ASSESSING CARBON SEQUESTRATION POTENTIAL AND SOIL QUALITY INDEX (SQI) UNDER HORTICULTURE BASED LAND USE SYSTEMS IN AGRO-CLIMATIC ZONE-I OF BIHAR

By

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Dr. RAJENDRA PRASAD CENTRAL AGRICULTURAL UNIVERSITY
PUSA, SAMASTIPUR- 848 125, BIHAR

2022

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A THESIS SUBMITTED TO
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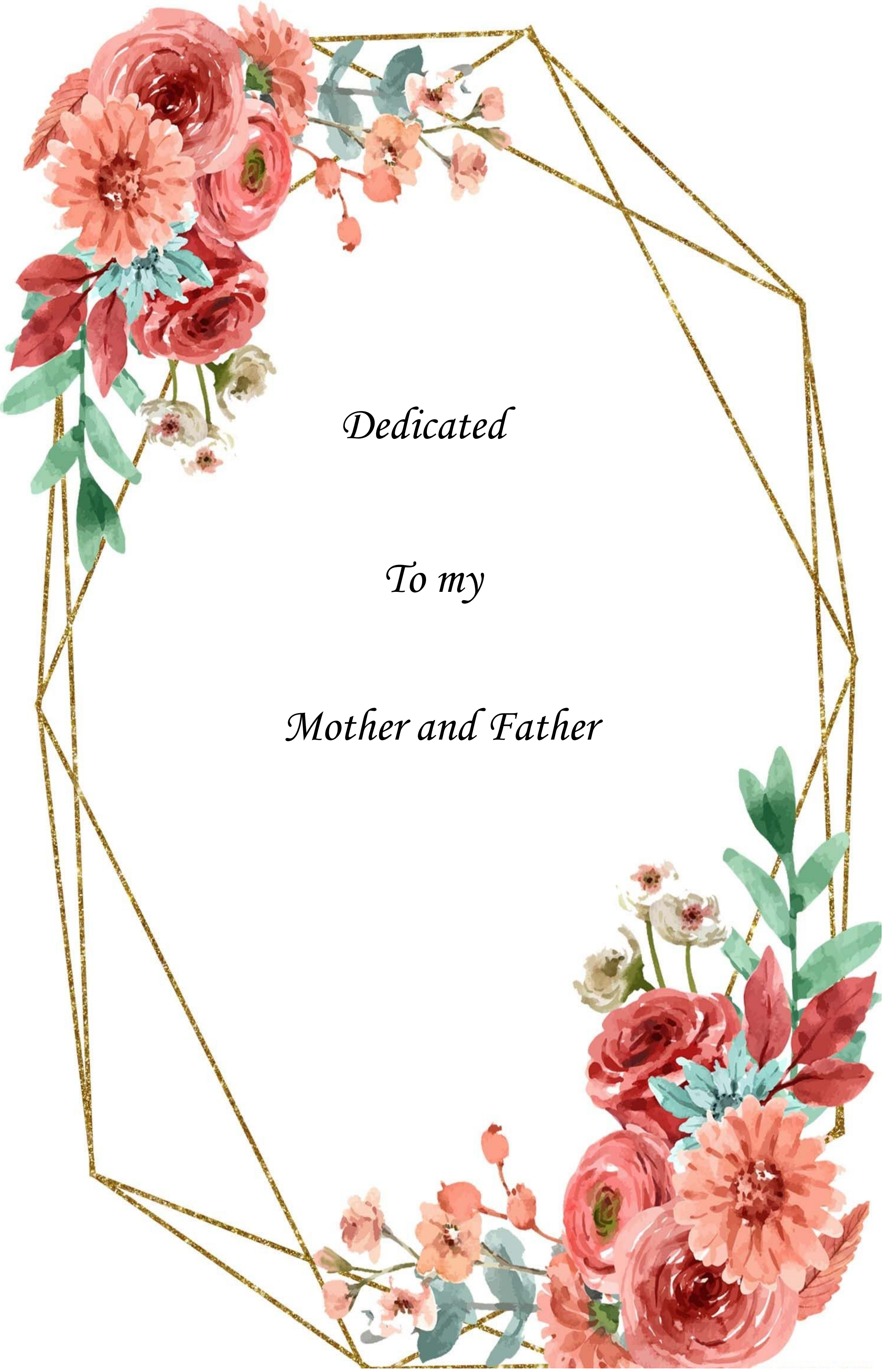

Dedicated

To my

Mother and Father

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Date 18/08/2022

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This is to certify that the thesis entitled **"ASSESSING CARBON SEQUESTRATION POTENTIAL AND SOIL QUALITY INDEX (SQI) UNDER HORTICULTURE BASED LAND USE SYSTEMS IN AGRO-CLIMATIC ZONE-I OF BIHAR"** submitted in partial fulfilment of the requirements for the award of degree of **DOCTOR OF PHILOSOPHY IN SOIL SCIENCE** of the Post-Graduate College of Agriculture, Dr. Rajendra Prasad Central Agricultural University, Pusa (Samastipur), Bihar is a genuine record of bonafide research work carried out by **Mr. Prabhat Kumar** under my guidance and supervision.

The results of the investigation reported in this thesis have not so far been submitted for any other degree or diploma. The assistance and helps received during the course of this investigation and sources of literature have been duly acknowledged.

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ABSTRACT

Soil carbon sequestration research has gained world focus as a cost effective and eco-friendly approach in mitigating elevated CO_2 level of atmosphere. The various anthropogenic activities have impacted our fragile ecosystem, leading to an increased level of carbon dioxide in the earth’s atmosphere which has not only affecting our ecosystem but also poses threat to our human race. The research was formulated with the hypothesis that SOC quality, and quantity varies due to variability in input and loss of soil C under different LUS’s of agro-climatic zone –I of Bihar. The main objective of the research undertaken was to assess carbon sequestration and soil quality under dominant LUS’s by evaluating the variation in measurable soils properties with carbon and nitrogen storage patterns.

The selected experimental area lies in the middle Gangetic alluvial plain having hot dry to moist sub-humid. Based on preliminary survey, five LUS’s namely litchi solo , mango solo, litchi intercrop, rice wheat, and uncultivated were selected and accordingly composite soil sample collected *i.e.* total 100 samples from different soil depth 0-15, 15- 30, 30-45 and 45-60 cm. The various soil measurable physico-chemical and biological parameters were analysed and the data revealed that soil carbon is the main driver influencing various soil characteristics. Among the different LUS selected, the superior LUS followed sequence mango solo >litchi solo > litchi intercrop > uncultivated > rice wheat. The analysed soil data revealed that soil *p*H in different LU was moderately alkaline and ranged from 7.91 to 8.26 while electrical conductivity ranged from 0.34 to 0.48 dS m^{-1} which is within the safer limit. The observed soil bulk density varied significantly and was found highest in uncultivated LU 1.46 Mg m^{-3} while lowest in 1.41 Mg m^{-3} in mango solo LU. The soil surface hardness was observed highest 1368.2 KPa in uncultivated LU having highest BD value compared to other LUS's. Soil texture in selected LU was mainly sandy loam, silty loam and clay loam but the effect of LU was non-significant. Among different LU system, the available macro-nutrient N, P, K and micro-nutrient Fe, Zn, Cu, Mn were found to be more in horticulture based LUS's compared to rice-wheat and uncultivated LU. Significant decreases in available nutrients were observed with increase in depth of soil. The biological soil properties assessed by DHA activity, SMBC, SMBN and soil protein and found significantly better microbial properties in all three horticulture-based LUS's when compared to rice-wheat LUS. A marked difference in SOC fraction constituents were found among different LUS's and observed sequence NLc>VLc> Lc>LLc carbon. Among the different LUS's soil carbon stock 0-60 cm soil depth was found to be highest in mango LU at 71.34 Mg C ha^{-1} followed by litchi solo 61.34 Mg C ha^{-1}, uncultivated LU 52.33 Mg C $ha^{-1}$and least it was observed in rice-wheat LU 44.69 Mg C ha^{-1}, while similar trend also was observed in soil nitrogen stock highest in mango LU 5408.01 kg N ha^{-1} and least 3771.51 kg N ha^{-1} observed in rice-wheat LU system. In the horticultural LUS's the total tree biomass carbon (both above and below ground) was observed highest in mango solo 51.59 q $tree^{-1}$ followed by litchi solo 16.32 q $tree^{-1}$ and least 15.82 q $tree^{-1}$ in litchi intercrop. Soil quality index was assessed among different LU and observed best in mango solo LU 1.15 then litchi solo 1.09, litchi intercrop 1.04, uncultivated 1.02 and least observed in rice-wheat LU 0.94. The soil quality data depicts sensitive indicators selected were soil carbon stock, metabolic quotient; soil respiration, clay% and sand% in assessing SQI which may be used in future research in related studies for assessing SQI. Finally, it may be concluded that over all soil quality and carbon sequestration followed sequence mango solo > litchi solo > litchi intercrop > uncultivated > rice wheat LUS. The problem of increased current fallow area under in ACZ-I may be addressed with incorporation of horticulture tree component and adoption of suitable agronomic management practices for maintaining sustainability in the region.

