similar findings were also reported by Tesfahunegn and Gebru (2020). Secondly, soils under agriculture LUS showed highest value of BD than the other LUS and this may due to greater compaction of soils by use of heavy machinery used for tillage operations which contributes for the reduction of soil organic carbon by disruption of soil aggregates, structure, thereby exposing organic matter for decomposition (Marcela, 2009; Negasa *et al.*, 2017). Different textured soils have different values of bulk density (Siyabulela *et al.*, 2019).

5.3 Effect of different land use systems on soil moisture retention characteristics

Water retention, storage and transport within the soil are directly dependent upon the pore size distribution of the soil and indirectly on the soil texture (Arnhold *et al.*, 2015). The amount of moisture retained by soils at field capacity (33 kPa suction) and plant available water content for different textured soils under four types of land use systems are represented in Fig. 4.1.3. The higher amount of moisture content at field capacity and plant available water under clay loam soils as compared to other soil types might be due to the presence of higher proportion of macro and micro-pores leading to higher porosity in these soils (Brady and Weil, 2002). Moreover, water holding characteristics of soils expressed as plant available moisture content and FC, are directly related to textural class as well as SOC content (Dlapa *et al.*, 2020), which was most prominent at finer textured soil. Forest soils retain more available water as compared to the cultivated lands due to higher content of clay, better root distribution throughout the soil profile (Owuor *et al.*, 2018; Gabriela de Queiroza *et al.*, 2020) and higher organic carbon contents in forest soils, provides large surface area for absorption and retention of water molecules (Materechera and Mkhabela, 2001). Similar findings were also reported by Hadda *et al.* (2020) where results of their study indicated that cultivated land had the lower moisture retention capacity. Cultivation reduces soil water retention capacity of soils by degrading soil structure and aggregation (Wakene, 2001).

5.4 Effect of different land use systems on aggregate size distribution

The water stable aggregates (WSA) of the size >0.25 mm in diameter of forest soils were higher (43.19 %) as compared to agro-forestry soils (42.48 %), horticultural (41.5 %) and agricultural soils (40.83 %). The amount of water stable aggregates (>0.25 mm) were found to be increase with increase in the fineness of soil texture at different locations among the different land use systems (Table 4.1.3). This could be possibly due to the reason that forest soils with permanent vegetation and plant cover are having more yearly input of organic matter which acts as a binding material in soil, leads to the increase in soil flora and fauna and consequently increase the amount of water stable aggregates (Chen *et al.*, 2017). In contrast, agricultural land are having less aggregate stability (Liu *et al.*, 2019) which may be due to lower organic matter content attributed to continuous cultivation and rapid decomposition of soil organic matter (Bot and Benites, 2005). Soil texture also plays an important role in soil aggregate formation, where soil with higher the clay content are having greater stability of soil aggregates (Zeng *et al.*, 2018). Significant differences in MWD under different land use systems, where forestry systems had the highest value and followed the order of decrease in MWD: forestry > agro-forestry > horticultural > agricultural land use system (Fig 4.1.4). MWD in forest soils was significantly higher as compared to other land use systems because of higher aggregate stability associated with improved organic carbon content in soils (Guo *et al.*, 2020; Gonzalez-Rosado *et al.*, 2020), through regular addition of leaf litter in soils (Somasundaram *et al.*, 2012), better rooting structure (Ronaldo *et al.*, 2017; Yang *et al.*, 2020). In addition, soils under agriculture is disturbed due to tillage operations which in turn reduces the amount and stability of aggregates in the soil (Six *et al.*, 2000; Shukla *et al.*, 2004). Moreover, use of agrochemicals may have the inhibitory action to growth of soil fauna, causing negative effects on soil aggregation (Kansakar *et al.*, 2002).