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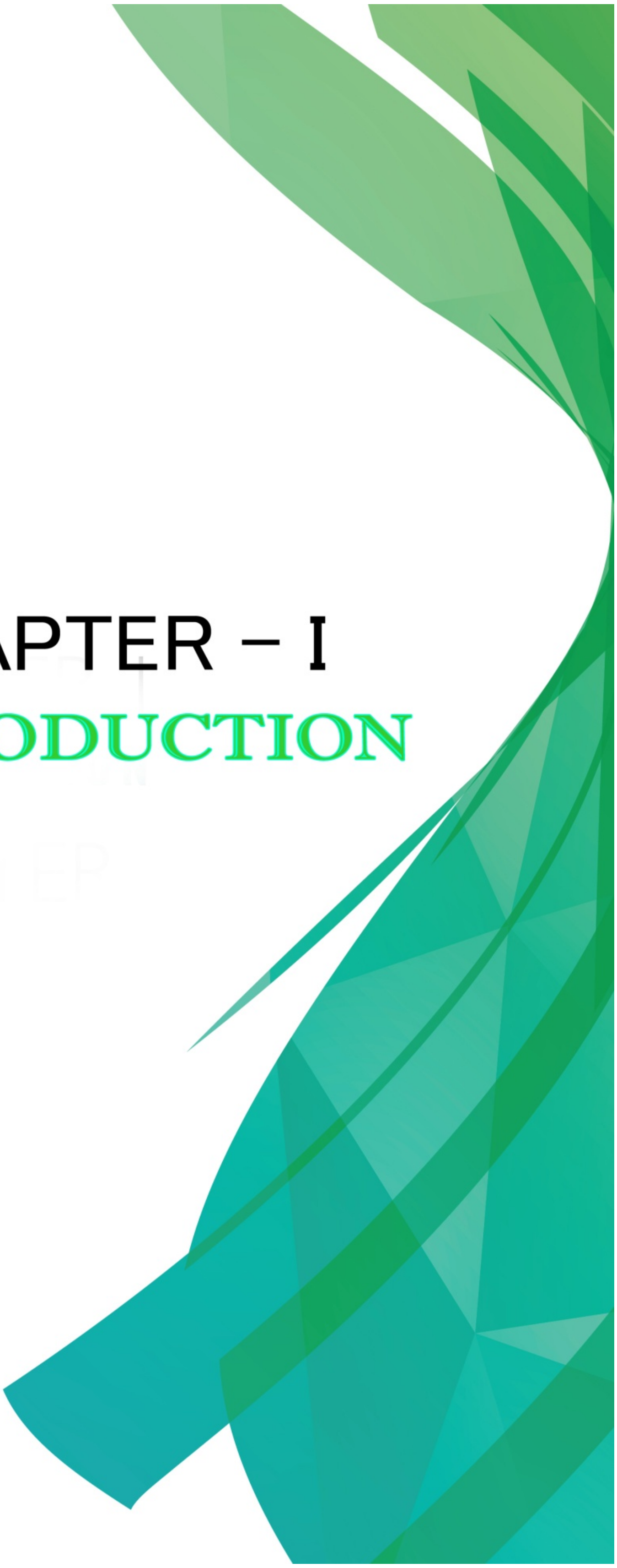
ABBREBRIATION

&	:	And
<	:	Less than
=	:	Equal to
>	:	Greater than
°C	:	Degree Celsius
%	:	Per cent
LUS	:	Land use system
CD	:	Critical difference
dS m^{-1}	:	deci Simon per metre
EC	:	Electrical conductivity
et al.	:	(et alibi) and else where
mg kg^{-1}	:	Milligram per kilogram
Mg m^{-3}	:	Mega gram per cubic meter
KPa	:	Kilopascal
cm	:	Centimeter
Fig.	:	Figure
g kg^{-1}	:	Gram per kilogram
kg ha^{-1}	:	Kilogram per hectare
i.e.	:	That is
S.Em.	:	Standard error of mean
SOC	:	Soil organic carbon
TPF	:	Tri-phenyl formazan
TTC	:	Tri-phenyl tetrazolium chloride
TSOC	:	Total soil organic carbon
OC	:	Organic carbon
NS	:	Non-significant
Zn	:	Zinc
Cu	:	Copper
Fe	:	Iron
Mn	:	Manganese
C	:	Carbon
N	:	Nitrogen
SQI	:	Soil quality index
SOM	:	Soil organic matter
OC	:	Organic carbon
°N	:	Degree north
°E	:	Degree east
SMBC	:	Soil microbial biomass carbon
SMBN	:	Soil microbial biomass nitrogen
MDS	:	Minimum dataset
GHG	:	Green house gases
viz.	:	Namely
WSA	:	Wet stable aggregates
VLc	:	Very labile carbon
Lc	:	Labile carbon

LLc : Less labile carbon
NLc : Non labile carbon
MWD : Mean weight diameter
Pr : Penetration resistance
BD : Bulk density
DHA : Dehydrogenase activity
MQ : Microbial quotient
qCO_2 : Metabolic quotient
PCA : Principal component analysis
DBH : Diameter at breast height
AGB : Above ground biomass
BGB : Below ground biomass
CMI : Carbon Management Index

CHAPTER – I

INTRODUCTION



1. INTRODUCTION

Climate change is one the prime issue being faced by the word today mainly due to ever increasing level of GHG's in atmosphere. Due to its impact, earth surface temperature has increased up to 0.76 °C since the beginning of industrial revolution 1850 and the rate of global warming has doubled in the last 50 years when compared to last century. If the same trend continues, the likely increase in temperature is about 1.8 to 4.0 °C by next century (IPCC 2007). Global earth temperature has been increasing at alarming rate of 0.158 ^{o}C per decade since 1975. Also, a notable shift has being observed in ecosystems (Greene and Pershing 2007).

Anthropogenic activities, including LUC, increased agricultural activities and gases released during fuel combustion *etc.* has led to increased concentration of GHG's in the atmosphere. There has been sharp increase of carbon dioxide concentration in the beginning of industrial revolution 1850. The level of CO_2 in atmosphere has increased upto 31 percent from 280 ppm in 1850 to 380 ppm in 2005, and at present the estimated rise by1.7 ppm year^{-1} or 0.46% year^{-1} (IPCC 2007 and WMO 2006).

Climate change is not only degrading our environment but also posing threat to our food security. It has been projected that global food grain cereal production has to be increased around 50 percent by the end of 2050. Field crop yield in the region of Sub-Saharan Africa and South Asia observed to be stagnated in recent decades or has declined since 1990's due to widespread adoption of exhaustive farming system and increasing problems soil and degradation of our environment (Lal 2010).

Terrestrial ecosystems comprising of soil and vegetation are important constituent of the global C-cycle and under natural condition it acts as atmospheric CO_2 sink. Soil may act as sink of C or source of C depending upon LU under particular soil type, management practice and climatic condition prevailing over an area. Agriculture started around 8000 BC presumably and since then transforming terrestrial soil and vegetation C-sinks into a source of GHG's mainly CO_2 and CH_4. It has been estimated that the terrestrial C has depleted by 456 Pg since the onset of agriculture Ruddiman, (2003); Ruddiman, (2005). SOC stock depletion estimated to be around 130-135 Pg (Lal 2018 and Sanderman *et al.* 2017).

Recarbonization of terrestrial LUS's biosphere *i.e.* both soil and vegetation is an important natural process in mitigating the global warming and positively enhance ecosystem services Trenberth and Smith (2005). Carbon sequestration in the terrestrial biosphere influences positive C-budget in soil and terrestrial vegetation by restorative LU and adoption of BMP's (Smith *et al.* 2000; and Tang *et al.* 2017).

. Worldwide attention has focused on SOC due to soil potential to sequester carbon influences positively various ecosystems function and on other hand mitigate increased level of CO_2. The soil OC content differs in various LUS's due to difference in quality and quantity of organic input. Among different vegetative ecosystems the tree based ecosystem observed more efficient in sequestering atmospheric CO_2 into long lived pools while necromass gets returned back to the soil through litter fall. Trees based LUS have more below ground biomass which upon decomposition deposits carbon into deeper soil layer, moreover tree based LUS's have more rhizospheric volume of soil supporting more diverse and efficient microbial population needed for stabilised and sustainable ecosystem.

Different LUS's are known to influence the various soil-physical, chemical and also biological characteristics and hence have different carbon sequestration potential. Perennial horticulture LU is one of the strategies to sequester higher SOC when compared with annual crops and which results in enhancing soil attributes and contributing to the better soil quality. The benefits of perennial horticulture crops on soil in improving its chemical properties have been well known. Horticulture LUS incorporation is one of the best options for LU diversification for meeting the needs food, fuel, fodder *etc.* and also gives good economic return helping in employment generation opportunity. Investment in horticulture sector found to be more beneficial as economic returns are more satisfying besides increasing productivity of horticultural produce. India ranks second in production of fruits and vegetables. Horticulture in India has around 30.4% GDP share of agriculture.