5.5 Effect of different land use systems on soil erodibility indices

Erodibility is defined as the resistant offered by the soil against erosion caused by its own features (Balci, 1996), governed by various factors, including texture, aggregation, consistency, and tensile strength, as well as other soil properties (Rorke, 2000). The soil physical properties which predominantly influence the soil erodibility indices were compared among the different land use systems with the premise that the land uses are many a times decided by the soil physico-chemical properties (Olaniya *et al.*, 2020). Erodibility indices changes with the change in land use types probably due to the changes in biological soil crust thickness, litter content, root mass density, soil organic matter and bulk density of soils (Wang and Zhang, 2021). In the present study, erodibility was assessed using various indices such as dispersion ratio, erosion ratio, clay ratio, modified clay ratio, suspension percentage and suspension ratio under different LUS. The dispersion ratio (DR) which is commonly used to evaluate the erosional action was higher in agricultural LUS and lower in forest soils under different LUS. The dispersion ratio (DR) concerns the ability of both clay and silts to be dispersed by water (Igwe *et al.*, 2009; Nguetnkam and Dultz, 2014). The mean values of DR under agriculture, horticulture, agro-forestry and forestry were 64.8, 63.5, 62.3 and 60.8 with loamy sand soils, 57.7, 57, 55 and 53.8 in sandy loam soils, 52.8, 52.3, 51.3 and 50.8 in loam soils and 47.4, 47.3, 45 and 43.2 with clay loam soils respectively as depicted in figure 4.1.. Similar findings were also reported by Obiechefu *et al.* (2020). This could be attributed to the reason that soils under forest LUS are considered to be more stable than soils under agriculture, higher organic matter content (Ayadiuno, 2021), which results in stabilization of soil aggregates (Kukal *et al.* 1993). The higher proportion clay particles (Babur *et al.*, 2021) and lower sand fractions in different LUS might be attributed to a lower dispersion ratio in forests as compared to other LUS (Korkanc *et al.*, 2008). Singh *et al.* (2006) also stated that soils under forest LUS have low erodibility due to increased organic matter content, better aggregation and lower dispersion. The dispersion ratio describes the easiness by which finer particles dissociate in soils based on aggregate stability, clay and organic carbon content. Erosion ratio (ER) is the most appropriate index for characterizing soils based on their erodibility by predicting soil vulnerability to erosion (Sharma and Biswas, 1972). The higher value, larger the investment necessary to keep soil viability. The ER values in agriculture, horticulture, agro-forestry and forestry were observed to be 56.3, 55.1, 52.8 and 51.5 with loamy sand soils, 38.9, 38.1, 37.1 and 35.8 with sandy loam soils, 36.0, 35.4, 35.5 and 34.9 with loam soils and 22.7, 22.3, 22.1 and 21.0 in clay loam soils respectively (Fig 4.1.6). This may be possibly due to the reason that conversion of forest and grazing land to agriculture degrades soil quality, cause decrease in organic matter content and alters the stability of soil particles (Yilmaz *et al.*, 2015). High erosion ratio may be because of high dispersion ratio and a reduced colloid-moisture equivalent ratio (Ozhan, 2004). Khera and Kahlon (2005) also observed that forest soils had a lower values of dispersion and erosion ratio as compared to bare and arable soils. Sharma and Bhatia (2003) reported that both ER and DR are equally good indices of soil erodibility, but Mukhi (1988) studying on vertisol soils of Karnatka observed that ER was better index of soil erodibility than DR. The CR values for agriculture, horticulture, agro-forestry and forestry were 9.57, 9.53, 8.62 and 8.13 with loamy sand soils, 4.98, 4.88, 4.61 and 4.37 with sandy loam soils and 4.08, 4.09, 3.93 and 3.81 with loam soils while CR values were observed to be 1.99, 2.01, 1.92 and 1.82 with clay loam soil, respectively (Fig 4.1.7). Within the similar textural variations, forest soils had the lower value of clay ratio followed by agro-forestry, horticulture and agriculture. Bouyoucos (1935) proposed the clay ratio (CR) as a measurement of the extend of binding induced by the action of clay, which is inversely proportional to soil erodibility. Another erodibility indices, modified clay ratio (MCR), similar as CR except organic matter content included in denominator. This is the reason for greater values of CR than MCR (Singh and Khera, 2008). The MCR values for agriculture, horticulture, agro-forestry and forestry were 9.01, 8.88, 8.01 and 7.56 with loamy sand soils, 4.74, 4.62, 4.36 and 4.12 with sandy loam soils and 3.87, 3.86, 3.72 and 3.60 with loam soils while, the MCR values were observed to be 1.92, 1.95, 1.85 and 1.76 under clay loam texture respectively (Fig 4.1.8) The values of CR and MCR was observed within the higher range which indicating the susceptibility to erosion (Kusre *et al.*, 2018). The values of suspension percentage under four types of land use systems *i.e.* agriculture, horticulture, agro-forestry and forestry were 11.95, 12.85, 11.70 and

11.95 with loamy sand soils, 16.72, 16.86, 16.76 and 16.04 with sandy loam soils and 25.58, 25.76, 24.30 and 23.20 with loam soils while the SP values were 27.47, 27.07, 27.23 and 26.93 with clay loam soils, respectively (Fig 4.1.9). Suspension percentage (SP) expresses the ease with which fine fractions (silt + clay) of soils become dispersed in water. Datta *et al.* (2015) stated that the higher the value of SP, the easier the soil will erode. The highest value of SP was found in agricultural soils where lowest values was observed in forest soils which indicated that soils under forest were least susceptible to erosion due to their higher organic carbon content and better surface soil binding ability (Saha *et al.*, 2011). Higher values of SP indicated the immense need of conservation measure to be adopted for conserving the soil from erosion (Kumar *et al.*, 2017). Clay loam soil having greater retention of organic carbon and higher percentage of water stable aggregate (> 0.25 mm) (Kumar *et al.*, 2000). The SR values with agriculture, horticulture, agro-forestry and forest land use systems were 112.6, 110.2, 105.7 and 103.1 with loamy sand soils, 77.8, 76.2, 74.2 and 71.6 with sandy loam soils, 72.0, 70.8, 71.1 and 69.9 with loam soils and 45.4, 44.5, 44.2 and 42.1 with clay loam soils, respectively (Fig 4.1.10). The higher vegetative cover, clay content and organic matter in forests and agro-forestry soils tends to form clay-organic matter complex which in turn increase the water repellency of the aggregate in forest soil. This leads to reduction in the wettability of the aggregate and increases its resistance to the water detachment effect (Yakupoglu *et al.*, 2017), which may be ascribed to least susceptibility of forest soils to erosion with respect to suspension ratio, whereas continuous tillage operations in agriculture might contribute to higher erosion than horticultural land use (Abrol *et al.*, 2019). The soil erodibility indices for the different types of land use systems at different locations were observed to be better correlated with forest LUS as compared to other types of LUS, but found on higher side than their prescribed limits and therefore, DR and ER could not be relied upon while evaluating erodibility of soils.