Horticulture based LUS's has tremendous and wide range option in carbon sequestration and has potential to decrease elevated level of CO_2 in atmosphere and mitigate the effects of climate change vagaries. The perennial horticulture tree LUS's are carbon sinks which has ability to store and sequester atmospheric carbon. The threshold level of increasing earth surface temperature is 2 °C beyond which irreversible devastating consequences of climate change would be faced by whole world. Global warming has influenced cropping pattern, causing erratic rainfall and events of extreme weather incidence like floods, frosting, and crop failure due to droughts. However, horticulture LUS's has clear edge advantage over agro-forestry in terms of carbon sequestration potential. Brown *et al.* (1996) reported by 2050, horticulture LUS's in the tropical countries would have greater potential to sequester carbon estimated 16.4 Gt carbon while agroforestry would have potential to sequester 6.3 Gt carbon. Carbon sequestration potential by perennial tree is faster in tropical area because of the favourable climatic condition prevailing in these areas. Perennial horticultural fruit trees LUS's contains 25 to 100 times more stored biomass carbon when compared with agricultural LUS's.

According to the Paris Climate change meeting Agreement which suggested voluntary plan adoption *i.e.* "4 Per Thousand" 4PT that is to sequester carbon in soil layer of world with rate annually 0.4% in soil layer and 0.4 m around 1.3 ft soil layer (UNFCC 2015). This recommendation has encouraged worldwide in adoption of low emission carbon agriculture (Griscom *et al.* 2017; Tang *et al.* 2017 and Smith 2012).

To achieve the sustainable production system while maintaining the soil quality in a particular agro-climatic-zone, the knowledge of soil carbon sequestered both quantity as well as quality is essential. There is need of research, region specific, related to carbon and nitrogen stock in various LUS's in the north alluvial plain Agro Climatic Zone-I of Bihar to understand its carbon sequestration under prevailing LU, moreover, limited information in this regard is available for this region. Keeping above fact in mind the research work formulated entitled "**Assessing carbon sequestration potential and Soil Quality Index (SQI) under horticulture based land use systems in Agro-Climatic Zone-I of Bihar"** with following objectives.

1. **To evaluate soil organic carbon, nitrogen stock and their fractions under different land use systems;**
2. **To evaluate above ground biomass and below ground biomass stock of horticulture based land use systems; and**
3. **To characterize soil properties and assess soil quality index under different land use systems.**

* * *

CHAPTER – II

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Soil may act as both sink and source of carbon which mainly depends upon the different LUS's adopted and management practices being followed. There is need of comprehensive knowledge of the influence of LUS's on soil characteristics and soil quality which consequently would help in planning for restoration of natural resources and sustainability of production system. In this chapter the relevant scientific review pertaining to impact of different LUS on carbon, nitrogen and related soil properties presented in following sub-heading

2.1 Effect of LUS's on soil carbon and nitrogen stock

2.2 Effect of LUS's on soil carbon and nitrogen fraction

2.3 Effect of LUS's on physical and soil chemical properties

2.4 Effect of LUS's on soil biological properties

2.5 Effect of LUS's on microbial quotient, metabolic quotient and soil protein

2.6 Effect of LUS's on soil quality indices.

2.7 Tree biomass carbon stock

2.1 Effect of LUS's on soil carbon and nitrogen stock

SOC plays crucial role in maintaining soil health and SOC is more sensitive parameter of LUC and management practices being followed as observed by several researchers (Chan 1997 and Bhattacharyya *et al.* 2011). Martin *et al.* 2010 observed the dynamics of carbon in different LUS's is important for mitigating the climate change effect. Agriculture LUS lower SOC in comparison to other due to imbalance use of inputs, SOM input and output taken in form of crop residue (Kaur *et al*. 2008).

Global warming is an important issue being faced by world today leading to research on quality and quantity and nature of SOM. Global warming impact on SOC management research has determined world soil carbon stock. The estimated world SOC stock is around 1,500 - 1,550 Pg observed by Eswaran *et al.* (1993). In India, first time of the SOC stock estimation observed was 24.3 Pg by Gupta and Rao, (1994). Soils of the native forest soils constitutes as major carbon storage because of more organic residue being accumulated which are accounting to around 40% SOC stock of world stored in forest ecosystem.

Buringh (1984) estimated world agricultural SOC stock and found around 142 Pg C, which constitute around 8-10% of the soil C-stock.

Soil carbon cycle leads to sometime act as sinks or source for atmospheric carbon due to quality and also quantity of SOM. Balance or equilibrium between decomposition rate of SOM, input of SOM and carbon released during land-use changed (Lal 1999) increase or decrease in SOM depends on factors like climate, nutrient availability, vegetation type and tillage operation practices (Leifeld and Kogel-Knabner 2005).

Singh *et al.* (2007) assessed soil carbon stocks in different soils and found that surface soil 0-25 cm was the major sink for carbon stock that stored 31% of the carbon stocks 2.13 Pg.

In Indo-Gangetic alluvial soils, long term study in prevailing rice based LU, Mandal *et al.* (2008) observed that the soil carbon was highest in the rice-wheat-jute 535 kg $ha^{-1}yr^{-1}$ at Barrackpore than rice-mustard-sesame observed 414 kg ha^{-1} yr^{-1} and rice-fallow-rice observed 402 kg ha^{-1} yr^{-1} systems at CRRI in Orissa, India.

Kishwan *et al*. (2009) studied carbon sequestration in different forest of India from FSI data and estimated from 1995 to 2005, forest soil carbon increased from 3552.30 to 3755.81 mt. Showed that soil sequestered more carbon as compared to plant biomass in different forests.

Guang-Lu and Xiao-Ming (2010) studied the LU change effect *i.e.* from grassland to cropland and after 23 years cropland to forest and then after 7 years to horticulture on carbon and nitrogen in soil. The results showed that 31 and 26% loss in carbon and nitrogen, respectively in cropland soil compared to grassland. Also, observed that carbon and nitrogen, stocks increased 76 and 40% in forest soils and in orchard soils 66 and 63%, respectively due to LUC.

Zeraatpishe and Khormali (2012) observed, SOC stock most likely controlled by climatic factors in comparison to clay minerals. The results showed the lowest organic carbon was in aggregates < 0.053 mm size in soils. C-stock and aggregate size distribution showed positive while SOC and clay mineral observed not correlated significantly but significant correlation found between illite and chlorite with SOC.

Beheshti *et al.* (2012) researched the impact of LUC from natural forest to agricultural lands in Iran and observed that LUC from forest to agricultural lands (rice cultivation) aggravated the SOC loss and also total nitrogen. Soil organic carbon and total nitrogen stocks found to decline by 36 and 29%, respectively in soil depth 0 - 40 cm.

Poeplau and Don (2013) studied LUC impact on SOC stocks and its pool revealed that the highest variations in SOC stocks were observed in agriculture to the forest 21±13 Mg ha^{-1} and agriculture to grassland 18±11 Mg ha^{-1}. LUC from grassland to agriculture and grassland to forestland resulted in SOC stocks reduction of -19±7 Mg ha^{-1} and -10±7 Mg ha^{-1}, in 30 cm soil depth. After afforestation of agriculture land and grassland, the POM accounted 50 percent, 9.1 Mg ha^{-1} and 34% 5.9 Mg ha^{-1}, of the sequestered SOC stocks in top 30 cm soil depth, that reveals POM fraction is most sensitive indicator of LUC.

Wei *et al.* (2013) observed LUC from forest to agriculture has significantly decreased TOC stocks in soils. The results showed, LUC from forest land to agricultural lands changed the distribution of SOC in various aggregate sizes of soil and depths of soil. In cropland largest decline observed in macro-aggregate and associated OC fraction while micro-aggregate carbon increased and also observed silt plus clay associated OC was not affected by the LUC.

Benbi *et al.* (2014) reported that labile carbon of SOM may be used as indicators for LUS's induced effect on soil quality. Variation in carbon pools of soil under agriculture and uncultivated LU soils results differences in soil carbon sequestration. The impact of different LUS's such as agro-forestry, rice-wheat, maize-wheat and sugarcane was selected for research at 22 locations for every LUS. Cultivation activity caused declined in total organic carbon by 21 to 36 percent and soil DHA observed to be reduced by 2.8 to 3.4 mg kg^{-1} soil h^{-1} when compared with uncultivated LU soils. Agroforestry LU and sugarcane LUS characterized by VLc when compared with uncultivated LUS and maize-wheat, rice-wheat LUS. While uncultivated LUS and rice-wheat, maize-wheat observed with more proportion of recalcitrant carbon fractions. Results indicate that SOC observe pools in agro-forestry LU and also sugarcane LUS might decompose during LUC. Also observed that no single constituent of soil carbon pool considerable as sensitive indicator for assessing LUS effect on soil organic matter.

Dlamini *et al.* (2014) assessed grass cover LU influence on organic carbon and nitrogen-stock of soil and reported a decline in soil surface grass coverage from 100 to 5% that had significant effect on SOC and N-stocks. The SOC declined by 79% in 0 to 5% grass cover, while 42% SOC decline in 25 to 50% grass cover and very low decline observed in 50 to 75% grass cover compared to 100% grass cover. Similarly, N-stocks declined by 48% in 0 to 5% and 39% in 25 to 50% grass aerial cover. The critical threshold grass cover was found to be 50%.