5.6 Effect of different land use systems on soil pH, electrical conductivity (EC) and $CaCO_3$ content

Soil pH is considered as one of most important soil property because it affects the various processes with in soil, such as micro-organisms activity, nutrient cycling and their availability. Conversion of land changes from forest to agriculture resulted in an increase of soil pH at different locations. Among the different land use systems, the average soil pH was observed to be lowest (7.46) in forest soils, while highest (7.82) pH was recorded with agriculture land use system (Table 4.2.1). The results are in agreement with those reported by Abbasi and Rasool (2005); Romero *et al.* (2016); Kumar *et al.* (2020) and Bizuhoraho *et al.* (2018). Among the different land use systems, a reverse trend was observed as that of pH and highest EC (0.45 dS m^{-1}) was observed in forest soils, while lowest (0.35 dS m^{-1}) in agriculture soils (Table 4.2.1). This may be due to the accumulation of organic inputs, there is slight increase in soluble salt content which increase electrical conductivity. Similar findings were also reported by Hueso-Gonzalez *et al.* (2014) where they concluded that lower value of EC in the agricultural soil might be due to the agricultural practices (irrigation) leached down the soluble salt. Our results are in agreement with those of Hammad *et al.* (2020) who concluded that cropland soils had the lowest EC value. However, no definite trend was observed in EC under different LUS at different locations of Eastern Haryana. The data presented in table 4.2.1 further indicated the mean $CaCO_3$ content which was 0.55 % under forest land use system, was significantly reduced to 0.17 % in agricultural soils. However, the $CaCO_3$ content was also observed to be nil (0 %) at different locations under the four types of land use systems. This may be due to the reason that with the increase of organic matter content of the soil, earthworm activity was also increased which had the positive relation with calcium carbonate content of the soil. This is corroborated by the findings of Garcia-Montero *et al.* (2013).

5.7 Effect of different land use systems on cation exchange capacity (CEC)

The cation exchange capacity (CEC) is the dynamic property of soil which affects the nutrient retention and their availability from the exchange sites. The CEC of soils was significantly enhanced in forest soils as compared to other land use systems and followed the trend as: forestry > agro-forestry > horticulture > agriculture. The mean value of CEC was observed to be higher under forest syatem (11.79 cmol (P+) kg^{-1}), while it was lowest (9.25 cmol (P+) kg^{-1}) under agriculture land use system. The low CEC in agricultural land in the soils under this land use may be due to reduction in organic matter content (Nega and Heluf, 2009). Our results are in agreement with those reported by Akinde *et al.* (2020). In comparison to agricultural and horticultural lands, where basic nutrients leached down, the results showed that the exchangeable cation contents are well preserved in the forest and agro-forestry LUS due to nutrient recycling (Bohn *et al.*, 2001). Moreover, soils under forests accumulate higher organic carbon and has greater ability to hold cations thereby resulting in greater potential fertility of soil (Hazelton and Murphy, 2007).

5.8 Effect of different land use systems on organic carbon and organic carbon stocks

Soil organic carbon content (SOC) in soils for four types of land use systems at different locations ranged between 0.54 to 0.66 % (Table 4.2.3). Forest soils had the highest SOC content (0.66 %), followed by agro-forestry (0.61 %), horticulture (0.57 %) and it was lowest in agriculture (0.54 %) soils. The bonds between clay particles and organic matter slows down the process of decomposition and increase the possibility of stable aggregate formation, which physically protects organic matter from microbial degradation (Seremesic *et al.*, 2020).

Moreover, it may be attributed to the reason that more addition of above and below ground biomass through addition of litter and fine root biomass (Mishra *et al.*, 2002) along with accumulation of tree leaves, stems, barks, flowers, logs and fruits increase the soil organic carbon content (Bizuhoraho *et al.*, 2018). Similar findings were also reported by Sandhage-Hofmann *et al.* (2015). The lower SOC build up in agricultural soils compared to other LUS could be related to intensive cultivation, which has exacerbated organic matter decomposition (Alemayehu *et al.*, 2011; Kizilkaya and Dengiz, 2010; Fentie *et al.*, 2020). Additionally, complete removal of crop residues in the agricultural land also resulted in decline in SOC in soils (Sheleme, 2011).

Soil organic carbon stocks (SCS): The data presented in table 4.2.4 revealed that both land use systems and location had a significant effect on the soil organic carbon stocks (SCS) in the soil and followed the same trend as that of SOC. Comparison of mean values revealed that the SOC stocks were found to be superior in forest soils (13.29 Mg ha^{-1}), followed by agro-forestry system (12.55 Mg ha^{-1}), horticulture (11.82 Mg ha^{-1}) and lowest value of SCS (11.22 Mg ha^{-1}) were observed with agriculture land use system (Table 4.2.4). The possible reason may be the higher litter biomass formation, residue and rhizo-deposits, and relatively slow rate of organic matter decomposition in undisturbed forest soils (Manjaiah *et al.*, 2000; Benbi *et al.*, 2012) and due to higher inputs of dead root biomass from the slashed vegetation which is an important source for higher carbon stocks (Bruun *et al.*, 2021). The SCS not only depends on the SOC content but also varied with the bulk density (BD) of the soil (Wang *et al.*, 2021).

5.9 Effect of different land use systems on soil organic carbon fractions

The particulate organic carbon (POC) and mineral associate organic carbon (MOC) were observed to be significantly higher in forest soils (1307 mg kg^{-1} and 2793 mg kg^{-1}, respectively), followed by agro-forestry (1185 mg kg^{-1} and 2522 mg kg^{-1}, respectively), horticulture (1129 mg kg^{-1} and 2507 mg kg^{-1}, respectively) while lowest value was observed under agriculture (1091 mg kg^{-1} and 2382 mg kg^{-1} respectively) land use system (Table 4.2.5). Particulate carbon fractions (POC) primarily consist of partially decomposed organic compounds, whereas mineral associate carbon fractions (MOC) are complex organic fractions that are tightly bound to the mineral component of the soil resistant to decomposition (Zhao *et al.*, 2020). Cultivated soils appear to have lower POC content (Bongiovanni and Lobartini, 2006) because cultivation cause deterioration of protective macro-aggregates, exposing the POC degradation by microbes and thereby, enhancing the process of mineralization. Soil management practices under different land use systems have a significant influence on soil organic carbon fractions (Zhao *et al.*, 2021). The higher POC content in forest and agro-forestry soils indicates that soils under these land use systems tends to accumulate active C pools (Gerzabek *et al.*, 2001). The majority of SOC is derived through addition of plant residue and plant waste becomes associated with inorganic soil particles may forming stable organo-mineral structures (Post and Kwon, 2000). This may be possibly due to the reason that forest soils had higher value of SOC as well as SCS content at different locations. Moreover, MOC fractions of SOC were found to be less sensitive to land use systems as compared to POC fractions, indicating that recalcitrant substance had a limited reduction across different LUS (Datta *et al.*, 2015). This could be attributed to the and it the locations where soils are having higher proportion of finer silt and clay particles which are highly enriched with MOC (Sanderman *et al.*, 2021).

5.10 Effect of different land use systems on available NPK and DTPA extractable micronutrients

The available NPK content under different land use systems varied significantly varied at different locations (Table 4.2.6). Among the different locations, the available nitrogen content in soils ranged from 110 kg ha^{-1} to 268 kg ha^{-1} at L_7 and L_{12} location, respectively under different land use systems. The available nitrogen content in forest land use systems was significantly higher (235 kg ha^{-1}) as compared to agro-forestry (200 kg ha^{-1}), horticulture (192 kg ha^{-1}) and agriculture (183 kg ha^{-1}) land use systems. The increase in N content in clay soils can be attributed to the fact that higher the clay content in soil, greater the nutrient supplying capacity of the soil. Higher organic matter content in these soils and the favourable prevailing conditions which increase the rate of SOC mineralization leading to higher N content (Sepehya *et al.*, 2012; Figueroa *et al.*, 2020). Ayoubi *et al.* (2011) also reported that natural forest soils had more nitrogen as compared to the cultivated lands. Significant differences in available P contents were recorded under different land use systems at different locations. Results from soil analysis indicated that the highest available P content was found in the forest soils with value of 18.3 kg ha^{-1}, followed by agro-forestry (17.9 kg ha^{-1}), horticulture (17.5 kg ha^{-1}) and the lowest available P content was observed in agricultural soils (16.6 kg ha^{-1}). Similar result was reported by Ebabu *et al.*, (2020). Increase P content in soils may be contributed to the solubilizing effect of different organic acid produced during mineralization of SOC, which helped in increase the availability of phosphorus in forest soils (Selassie and Ayanna, 2013). Moreover, enhanced P content is related to soil organic matter which increases the available P by anion replacement of $H_2PO_4^{\,-}$ ion on adsorption sites thereby increasing the quantity of organic P mineralized to inorganic P (Havlin *et al.*, 2016, Bhat *et al.*, 2017). The available K content in forest soils reaching a highest value of 254 kg ha^{-1}, which was significantly higher in comparison to agro-forestry (208 kg ha^{-1}), horticulture (191 kg ha^{-1}) and agriculture (153 kg ha^{-1}) land use systems. Significant higher K content within soil may be due to relatively higher clay content (Azadi and Shakeri, 2020) along with the formation of clay-humus complex having higher release of K with in the soil (Srinivasarao *et al.,* 2014). Higher potassium content in forest soils compared to agriculture can also be ascribed to leaf litter deposition and its subsequent mineralization, carried out by microbes which are stimulated by organic matter input in forest soils (Atta *et al.*, 2013; Tanga *et al.*, 2014). Moreover, presence of dense vegetation in the forest land use system affords the soil adequate cover thereby reducing the loss in NPK that are essential for plant growth and energy fluxes (Iwara *et al.*, 2011).

Micronutrients: The data of available micronutrients (Fe, Mn, Cu and Zn) content in soils of different locations under different land use systems are presented in table 4.2.7; 4.2.8; 4.2.9 and 4.2.10. Among the different land use systems, highest mean value of iron content was observed in horticulture (5.70 ppm) soils while lowest value was obtained with agro-forestry system (5.02 ppm) and the available Zn content in soils under different land use systems was 1.13, 1.09, 0.97 and 0.94 ppm under horticulture, agriculture, agro-forestry and forestry land use system, respectively. Similar findings were also reported by Dhaliwal and Bijay Singh (2013), the increase in $CaCO_3$ content in soil under forestry systems reduces the iron and zinc availability. Result was supported by findings of Palani and Raju (2019). This might be possibly due to the reason that high calcium carbonate in soil declined the Fe and Zn availability due to raised soil pH where the OH^- reacts with Fe^{3+}, Zn^{+2} and decrease the of these micronutrient by forming ion complexes of $Fe(OH)_3$ and $Zn(OH)_2$. The highest average value of Mn content was observed under forestry system (6.62 ppm), followed by agriculture (6.44 ppm), horticulture (6.35 ppm), and agroforestry system (6.34 ppm) at different locations (Panwar *et al.*, 2011). Similar findings was also reported by Choudhury *et al.* (2021), as they stated that moreover, the forest soils had higher clay contents and SOC through the deposition of litter-falls without any soil disturbances might have favoured the accumulation of comparable DTPA-Mn along with other nutrients. The available Cu content in soils ranged from 0.43 to 0.95 ppm at different locations, while, highest mean value of Cu content was found in agro-forestry soils (0.66 ppm) and lowest value was observed under horticultural (0.58 ppm) land use systems. The Cu content was highest in agroforestry soil, where lowest Cu content was found in horticulture land use systems the relation of copper with organic carbon (Kiflu and Beyene, 2013). which comes under the sufficient range of copper content for the soils of Haryana.