Sharma *et al.* (2014) assessed SOC stock under different LUS and reported that the highest SOC stocks in 0 to 50 cm soil depth of forest land was 47.5 Mg ha^{-1} followed by horticulture 42.4 Mg ha^{-1}, degraded LU 36.3 Mg ha^{-1} and cultivated LU 35.1 Mg ha^{-1}. Up to 25% lesser SOC stocks observed in cultivated & degraded lands than forest LU soils. The transformation of forest LUS to cultivated LU resulted in loss of organic carbon of soil upto 12.4 Mg ha^{-1}. Bhardwaj *et al.* (2013) observed that the forest LUS had highest SOC stock of 52.01 t ha^{-1} in the soil depth from 0 to 40 cm while least in silvi-pasture LUS 17.01 t ha^{-1}. The total C-stocks was observed to decline when soil depth increases.

Gelaw *et al.* (2014) assessed SOC and TN stocks under different LUS's in Ethiopia, and revealed that open pasture (OP) LUS showed highest total SOC stock of 52.6 Mg ha^{-1} in 0 to 30 cm soil layer then silvo-pasture (SP) 39.1 Mg ha^{-1}, agro-forestry (AF) 25.8 Mg ha^{-1}, horticulture LU 24.4 Mg ha^{-1} while lowest in agriculture LUS 16.1 Mg ha^{-1}. The TN stock followed similar trend, highest in (OP) LUS 4.9 Mg ha^{-1} while lowest agricultural LUS 1.6 Mg ha^{-1}. With agricultural LUS as a reference line, the observed average rate increase of carbon sequestration observed to be 0.73, 0.46 and 0.19 Mg C ha^{-1} yr^{-1} of SOC and 0.06, 0.038, and 0.022 Mg N ha^{-1} yr^{-1} of TN in open pasture, silvo-pasture and agro-forestry LUS's, respectively.

Manna *et al.* (2015) observed that the carbon sequestration potential of different cropping systems in black cotton Vertisols and red soil Alfisols. It was reported that the behavior of cropping systems and carbon sequestration has differed with soil type. The carbon sequestration was observed highest in the cotton / greengram + pigeonpea cropping system 885 kg ha^{-1} yr^{-1} followed by paddy-paddy LUS 861 kg ha^{-1} yr^{-1}, and horticulture crop 745 kg ha^{-1} yr^{-1} in vertisols. Also, observed that the intercropping system of (castor + pigeon pea) sequestered the higher soil carbon of 936 kg ha^{-1} yr^{-1} when compared to the finger millet with 130 kg ha^{-1} yr^{-1} in alfisols.

Pinheiro *et al.* (2015) assessed the influence of land cover & tillage practice on soil C-stocks and observed that no-till system recorded higher SOC of 17.6 Mg ha^{-1}when compared to conventional practice of tillage system with 12.3 Mg ha^{-1} after six years of continuous cropping, results indicated that conventional tillage resulted higher carbon loss when compared to no-till system. Vegetable crop under various tillage systems such as zero-tillage, use of animal in traction and conventional practice of tillage observed that negative SOC stock of -0.7, -1.3 and -1.4 Mg C ha^{-1} yr^{-1}, respectively compared to grass LUS.

Singh *et al.* (2015) studied the effect of LUC and observed SOC and SMBC significantly varied among LUs and varied from 3.78 to 9.47 Mg C ha^{-1} and 257 - 723 μg g^{-1}, respectively. The highest SOC and SMBC observed in forest LU followed by jatropha plantation then degraded forest and lowest was in agricultural LU.

Garcia *et al.* (2016) assessd the effect of the topography in native forest and reforested areas on C-stock and N-stocks and observed that in all topographical condtion, the SOC-stocks were higher in reforested area of North: 147.1 Mg ha^{-1}, East: 137.3 Mg ha^{-1}, West: 124.9 Mg ha^{-1} and South: 87.0 Mg ha^{-1} compared to natural forest such that in North: 110.4 Mg ha^{-1} and East: 80.9 Mg ha^{-1}. The SOC stocks observed to be reduced when depth of soil increased in all LUS's and the surface soil (0-25 cm soil layer) contained 59% of SOC stock. SOC stocks were recorded in the North position higher as compared to other aspects. The N-stocks trend was similar to SOC-stocks in all sites.

Signor *et al.* (2018) studied soil N-stock and C-stock in different LUS and observed that highest C-stock was in improved pasture land soils 50.37 Mg ha^{-1}, then native vegetation 42.63 Mg ha^{-1} and horticultural LU 32.19 Mg ha^{-1} and least was in degraded pasture lands 30.60 Mg ha^{-1}. N-stocks found higher in improved pasture lands 3.33 Mg ha^{-1}. Also, observed that when land use change from native vegetation to degraded LUS's decreased the SMBC and carbon and nitrogen stocks.

Shi *et al.* (2019) studied that LUC influenced the carbon stock in soil and also the SOC distribution across the LUS's. LUC from agriculture land to forest LU, shrub LU, grass LU, and terraced land lead to more SOC storage. The soil depth of 0 to 20 cm had more SOC content and it decreased in deeper soil layer. The higher SOC content 0 to 100 cm observed in forest LU 11.99 kg m^{-2} followed by shrub land 11.89 kg m^{-2}, grassland 11.77 kg m^{-2}, as compared to agriculture LU 11.41 kg m^{-2}.

Tesfahunegn and Gebru (2020) assessed carbon and nitrogen stocks in different LUS's and observed highest carbon and nitrogen stock of 175.30 Mg ha^{-1}and 13.60 Mg ha^{-1} were found in natural forest while lowest in untreated gully lands of 14.5 Mg C ha^{-1} and 1.20 Mg N ha^{-1}, respectively.

2.2 Effect of Land-use systems on soil carbon and nitrogen fraction

Organic matter contains different fractions from easily decomposable to recalcitrant and categorized in two major pools such as Labile (Lc) and non-labile (Haynes 2005). The (Lc) fractions are more sensitive to LUC and its turnover rate is fast. The organic substrate serves as food for microbes that governs nutrient mobilization and cycling which enhances soil quality and productivity (Majumder *et al.* 2008). The soil organic carbon constituents and the labiality of carbon, influences soil physical, chemical and also biological characteristics (Blair and Crocker 2000). Blair *et al.* (1995) reported that labile carbon is easily oxidised by solution of 333 mM $KMnO_4$. That's why in assessing Carbon Management Index (CMI) the Lc is taken into consideration to evaluate the management systems for enhancing soil quality. The SOC pool decrease by 15 to 40% in two year period in one meter depth of soil when tropical forest LU changed to agriculture LU reported by (Ingram and Fernandes 2001) and it may go upto 50 to 75% (Lal 2004). Through restorative LU and best management practice in agricultural LU may check depletion of the SOC pool and sequester more carbon in soil.

Lakaria *et al.* (2012) estimated SOC fractions under different LUS in central India and observed that the forest, mainly dominated by mahua, eucalyptus, and tendu species and horticultural LUS showed highest labile carbon fraction, water-soluble carbon and SMBC. Whereas, in agri-horticulture plantations of aonla and guava with gram in *rabi* season crop increased soil carbon.

The DHA activity in soil and other fractions like SOC, SMBC and water-soluble carbon significantly affected by different LUS. The ratio of resistant carbon to total carbon was constant 66 to 68% among different LUS. The higher content of resistant carbon pool which was 78% of total carbon observed in the sub-surface soils that shows, the resistant carbon fraction increased when soil depth increased in different LUS (Jha *et al.* 2012).

Wang *et al.* (2013) revealed that LUC from natural forest to commercial tree plantation species significantly influenced the SMBC. The SMBC was higher around 45.9% in *Michelia macclurei* (Dandy) soils as compared to natural forest soils. Whereas, the total SOC, dissolved organic carbon (DOC), and permanganate oxidizable carbon (POC) not significantly influenced by forest LUC. The highest ratio of SMBC to total SOC observed in *Michelia macclurei* (Dandy) plantation then *Pinus massoniana L.*, *Cunninghamia lanceolata Hook* while the lowest observed in natural forest soils.

Selassie and Ayanna (2013) observed that highest SOC, total nitrogen, and C: N ratio recorded in the natural forest LUS and the lowest values observed in agricultural LUS. The soil OC and total nitrogen observed to decrease when the soil depth increased across LUS. The study concluded that forest LUC to cultivated LUS had more impacts on the soil physical and soil chemical properties.

Verma *et al.* (2013) observed that Walkley and Black carbon, $KMnO_4^-$oxidizable carbon, and SMBC constituted by 26.2%, 9.16%, and 2.15% of the total (SOC), respectively in the cultivated alluvial soils. The soyabean-wheat and rice-wheat cropping system that received total amount of nitrogen through FYM resulted in higher carbon management index (CMI). However, in maize-wheat LU, the highest CMI was under chemical fertilizer with green manure treatment receiving NPK.

Pinheiro *et al.* (2015) observed physical fractions of SOM under different LU and tillage systems and reported that most of the carbon accumulated as mineral associated carbon (MAC) fraction in the zero till system compared to conventional tillage system. Grassland LU had maximum carbon sequestration and MAC fraction 14.9 g C kg^{-1} and soil nitrogen 5.1 g N kg^{-1} in the 0 to 5 cm soil layer. Almost more than 55% of stored soil carbon HFC/ Soil-carbon was in (HF) heavy fraction among all treatments.