5.11 Effect of different land use systems on microbial biomass carbon (MBC)

Soil microbial biomass carbon acts as a potential indicator of soil organic carbon as it plays a key role in decomposition of organic matter and increase the nutrient accumulation in the top soil layer (Hu *et al.*, 2016). The accumulation of microbial biomass during biodegradation of SOC and biomass turnover differs in soils of varying with vegetation and land use systems (Stevenson *et al.*, 2016). The higher value of microbial biomass carbon was found in agro-forestry because of presence of trees coupled root and shoot biomass in cropland continuously adds litter in the upper layer which acts as a source of labile carbon pool (Kimmins, 2004; Zhao *et al.*, 2013). In agricultural soils, low SOC content along with the toxic effects of applied pesticides may reduce the microbial biomass (Maharjan *et al.*, 2017; Huang and Song 2010; Reza *et al.*, 2018). Secondary compaction of soils also had a negative impact on soil microbiological properties through degrading microbial habitat with poor aggregation (Udawatta *et al.*, 2008). Among the different textured soils, clay loam soils showed higher values of microbial biomass carbon content as it increases with the higher proportion of finer fractions of soil (Walkiewicz *et al.*, 2020). Carney and Matson (2005) also mentioned that fine textured soils support more microbial biomass than coarse textured soils. The distribution of microorganisms in various soil textures might be also related to soil moisture and nutrient contents (Heritage *et al.*, 2003).

5.12 Effect of different land use systems on enzyme activity

The dehydrogenase activity (DHA) differed from one location to another under different land use systems (Table 4.3.2). Among the different land use systems, agro-forestry had maximum dehydrogenase activity (41.6 µg TPF g^{-1} soil d^{-1}) which was at par with the forest soils (39.9 µg TPF g^{-1} soil d^{-1}), followed by agricultural soils (37.7 µg TPF g^{-1} soil d^{-1}) and lowest was observed in horticultural soils (36.9 µg TPF g^{-1} soil d^{-1}) at different locations. The results revealed that the magnitude of alkaline phosphatase activity varies with locations under the four types of land use systems (Table 4.3.2). The alkaline phosphatase activity at different locations was significantly higher under agro-forestry (190.1 µg PNP g^{-1} soil h^{-1}) systems, followed by forest (186.8 µg PNP g^{-1} soil h^{-1}), agriculture (182.7 µg PNP g^{-1} soil h^{-1}) and horticulture (180.9 µg PNP g^{-1} soil h^{-1}) and followed the similar trend as in case of DHA as: agro-forestry > forestry > agriculture > horticulture land use system. Dehydrogenases enzyme resides inside the soil indicate the status of soil environment and microbial activity in the soil (Gil-Sotres *et al.*, 2005). Soils under agro-forestry systems had an addition benefit of agricultural operations performed during crop growing season through increase the rate of organic matter decomposition (Ostrowska and Porebska, 2015). Moreover, crop grown provides different quality and quantities of crop residue and root exudates, which are considered to be the substrates for microorganisms and thereby support the enzyme production (Maharjan *et al.*, 2017). These research finding followed that enzyme activities in agro-forestry systems favours the balanced functional diversity of microorganisms reflected by presence of sufficient amount of organic matter in terms of exudates, mucilage, favourable pH and moisture conditions that led to the establishment and higher rate colonization by enzymes in the prevailing congenial edaphic and climatic conditions Our results in agreement with those reported by (Neha *et al.*, 2020). In addition, mycorrhizal associated with the roots of small trees in coniferous and deciduous tree stands enhance the availability organic carbon content and increased microbial activity leading to higher enzymatic activity (Adak *et al.*, 2014) in soils under agro-forestry and forestry land use systems.

5.13 Correlation matrix between soil erodibility indices and soil properties

Appraisal of data on correlation matrix between soil erodibility indices and soil properties revealed that the ratios of soil erodibility indices are in a linear correlation with soil properties under different land use systems (Table 5.1). Ratios of erodibility indices under different land use systems were affected by several soil properties including bulk density (BD), mean weight diameter (MWD), water stable aggregate (WSA), cation exchange capacity (CEC), pH, electrical conductivity (EC), organic carbon (OC), available N, P, K, microbial biomass carbon (MBC), dehydrogenase activity (DHA) and alkaline phosphatase activity (APA). A significant positive correlation (r = >0.965) was observed between the different erodibility indices (CR, MCR, DR, ER, SP and SR), substantiating the earlier findings of (Kumar *et al.*, 2017). Among different soil physical properties, soil erodibility indices showed a significant positive correlation with bulk density of the soils, which is supported by the findings of Abrol *et al.* (2019). While, a significant negative correlation was observed between soil erodibility indices and WSA of the soils under different land use systems. Cation exchange capacity of various soils was found to have significant negative correlation with the erodibility indices. Correlation between soil erodibility indices and pH of soil was observed to be non-significant, while irregular trend was observed in case of EC. Similar findings were also reported by Dhaliwal *et al.*, (2008). Organic carbon of the soils was found to have significant negative correlation with the erodibility indices. These findings are corroborated by the results reported by Saha *et al.* (2011) who also derived similar correlations between erodibility indices and BD, WSA, OC content of soils. Available macronutrient (NPK) content in various soils had a significantly positive correlation with the erodibility indices of the soils under different land use systems. As per the data, with different microbial parameters (MBC, DHA and APA) of the soil, erodibility indices showed a significant negative correlation under different land use systems.