Naik *et al.* (2016) observed that soil carbon plays crucial role in the soil nutrition supply and productivity. SOC broadly categorized into labile carbon and other non-labile carbon that are important in maintaining quality and health of soil. Evaluated dynamics of TOC, oxidisable SOC, labile carbon (Lc), very labile carbon (VLc), non-labile carbon (NLc) and less labile carbon (LLc), SMBC and soil OC sequestration in horticulture LUS's. The experiment showed that out of total soil OC enrichment, mango, guava and litchi accounted 17.2%, 12.6% and 11.0% carbon, respectively over control. The mango orchard LU recorded highest value of very labile carbon with 20.7%, labile carbon 13.5%, and non-labile carbon with 17.4% over control. The upper surface soil of 0 to 0.30 m accumulated more C fractions and it reduced when soil depth increased. Mango LUS reported maximum active carbon pool of 36.2 Mg C ha^{-1} accounted 1.20 times higher compared to control while the passive carbon pool constituted 42.40% of total SOC also observed to be highest. The mango LU showed higher SMBC than litchi LU and control. The CMI observed to be 1.20 times higher in mango LUS and 1.13 times in both litchi and guava LUS compared to control. The mango LUS observed highest carbon accumulation rate of 1.53 Mg C ha^{-1} $year^{-1}$ and sequestered 17.30 % soil carbon more over the control. Among different carbon fractions, very labile carbon was observed highly correlated with SMBC (r = 0.56**).

Souza *et al.* (2016) observed that light fractions of carbon were sensitive to different soil management practices. Oxidizable $KMnO_4$ soil carbon was observed as the best indicator of SOC lability. All labile carbon fractions of SOM in surface soil observed to decrease due to conventional tillage system. Also reported that long term phosphorus fertilization not influenced total organic carbon but it improved the oxidizable soil organic carbon, POC and SMBC in soil.

Moharana *et al.* (2017) observed that LUC from sandy barren LU to agriculture LUS significantly increased the available soil nutrients and soil OC fractions. The pearl millet-wheat cropping system observed the highest content of total OC 6.12 g kg^{-1}, POC 1.53 g kg^{-1} and water-soluble carbon 0.19 g kg^{-1}. Whereas, barren land observed the lowest TOC of 2.41 g kg^{-1}, POC of 0.58 g kg^{-1} soil and water soluble carbon of 0.08 g kg^{-1} among all cropping systems. Strong relation was observed among very labile and labile carbon with available nutrients ($P < 0.05$).

Meena *et al.* (2018) estimated the SOC, total nitrogen and CMI in different LUS's and reported that the highest SOC of 14.45 g C kg^{-1}, total carbon of 26.93 g C kg^{-1}, total-nitrogen of 2.31g N kg^{-1} and CMI of 49.80% under forest LUS whereas, the lowest values were observed under barren LUS. The LUS had the least effect on (NLC), Lability of carbon (LC) , lability index (LI), and also carbon pool index (CPI). Moreover, an increase in total content of carbon and total content of nitrogen in grassland and forest LU soils as compared to the barren land and agricultural LU soils.

Zhang *et al.* (2018) observed the SOC fraction in reclaimed agricultural LU from coastal wetlands and reported that SOC and (POxC) permanganate-oxidizable carbon increased significantly during reclamation period. The human controlled LU had observed significantly ($p<0.05$) more amounts of soil OC and POxC compared to the sea tidal land. Upland paddy soil sequestered more SOC and POxC as compared to other LU. Soil *p*H, total phosphorus and total nitrogen observed the most significant factors influencing POxC and SOC in the reclaimed land.

Sainepo *et al.* (2018) revealed that the total-OC, particulate OC (POC), and mineral-associated OC (MOC) significantly varied among different types of land-uses. The shrubland had the highest total OC 22.26 g kg^{-1} followed by agricultural land 12.07 g kg^{-1} and grassland soils 10.29 g kg^{-1} while the lowest TOC was found in bare land soil 7.56 g kg^{-1}. The POC 7.79 g kg^{-1} and MOC 10.04 g kg^{-1} had also reported significantly higher in shrubland soils than other land-use systems in the study.

Moharana *et al.* (2019) appraised SOC and nitrogen fractions and carbon management indices in wheat–green gram LUS and reported that use of rock phosphate enriched composts with fertilizers + 50% NPK increased TOC and nitrogen, microbial SMBC and their fractions in soil as compared to application of 100% inorganic NPK fertilizers. The use of enriched composts alone or applied in combination with 50 percent N, P, K has significantly increased the total nitrogen, labile-N, and mineral nitrogen in soil. The highest CMI of 219 was reported in mustard stove compost + 50% NPK, while the highest nitrogen management index (NMI) of 274 was observed in rice-straw compost + 50 percent

NPK-treated plots. The VLc fraction was showed more sensitivity to management practices when compared to TOC and LLc fraction.

Sahoo *et al.* (2019) studied the different carbon fractions under different LUS and reported the highest TOC 2.75% was in forest LU whereas the lowest in grassland 1.31% system and it reduced with the depths of soil. The very labile (VLc), labile (Lc), and less labile carbon (LLc) fractions ranged from 0.22 -1.43%, 0.15 - 0.62%, and 0.15-0.72%, respectively in different LUS in 0-45 cm soil layer. The VLc was major constituent of TOC with average value of 40.27% of it, among all the LUS. The active carbon pool VLC + LC was more 59.76% as compared to passive carbon pools LLc + NLc in the all LUS's, and reported that the soil carbon may be easily lost subsequent due to LUC.

Hussain *et al.* (2019) reported the influence of various LUS's on soil organic and inorganic carbon constituting total carbon in the Himalayan foothill soils. The study revealed that the highest TOC was found in forest soils 24.3 g kg^{-1} followed by horticultural LU 22.4 g kg^{-1} and degraded soils 17.70 g kg^{-1} while the least TOC was observed in agriculture LUS 17.1 g kg^{-1} in the 0-15 cm soil depth. The maximum inorganic carbon (IC) was recorded in degraded land 7.26 g kg^{-1} than forest 4.14 g kg^{-1} and horticultural LU 3.01 g kg^{-1} and lowest in agricultural LU 2.68 g kg^{-1} in the upper top soil layer. The IC constituted nearly 39% to total carbon (TC) in degraded land. The soil IC increased, while soil TOC decreased with the soil depths across the LUS.

Kumar *et al.* (2020a) observed the effect of different nutrient sources under agroforestry systems on soil organic carbon fractions. The study revealed that higher amount of active (very labile- 13.8% + labile- 4.8%) and lower passive carbon pools (less labile- 8.3% + non-labile-11.1%) under agroforestry LUS than an open system along with SMBC with 298.31 µg g^{-1}. All carbon fractions and SMBC were recorded higher in 100% INM as compared to control treatment.

Mishra and Sarkar (2020) studied the SOC pools under different LUS and management systems in Meghalaya, India. The results showed significant correlations between TOC and carbon pools in most LUS, except the non-labile pool (NLc). The active pool 12.03 mg g^{-1}, passive pool 4.60 mg g^{-1} and very labile carbon (VLc) were positively correlated with TOC and soil active carbon pool, while less labile carbon (LLc) also positively correlated with passive carbon pool.

Kumar *et al.* (2020b) observed the impact of different sources of nutrient on carbon mineralization and also on in-organic nitrogen fractions under agroforestry system and reported that maximum CO_2 evolution and inorganic nitrogen observed in 100% integrated nutrient management (INM), while minimum CO_2 evolution and inorganic nitrogen was observed in farmyard manure and stray plots, respectively. The maximum inorganic nitrogen was observed in the agroforestry system (Turmeric + *Terminalia chebula*) while lowest in open system turmeric only.

Selassie and Ayanna (2013) observed that highest SOC, total-nitrogen, and C:N ratio were under natural forest LUS and the lowest values observed in agricultural LUS. The SOC and total-nitrogen were decreased with increase of soil depth across the LUS. The study concluded that forest LUC to cultivated LUS had more impacts on the soil physical and soil chemical characteristics of soil.

Zeraatpishe and Khormali (2012) observed that SOC stock most likely controlled by climatic factors in comparison to clay minerals. The results showed the lowest organic carbon was in aggregates < 0.053 mm size in soils. A positive correlation was found among carbon stock and aggregate size while soil OC and clay mineral observed not correlated significantly but found significant correlation between illite and chlorite with SOC.

Wei *et al.* (2013) observed LUC from forest to agricultural LU significantly decreased TOC stocks in soils. The results showed, LUC from forest land to agricultural lands changed the distribution of soil OC in various soil aggregates sizes and the soil depths. In cropland, largest decline observed in macro-aggregates and its associated OC fraction while micro-aggregate carbon increased. It was also observed that silt plus clay associated OC was not influenced due to LUC.

Zhang *et al.* (2013) reported that TOC in sand fraction > 53µm and the silt fraction 2-53 µm and non-protected coarse particulate OM cPOM > 250 µm increased with increasing manure input.

Soil OC considered as central element which governs the soil quality, soil fertility, and the productivity in the field. It was observed with decline in soil OC that adversely affected the beneficial soil parameters and which results in reduced crop productivity. The soil OC plays important role in controlling various eco-system functions attributing to soil quality and the sustainability of the system, as it is main driver in governing soil physical, soil chemical and also soil biological properties. Through various soil functions like mineralization, it mobilizes nutrients in soil making nutrient availability in soil. Soil OC influences the soil aggregate stability, retention of water and also the various hydraulic properties of soil (Haynes, 2005). Soil OC conserves the environment and it is store house of global C-stock (Lal *et al*. 1998 and Verma *et al*. 2010).

2.3 Effect of LUS's on soil physical and chemical properties

Prevailing LUS in particular area affects soil properties and if land use changes are brought that results in change in soil properties and related parameters. It relates to problem of food security (Tao *et al*. 2009) and the soil quality (Mueller-Warrant *et al.* 2012). LUC and soil management practice governs different soil properties, and also soil's biological and microbial-activities (Saraswathy *et al*. 2007). In research, it has been observed with good relationships between LUC and the availability of soil nutrient. The world population is ever increasing which has led to increase in food demand that resulted in LU change (Lambin *et al.* 2000). LUS not well managed often results in nutrient depletion, SOM depletion, soil quality and biodiversity decreases (Ayoubi *et al.* 2011).

Braimoh and Vlek (2004) reported that LUC impact consequently brings changes in soil characteristics and the productivity later causing deterioration of soil quality and available nutrients over time. Land use influences changes in soil physical and chemical properties and can also affect fertility and causes soil erosion or soil compaction. Land use change requires management of soil carbon & fertility for the sustainable growth and development (Smith 2008). There is need to establish sustainable LUS for conserving soil fertility. SOC is the key factor governing soil fertility and physical properties.

The total nitrogen value of the soil observed to be associated with SOC while it decreased in cultivated land due to continuous soil disturbance in soils in humid and also sub-humid tropical climate due to lower SOC (Tisdale *et al.*1995).

Wakene, (2001) observed depletion of total-N with 30% and 76%, respectively in agricultural LU and abandoned LU after 40 years when compared to virgin land. (Nega 2006) reported that total-N positively increases when agriculture LU changed from grazing to forest LUs. Also, observed that the N-content decreased when soil depth increased. Soil texture is inherent physical property and is less affected by management practice over short period of time. Soil texture influences infiltration rate, water retention, soil aeration, soil microbial activities, absorption of soil available nutrients, tillage practice (Gupta 2004).

Soil texture of the region is good indicator of different soil characteristics and it depends upon the parent material, soil profile homogeneity, and heterogeneity migration of soil separates, rate of weathering, parent material constituents and age of soil (Weil 2002).

Bulk density of soil is related to degree compactness of soil layer, soil aeration, and moisture content in soil. Soil BD is also related to soil pore space which has inverse relationship between soil pore space existing and soil organic matter contained in soil. (Gupta 2004) also reported that intensive practice of cultivation found to increases soil BD which consequently lowers the soil total porosity. Yao *et al.* (2010) observed that BD of agricultural LUS have higher value compared to native forest soils. Yuksek *et al.* (2009) observed that in various LUS's like forest LUS, horticulture LUS and pasture LUS, BD value increases when depth of soil layer is increased. Islam and Weil (2000) observed lower soil *p*H in the forest LUS when compared to grassland LUS and cultivated LUS. Which is mainly due to inherent parent materials possessing amphoteric chemical properties (Aluminium), also other reason like leaching activity that intensively removes basic cations are mainly responsible for low soil *p*H in forest LUS.

In the tropics ecosystem, when forest LUS is converted to other LUS's like agriculture *etc.* leads to lowering of SOM content which results in imbalanced equilibrium of fragile ecosystem Marzaioli *et al.* (2010).

Laxminarayana (2010) observed that in cultivated soils SOC found to be low due to low organic input addition in soil and removal of crop residue biomass from field, intensive agriculture and erosion. Biological properties of soil degrade with decrease of vegetation, soil surface cover and SOC. The soil micro-organisms are important indicator of soil quality.

Zeidler *et al.* (2002) observed that 20 to 50 percent of SOM declined as a result of deforestation and its change to agricultural LUS. It is observed that SOM and aggregate stability observed to be enhanced in soils when agriculture LUS converted to forest LUS (Bouajila and Gallali 2010). Geissen *et al.* (2009) reported that SOC declined when soil depth increased under the forest LU, agriculture LU, horticulture LU.

Gilley and Doran (1997) observed the impact of different LUS on soil texture of surface soil layer. Very fine silt and clay% were reported to be higher in undisturbed LUS 34% followed by cultivation 24%. The sand perentage was 14 and 16 in undisturbed LU and nine months tillage systems, respectively. They conclude that the clay content redistributed during cultivation practices.

Negassa and Gebrekidan (2001) observed that most of the soil physical properties were influenced by different LUS. The abandoned LU showed the highest BD of 1.57 Mg m^{-3} than agriculture LU 1.22 Mg m^{-3} and virgin LU 1.16 Mg m^{-3}. The total nitrogen and SOC decreased by 79 and 76%, respectively under abandoned LU compared to reference site. The decrease of CEC in abandoned LU and the cultivated LUS was observed to be 69.44% and 52.76%, respectively compared with the virgin LUS's.

Noellemeyer *et al.* (2008) observed short term and long term effect of LUC's from the field-pasture LUS to agriculture LU on SOC and soil aggregation. The results showed that the short term study soils >3years of agriculture had 29% less large sized aggregates >4 mm and 37% more very small sized soil aggregates <1 mm while, SOC loss was 16% more compared to pasture LU while intermediate size 1-4 mm soil aggregates not changed. Whereas in long term study of 14 years of agriculture, observed intermediate size soil aggregates and SOC decreased by 30% and 32% observed, respectively, when compared to pasture LUS. Data of study showed SOC and aggregation changed very rapidly but soil water retention, soil water infiltration, soil hydraulic properties, and soil bulk density were affected in long term cultivation only as compared to pasture LU.

Ceyhun G. (2009) reported that LUS significantly affected the SOC, WSA, total nitrogen, soil saturated hydraulic conductivity and soil BD. The natural forest LU soil showed more saturated hydraulic conductivity 82.4 cm h^{-1} than cornfield 30.0 cm h^{-1} and garden of hazelnut LUS soils 11.5 cm h^{-1} while the lowest observed in grassland soils 8.4 cm h^{-1}. The higher WSA was observed in natural forest LU 79.4% and grassland LU 60.4% soils compared to cultivated LU soils 46.7%.

Silva *et al.* (2011) studied physical properties of soil under different LUS and reported that more water retention and soil porosity under natural vegetation LU followed by agrosilvipasture then silvipasture and found lowest in conventional agriculture LU system.

In Agricultural soil compaction is mainly due to natural processes and utilization of heavy machinery (Grzesiak, 2009). During compaction due to applied force pore volume reduces and bulk density increases.If soil density increases then soil penetration resistance (*Pr*) also increases (Abu-Hamdeh 2003). The soil compaction affects plant root growth affecting physiology of plant (Iijima *et al.* 1991 and Grzesiak *et al.* 2002).

Soil penetration resistance influenced by other factor also like soil texture, Soil moisture, bulk density and SOM. Found penetration resistancelowered with increased BD and clay while decreases with decrease in soil moisture and soil-OM Unger and Jones (1998); Canarache (1990); Vaz *et al.* (2001); Quraishi and Mouazen (2010).

Fagotti *et al.* (2012) observed nitrogen supply potential of soils under different LUS and revealed that native forest LU soils (NAT) highest total and microbial biomass nitrogen followed by reforestation LU and agricultural LUS (AGR). The highest potential of nitrogen mineralization was observed the forest, and reforested soils. The native forest soils revealed maximum ammonification rate 1 mg $NH4^{+}$ - N kg^{-1} day^{-1} while the lowest rate was under the agricultural soils 0.4 mg $NH4^{+}$ -N kg^{-1} day^{-1}. However, it was opposit in case of nitrification rate 12 and 26%, showing the lower capacity of N-supply and more risk of nitrogen losses in agricultural LU soils.

Beheshti *et al.* (2012) investigated that soil physical properties in natural forest LU and agriculture LUS observed no difference in soil texture and bulk density between both LUS. Forest LU soils had better aggregate stability and a higher amount of soil moisture (v/v) at field capacity and soil available water content in 20-40 cm soil depth compared to agriculture LU soils. The dispersible clay in 0-20 cm of soil layer was higher in agricultural LU soils (19.6%) than forest LU soils (11%). Dadhwal *et al*. (2012) observed the LUS effect on soil properties and reported that the highest total nitrogen, SOC and available potassium observed in natural forest LU soils followed by degraded forest LU, scrubland LU, horticulture LU, and lowest in agriculture LUS that due to more soil disturbance by intensive cultivationWhereas, available phosphorus found highest in the agricultural LUS as compared to the other LUS's due to application of phosphatic fertilizer. Overall it was observed that LUS have impact on soil properties mainly due to its influence on SOC and total nitrogen.

Jha and Mohapatra (2012) observed that tree based LUS under ravine land improved overall soil properties while LUC of ravine lands to the cultivated LU further deteriorated the hydrological, physico-chemical and soil biological properties.