Table 5.1: Correlation matrix between soil erodibility indices and soil properties under different land use systems

	CR	MCR	DR	ER	SP	SR	BD	MWD	WSA	CEC	PH	EC	OC	N	P	K	MBC	DHA	APA
CR	1																		
MCR	.998**	1																	
DR	.990**	.996**	1																
ER	.965*	.977*	.991**	1															
SP	.967*	.973*	.980*	.990**	1														
SR	.966*	.978*	.991**	.990**	.990*	1													
BD	.969*	.971*	.973*	.978*	.997**	.978*	1												
MWD	-.980*	-.984*	-.988*	-.989*	-.998**	-.989*	-.997**	1											
WSA	-.971*	-.983*	-.995**	-.994**	-.972*	-.994**	-.957*	.976*	1										
CEC	-.996**	-.996**	-.988*	-.957*	-0.948	-.958*	-0.947	.965*	.972*	1									
PH	0.717	0.752	0.804	0.873	0.84	0.873	0.801	-0.813	-0.85	-0.705	1								
EC	-.968*	-.959*	-0.936	-0.879	-0.871	-0.88	-0.878	0.899	0.908	.979*	-0.552	1							
OC	-.975*	-.984*	-.994**	-.999**	-.993**	-.999**	-.984*	.994**	.992**	.965*	-0.853	0.893	1						
N	-0.929	-0.932	-0.937	-.956*	-.987*	-.955*	-.991**	.980*	0.92	0.897	-0.812	0.811	.961*	1					
P	-0.874	-0.9	-0.934	-.960*	-0.917	-.960*	-0.884	0.909	.965*	0.879	-0.944	0.778	0.948	0.857	1				
K	-0.925	-0.941	-.964*	-.991**	-.984*	-.991**	-.968*	.975*	.973*	0.91	-0.922	0.808	.987*	.961*	.966*	1			
MBC	-.991**	-.995**	-.997**	-.991**	-.990**	-.991**	-.987*	.996**	.987*	.983*	-0.799	0.928	.995**	.958*	0.919	.967*	1		
DHA	-.988*	-.991**	-.992**	-.988*	-.994**	-.988*	-.994**	.999**	.979*	.975*	-0.795	0.918	.993**	.971*	0.906	.967*	.998**	1	
APA	-.980*	-.986*	-.992**	-.994**	-.998**	-.994**	-.994**	.999**	.983*	.967*	-0.828	0.899	.998**	.974*	0.924	.980*	.997**	.998**	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

CHAPTER-VI

SUMMARY AND CONCLUSION

The present study entitled "Effect of different land use systems on soil erodibility, aggregation and organic carbon dynamics in soils of Eastern Haryana", was carried out by collecting 180 surface soil (0-15 cm) samples in triplicates from four types of land use systems *i.e.* agriculture, horticulture, agro-forestry and forestry at various locations of Eastern Haryana (Ambala, Panchkula and Yamunanagar). The soils under different land use systems at different locations showed variation in sand, silt and clay content and represented four textural classes *i.e.* loamy sand, sandy loam, loam and clay loam. The effect of different land use systems on physico-chemical and biological properties of soil have been summarized in this chapter as:

1. Bulk density (BD) of soil at different locations under different land use systems showed significant variations. The highest BD was observed in soils under agriculture (1.41 Mg m^{-3}) while, the lowest BD (1.34 Mg m^{-3}) was found in soils under forest land use system. Among the different land use systems, the values of BD followed the order: agriculture > horticulture > agro-forestry > forestry.
2. Among all the textural classes of soil, forest land use systems showed an increase in the amount of moisture retention at field capacity (FC) and plant available water content (AWC) as compared to other land use systems. The moisture content in clay loam soils at FC and AWC were 32.63 % and 23.8 %, respectively under forest land use systems. Overall, the trend of moisture retention followed as: forest > agro-forest > horticulture > agriculture.
3. The WSA (>0.25 mm) of forestry soils were higher (43.19 %) as compared to agro-forestry soils (42.48 %), horticultural soils (41.5 %) and agricultural soils (40.83 %). The highest MWD under different land use systems was observed in forest soils and followed the order as: forestry > agro-forestry > horticultural > agricultural land. The amount of WSA and MWD was found to be increased with increase in heaviness in texture from loamy sand to clay loam soils.
4. Higher values of erodibility indices (DR, ER, CR, MCR, SR and SP) were observed in case of agricultural soils followed by horticulture, agro-forestry and forestry land use systems indicating the higher susceptibility of agricultural land to erosion as compared to other land use systems.
5. The average surface soil pH value of different land use system ranged from neutral to slightly alkaline and change of land use system from forest to crop land resulted in

significant increase in soil pH (7.46 to 7.82) at different locations. The soil EC under different land use systems varied from 0.33 to 0.45 dS m^{-1}. The highest and lowest soil EC was observed under forestry and horticultural land use system, respectively. Almost all the soils except few locations showed nil $CaCO_3$ content under different land use systems.