Moges *et al.* (2013) observed soil properties under different LUS and revealed, soil particle distribution differed with LU and soil depth even though soil textural class among the LUS was sandy loam. The mean bulk density (BD) not shown any significant difference in respect to LUS ($P = 0.565$). Whereas, soil depths significantly affected BD ($P=0.041$) that soil BD was more in deeper lower soil layer when compared with top soil. The forest LUS soils showed higher SOC 29.7 g kg^{-1} than grazing LU 26 g kg^{-1} and agricultural LU 18.4 g kg^{-1}. Among soil depth, SOC was highest in top soils than lower soil depth across all LUS.

Somasundaram *et al.* (2013) conducted a study on soil properties under different LUS in ravine affected zone of Chambal region. The study revealed that mean weight diameter (MWD) and SOC well correlated with each other reveals role of SOC in soil aggregation. The grassland LU observed larger MWD 3.42 mm than *Leucaena leucocephala* 1.42 mm and mixed forest LUS 1.34 mm. The natural vegetation LU soils showed more SOC, available nitrogen, available phosphorus, available potassium, and CEC compared to other LUS's.

Selassie and Ayanna (2013) observed the effect of LUS on soil properties in Ethiopia. The natural forest LUS showed minimum bulk and soil particle densities and found maximum total porosity and moisture in soil both FC and permanent PWP. However, the agriculture LUS showed more bulk and particle density and lower soil total porosity and soil water contents at both FC and PWP. While cultivated LUS showed the lowest SOC and total-N and C:N ratio, while forest LU observed highest content of same parameters.

Dlamini *et al.* (2014) studied a correlation among different soil properties in degraded grass LUS and reported SOC fraction positively correlated with (MWD) while negatively with clay particles, bulk density, and soil penetration resistance. SOC pools also revealed a positive association from one another, showing a dynamic of the relation between various pools of carbon.

Abad *et al.* (2014) revealed that LUC from forest LUS and pasture LUS to agricultural LUS had adverse effects on all soil physico-chemical properties, leads to decline in the soil quality that further increases the degradation and soil erosion. Moreover, soil aggregate stability, available nitrogen, phosphorus, potassium, and OC declined while bulk density and *p*H increased.

Singh *et al.* (2015) observed increase in soil aggregate size distribution and its relationship with soil CO_2 carbon flux CO_2-C flux under different LUS and revealed that macro-aggregates significantly varied with the LUS. The macro-aggregates observed highest in natural forest LUS 69% followed by jatropha plantation LU 62%, degraded forest land 59%, and lowest in agricultural LUS 51%. Macro-aggregates protect SOC that consequences lower soil CO_2 carbon flux and higher SOC stocks. CO_2 carbon flux showed significant negative (r^2 = 0.942) relationship with macro-aggregates while no relationship (r^2 = 0.008) with micro-aggregates among all LUS.

Zheng *et al.* (2018) observed effect of cover crop as intercrop mulch in horticulture LU and reported that the total nitrogen, SOC and soil moisture increased by 19.1, 15.2, and 27.8 %, respectively when compared to the conventional LUS in which cover crop not used as intercrop mulch.

Tellen and Yerima (2018) observed that the forest LUC into agriculture LUS decreases the moisture content, SOC, total nitrogen, available phosphorus, CEC, and exchangeable bases while increases observed in bulk density, electrical conductivity and exchangeable acidity. The study indicated deforestation and cultivation of soils results in adverse impacts on soil properties.

Willy *et al.* (2019) reported that in 50 years, the levels of TOC, magnesium, boron, iron, and total nitrogen declined by 72, 65, 61, 22, and 15%, respectively, in agriculture LUS as compared to undisturbed soils. The nutrient index also changed from high in undisturbed LU to low in agricultural LUS.

Zajicova and Chuman (2019) studied the effect of LUC from forest to agricultural LUS. The agricultural LUS indicated lower CEC, base saturation, available phosphorus, total nitrogen, and SOC.

Tufa *et al.* (2019) observed soil properties influenced by different LUS and revealed that LUC adversely affects the soil properties. The maximum SOM, total nitrogen and CEC were observed under forest LUS while lowest in grazing lands. The average CEC values recorded 41.7, 38.5, 33.2, and, 30.1 cmol(p^+)kg^{-1} soil under forest, grass, cultivated, and grazing LUS, respectively. The lowest bulk density observed in grassland LUS while highest in grazing LUS.

Msofe *et al.* (2019) assessed the effect of LUC on soil-physical, soil-chemical characteristics when forest and wetland changed to upland cultivation and rice farm, respectively and observed that the TOC, total nitrogen, CEC, soil moisture content, and water stable aggregates significantly decreased ($p<0.05$) whereas bulk density, soil *p*H and total phosphorus significantly increased ($p<0.05$).

Ebabu *et al*. (2020) observed differences in soil physical, soil-chemical characteristics under different LUS for sustainable management practices (SLM) in Ethiopia. The results revealed seven out of the nine studied soil properties significantly differed among the three LUS ($P<0.5$ to <0.001). Under agriculture LU, the lower values soil *p*H, CEC, SOC and total nitrogen recorded when compared to grazing and bush LU which indicated soil quality under agriculture LU deteriorated by unsustainable management practices. Three years after SLM practices introduced remarkable improvement was noted in bulk density, SOC, total nitrogen, available phosphorus, and potassium in treated plots. Natural forest LUC into cleared area deteriorate the soil physical quality as well as water-stable aggregate decrease by 36% and bulk density increase by 57% as observed by Zaher *et al.* (2020); Bizuhoraho *et al.* (2018).

Tesfahunegn and Gebruin the year (2020) studied the differences in soil charactristics in various cropping system and LUS and reported, soil bulk density, *p*H, EC, CEC, soil structural stability index, and porosity varied across the cropping and LUS. The highest soil bulk density found in untreated gully land 1.77 Mg m^{-3} while least observed with native forest soils 1.19 Mg m^{-3}. Maximum porosity and structural stability index was observed in natural forest while minimum in untreated gully lands.

Srivastava *et al.* (2020) reported that LUC from forest to other reduced soil porosity, water holding capacity and moisture content of soil. LUC from forest to savanna land, decreased SOC approximately 40 to 50%. Further, it revealed decline was more prominent under cultivated LU 65 to 70% and degraded LU 83 to 85%.

2.4 Effect of different LUS's onsoil biological properties

Soil biological properties are considered important as it is sensitive to undesirable changes or soil disturbances affecting soil quality (Hernandez *et al.*1997). Soil microbes play pivotal important in various soil process like nutrient recycling making nutrients available to plants. The soil microbial activity plays significant role in nutrient availability in various eco-systems (Onwonga *et al.* 2010). Arunachalam and Pandey (2003) reportedmore SMBC content observed in natural forest LUS's which is due to accumulation of more SOM both quantity and quality governs dynamics. Higher accumulation of SOM results in more availablesoil nutrient which consequentlycauses favourable soil changes insoil-physical, soil-chemical characteristics. Witter and Kanal (1998) observed positive relation between soil-OC and the in various LUS's.

Tripathi and Sharma (2005) reported soil biotic activity was significantly influenced by different LUS. Soil respiration and soil DHA activity and other soil properties like temperature, moisture, SOC, available nitrogen, and phosphorus were more under tree based LUS compared to agriculture LUS's.

Kara and Bolat (2008) assessed the SMBC and nitrogen under different LUS's and observed that the LU significantly influences the SMBC and SMBN. The forest soils observed the highest SMBC 1028.29 µg g^{-1} followed by pasture land 898.47 µg g^{-1} and lowest in agricultural soils 485.10 µg g^{-1}. SMBN followed a similar trend highest under forest soils 129.99 µg g^{-1} and lowest in agricultural soils 42.60 µg g^{-1}.

Tangjang *et al.* (2009) observed seasonal and also depth wise variation in soil microbial population in arecanut based agro-forestry systems and observed that the bacterial population highest during spring while fungal population during autumn season. However, the highest microbial counts were observed in topsoil 0-10 cm depth except during rainy season when the microbial population was more in the subsurface 10-20 cm layer. Soil OC and total nitrogen availability were well correlated with microbial CFU. The microbial population was influenced by vegetation density, organic residue input, plant species and mineral nutrients in agro-forestry systems.

Fagotti *et al.* (2012) assessed enzymatic activity in soil nitrogen cycle under different LUS's. The results revealed that forest soils had the highest enzymatic activity followed by reforestation with *Araucaria angustifolia*, reforestation with *Pinus taeda*, and least in agricultural soils. The enzymatic activity of glutaminase and urease was three times higher under forest then *Araucaria angustifolia* soils compared to *Pinus taeda* and agriculture LU. The *Araucaria angustifolia* soils observed three times more asparaginase activity than agriculture LU whereas, *Pinus taeda* showed about half the asparaginase activity than the forest soils.

Zhang *et al.* (2013) reported the importance of microorganism with different sizes of aggregate fractions and carbon sequestration in different tillage systems. The result showed conservation tillage (no-till & ridge tillage) had more activity of soil biota when compared to conventional tillage systems. Soil microbial biomass and its diversity found more in micro-aggregates (< 0.25 mm) whereas, abundance and diversity of nematode found more in macro-aggregates 2-1 mm in between fractions of aggregate. The more carbon accumulation was observed within <1 mm aggregates as more gram-positive bacteria and nematodes observed, but carbon retention improved within >1 mm aggregates because of more fungi abundance.