6. The highest value of CEC was observed under forest soils (11.79 cmol (P+) kg^{-1}), while, agricultural lands recorded the lowest CEC (9.25 cmol (P+) kg^{-1}) among different land use systems. Variations in CEC was also observed under different textured soils and clay loam showed the higher CEC values followed by loam, sandy loam and loamy sand soils.
7. The SOC content varied from 0.54 to 0.66 % among the different land use systems. The SOC content of forest soils was 22.2 % higher as compared to agricultural land and SCS followed the order: forestry >agro-forestry >horticulture >agriculture at different locations.
8. The organic carbon fractions *i.e.* particulate carbon fractions (POC) varied from 902 to 1440 mg kg^{-1} and mineral associate carbon fractions (MOC) varied from 2094 to 3156 mg kg^{-1}at different locations, were significantly affected by different land use systems and followed the trend: forest > agro-forestry > horticulture > agriculture.
9. In case of macronutrient (NPK) availability, forest soils have the higher values of NPK content (235, 18.3 and 254 kg ha^{-1}, respectively) followed by agro-forestry (200, 17.9 and 208 kg ha^{-1}), horticulture (192, 17.5 and 191 kg ha^{-1}) and agriculture (183, 16.6 and 153 kg ha^{-1}) land use systems, where micronutrient content of soils *i.e.* Fe (2.99-7.13 ppm), Mn (4.56-8.21 ppm), Cu (0.43-0.95 ppm) and Zn (0.68-1.50 ppm) differed widely among the different land use systems.
10. The microbial parameters followed the order: agro-forestry > forestry > agriculture > horticulture land use systems and the magnitude of increase of soil MBC, dehydrogenase activity and alkaline phosphatase activity were found 6.6%, 12.7% and 5.1% respectively in case of agro-forestry system over horticulture land use systems.

CONCLUSION

The different land use systems showed significant effect on soil physico-chemical and biological properties at different locations of Eastern Haryana. The bulk density of soils was found to be highest in agriculture and lowest in forest land use system. The soil moisture retention, percent of water stable aggregates and mean weight diameter were found to be greater under forest soils, followed by agro-forestry, horticulture and agriculture land use systems. Higher values of erodibility indices (DR, ER, CR, MCR, SR and SP) could reveal the information about the proneness of soil to erosion in qualitative manner and helped in prioritizing the study area as susceptible to erosion. The soil pH, EC and $CaCO_3$ content of the soil showed different trend as pH was higher in agricultural soils and EC and $CaCO_3$ content higher in forest soils. The macro- and micronutrient status also changed from one to another land use systems at different locations. The higher MBC content, dehydrogenase and alkaline phosphatase activity was found higher in agro-forestry systems followed by forestry, agriculture and horticulture.

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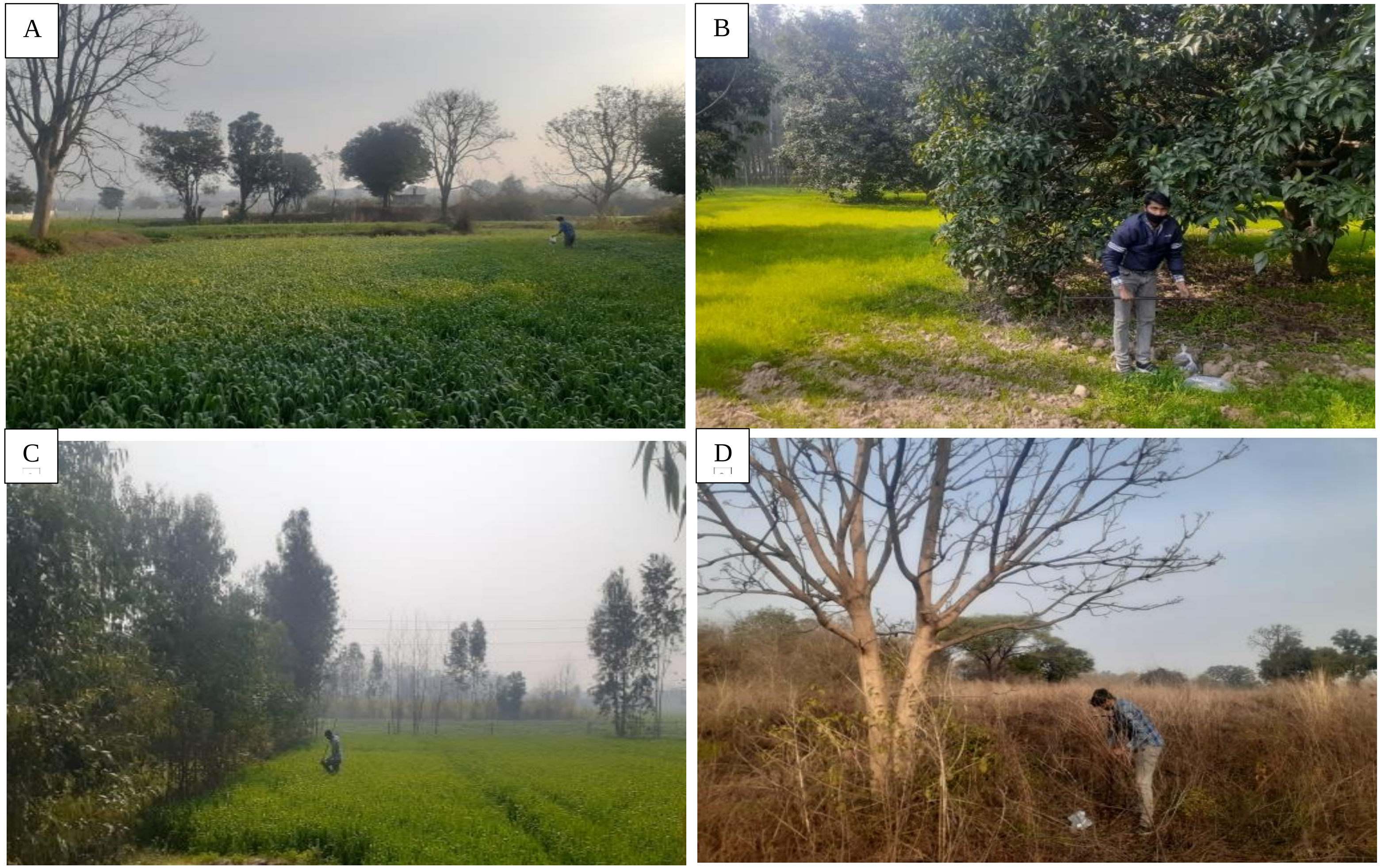

Soil Sampling Sites at different location under A) agriculture B) Horticulture C) Agro-forestry D) Forestry land use systems

ABSTRACT

Title of thesis	:	Effect of different land use systems on soil erodibility, aggregation and organic carbon dynamics in soils of Eastern Haryana
Full Name of degree holder	:	Koushik Bhattacharyya
Title of Degree	:	Master of Science in Soil Science
Name and address of Major Advisor	:	Dr. Hardeep Singh Sheoran Assistant Professor Department of Soil Science, CCS Haryana Agricultural University, Hisar-125004, INDIA
Degree awarding University	:	CCS Haryana Agricultural University, Hisar-125004, Haryana, India
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Key words: Land use systems, Erodibility indices, SOC, Biological properties

The present investigation was carried out on “Effect of different land use systems on soil erodibility, aggregation and organic carbon dynamics in soils of Eastern Haryana”. The experiment was planned in a two factorial randomized block design with three replications in fifteen locations under four types of land use systems (agriculture, horticulture, agro-forestry and forestry) in the districts of Ambala, Panchkula and Yamunanagar of Eastern Haryana. The values of BD were significantly higher in agriculture (1.41 Mg m^{-3}) and followed by horticulture, agro-forestry and forestry. The mean value of WSA and MWD was found highest in forest soils as compare to all other land use systems. In agricultural land use system had the higher value of erodibility index (DR, ER, CR, MCR, SR and SP) as compared to horticultural, agro-forestry and forestry land use systems. The significantly higher pH was recorded in agricultural land use system and lowest in forest soil and reverse trend was received in EC. The highest value of CEC was observed under forest soils (11.79 cmol (P+) kg^{-1}) as compared to all other land use systems. In forestry land use system, SOC content was significantly increased from 0.54 % to 0.66 % and the SCS increased from 11.22 to 13.29 Mg ha^{-1} over agricultural, agro-forestry and horticultural land use system. The available NPK content of the soils followed the trend: forestry > agro-forestry > horticulture > agriculture and the micronutrients differed widely among the different land use systems. The biological properties of the soil microbial biomass carbon (MBC), Dehydrogenase and alkaline phosphatase activity was increased significantly in agro-forestry land use system as compared to other land use systems.

Major Advisor **Signature of Student**

Head of the Department

CURRICULUM VITAE

Name : Koushik Bhattacharyya
Father's Name : Sh. Debabrata Bhattacharyya
Mother's Name : Smt. Chhanda Bhattacharyya
Date of Birth : March 15, 1996
Sex : Male
Marital Status : Unmarried
Nationality : Indians
Mobile : +91-7585802078
E-mail : kbhattacharyya764@gmail.com
Address : Boalia, Dhaneswarpur, Pingla, District- Paschim Medinipur, State-West Bengal,
Pincode-721166

Academic Qualification:

Degree	Univ./Board	Year of Passing	Percentage/ OGPA	Subjects
10th	WBBSE West Bengal	2013	90.14 %	Bengali, English, Mathematics, Physical Science, Life Science, History and Geography
12th	WBCHSE, West Bengal	2015	92.2 %	Bengali, English, Chemistry, Mathematics, Physics and Biology
B.Sc. (Ag.) Hons.	BCKV, West Bengal	2019	8.49/10	Agriculture Science and allied subjects
M.Sc. (Ag.) Soil Science	C.O.A, CCSHAU, HISAR	2021	8.27/10	Major: Soil science Minor: Agronomy

Co-curricular activities and achievements

i. Got Swami Vivekananda Merit –cum-Means scholarship throughout B.Sc. (Ag.) Hons.

ii.Got AIR 16 and selected for ICAR-Junior Research Fellowship (JRF) during M. Sc. (Ag.) Soil Science.

I hereby, declare that all the information provided in the resume is true to the best of my Knowledge.

Place: Hisar

Date: **(Koushik Bhattacharyya)**

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I, **Koushik Bhattacharyya,** Admn. No. **2019A125M**, undertake that I give copy right of my thesis entitled, **“Effect of different land use systems on soil erodibility, aggregation and organic carbon dynamics in soils of Eastern Haryana”** to the Chaudhary Charan Singh Haryana Agricultural University, Hisar.

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