Ravindran and Yang (2015) observed variation in SMBC and SMBN due to different types of vegetation in sub-alpine forest LU Taiwan. The study showed, highest SMBC and SMBN recorded in spruce than hemlock and grassland LUS. These SMBC and SMBN were also more in surface soils and observed declined when soil depth increased in all kinds of vegetation LUS. Microbial population's also revealed similar sequence as highest observed in spruce LU soils and lowest in grassland LU soils. Also found SMBC and SMBN decreased with depth in all LUS's. Zheng *et al.* (2018) observed cover crop as intercrop mulch in horticulture LU increased of β-glucosidase activity, β-xylosidase, and cellobiohydrolase enzyme in soil by 12.3, 22.0, and 14.7% than conventional system without mulch. The practice of intercrop mulch increased the *Firmicutes* 18.7% and reduced abundance of *Actinobacteria* and *Verrucomicrobia* compared to the 7.2% in conventional system.

Birt and Bonnett (2018) assessed effect of SOC and inorganic nitrogen on microbial activities under grass LUS urban and woodland soils. Woodland soil contained more SOM, dissolved organic carbon, and dissolved phenolic compounds when compared to grassland LUS. In woodland LUS activity of *β*-glucosidase and N-acetyl-glucosaminidase increased by inorganic nitrogen but microbial respiration decreased.

Yang *et al.* (2019) observed in subalpine forest lands, soil respiration, microbial biomass and enzymatic activities during soil carbon cycling decreased in winter due to increased frost that decreased availability of soil nitrogen in winter season. Grassland LUS contained higher rhizobia, organic carbon, and nitrogen, while lower in agricultural LUS (Aredehey *et al.* 2019).

Chen *et al.* (2019) observed intensive agriculture practices significantly transformed the bacterial population as well as nutrient availability under bamboo forest LUS. Available potassium, phosphorus, soil *p*H and nitrate nitrogen (NO_3^- N) were factors that govern the bacterial population dynamics. After 15 years intensive agriculture activity of soil enzyme *β*-glucosidase, urease, and phosphatase declined that again recovered after twenty five years of management.

Lopes and Fernandes (2020) observed the microbial population dynamics in various conservation agricultural LUS. The results showed that in fallow LU actinomycetes biomarkers, microbial stress, gram positive bacteria, and amino acid degradation capability decreased while arbuscular mycorrhizal and gram negative bacteria biomarkers, SMBC and soil respiration increased. In conventional tillage, arbuscular mycorrhizal fungi increased while stress biomarkers decreased when compared to conservation tillage. Intercropping lowered soil *p*H and improved SMBC when compared to mono-cropping system.

2.5 Effect of LUS's on microbial quotient, metabolic quotient and soil protein

Lungmuana *et al.* (2019) observed the impact of LUC jhum cultivation to different plantations and forests LUS's. The study revealed that LUC increased SOC and WHC of soils under alternative LUS's. The SOC improved SMBC and SMBN, the ratio of SMBC to SOC, basal soil respiration, and enzymes like *β*–glucosidase, DHA, arylsulphatase and urease. The metabolic quotient (qCO_2 -substrate use efficiency) in *jhum* LUS was 21.5, 25.8, 27.8, and 39.9% higher compared to forest, arecanut, rubber LU, and teak plantation, respectively into 0-15 cm soil depth that showed microbial stress due to more disturbances surface layer of soil.

Naik 2016 observed in different LU *i.e.* mango, litchi, guava LUS and control that the maximum SMBC was observed 370 mg kg^{-1} was recorded in guava LU then mango LUS 343 mg kg^{-1} and increase in 63.70% compared to control. The SMBC which generally constitutes around 1 to 5% of the total SOC may indicate early signs of possible degrading due to various practices and management followed influencing quality of soil (Mandal 2005 and Powlson 1994). Lesser SMBC may be related to unfavourable environment due to lower available nutrients, runoff from surface soil, while more SMBC content in horticulture LUS due to favourabe environment condition for microbe population and SOC accumulation through organic input through leaf litter fall (Grego *et al.* 1998). The cumulative total amount of leaf litter drop by six year old litchi LUS, guava LUS and mango LUS was 11.60, 11.90 and 12.20 t ha^{-1}.Higher value of SMBC in guava LUS and mango LUS mainly due to added quantity of soil orhanic matter as well as litter fall quality having higher rate of decomposition consequently more nutrients availability (Ramesh *et al.* 2013). The microbial quotient MQ, value ranged 2.79 to 4.26 with a mean 3.62%. The (MQ) of guava LUS and mango LUS found non-significant but found significantly with litchi LU and control. The MQ for soils found within the range of one to fivepercent as reported by (Powlson 1994 and Carter 2002). The more MQ value observed guava LUS and mango LUS revealed a more soil-OC stability under horticulture LUS's (Sparling *et al.* 1992). The least MQ observed in control signifies low SMBC and poor quality of soil (Chaudhury *et al.* 2005). The more nutrient availability to soil microbes results in increased the microbial quotient in guava and mango LUS (Rudrappa *et al.* 2005).

Benbi *et al*. (2014) observed that changes in SOM quantity and quality in different LUS affectssoil microbe population also its activity due to differences in supply of organic substrate, soil porosity, and soil-physical characteristics that gets reflects DHA activity and of soil microbe's metabolic intensity (Skujins 1973 and Alef and Nannipieri 1995). More DHA activity observed data of uncultivated LUS soils when compared to agricultural rice-wheat LUS soils, similar observation also observed Saviozzi et al. (2001) reported decrease in soil enzymatic activity due to corn cultivation in long term when value compare with undisturbed LUS. In all LUS, SMBC was ranged 1 to 4 percent of soil-OC (Sparling, 1992 and Nieder *et al.* 2008). Ratios of microbial properties are generally useful tool for assessing the microbe's eco-physiology revealing the relation between microbes physiology function with environment (Anderson 2003). The qCO_2 or also known as specific respiration represents soil respiration CO_2 released and SMBC in unit time. In experiment found lower qCO_2 and soil respiration under agro-forestry LUS and sugarcane LUS were recorded showing altered substrate and quality as observed mostly easily soil carbon oxidizable fraction. While, rice wheat-LUS, maize wheat-LUS, and the uncultivated LUS soilcontains more recalcitrant soil-OC fraction resulting higher qCO_2 due to energetically less efficiency of soil microbial population (Anderson 2003). The value qCO_2 has been observed under stress condition increases because of diversion of energy which otherwise might be used for growth of microbial population and microbial reproduction (Odum 1985).

Daniel *et al*. (2019) reported soil proteins (ACE) are one of the indicators being used to assess soil biological health. Soil protein ACE is generally related to supply of nitrogen available to plants upon mineralization. The study was conducted assess correlation between (ACE) soil protein with (potential-net-N-mineralization) in at fifty sevensites of California and found total-N in soilvariedwithin 0.65 and 12.5 g kg^{-1}. ACE-soil-protein varied from 1 to 45.20 g kg^{-1}. Also observed correlation with soil-protein and (potential-net-N-mineralization) was observed positive but ACE-protein results suggest that soil ACE protein was not good indicator of soil potential-net-N-mineralization compared tosoil total-nitrogen, may be due to some interference created by co-extracted humic matter during ACE-protein analysis.

Soil is considered as basis of agriculture system andany un-sustainable activity leads to soil degradation (FAO 2011). World-wide due to growing concern about soil has led more importance to soil quality also soil health research (Doran and Zeiss 2000). Soil health is assessments of soil chemical-physical-biological prevailing condition of soil.

Nitrogen considered major nutrient needed by plants for growth and development and N-availability in soil is dependent on nitrogen mineralisation processes. Plant uptake nitrogen mainly in form of nitrate and ammonium form which is often low when related to total-nitrogen in soil (Bronson 2008), to increase nitrogen availability nitrogen mineralisation can be enhanced (Osterholz *et al.* 2017). The extra-cellular enzymes depolymerises soil protein into small peptide and free amino-acids converting into mineral nitrogen but the process is often slow and limiting breakdown of organic matter (Schimel and Bennett 2004). Organic N forms are mineralised by microbes which releases mineral nitrogen making it available to plants. Potential-N-mineralisation estimated in laboratory by incubating soil taking weeks to month's time Stanford and Smith (1972) and Jarvis *et al.* (1996). There is need of rapid method of evaluating N-mineralisation Vigil *et al.* (2002). In soil, protein matter comprise organic pool of nitrogen including amino-acid-N which constitutes around 30- 45 percent of the total-N-hydrolysates (Stevenson 1982). Other organic nitrogen fractions are amino sugar and the heterocyclic-N-compound, Schulten and Schnitzer (1998). Soil protein related to capability of the soil to mineralise organic-nitrogen making it available to plants (Moebius-Clune *et al*. 2016).

Wright and Upadhyaya (1996) started methodology to extract soil glomalin by autoclaving soil in 20 mM sodium citrate having *p*H 7 for 30.0 minutes Moebius-Clune *et al.* (2016) and Hurisso *et al.* (2018) then quantifying proteins by Bradford method (Bradford 1976). This procedure was widely used in scientific research and was named different terms, initially termed as "easily extractableglomalin," then renamed "glomalin-related soil fractions"as along with glomalin, protein from other organic sources also gets extracted (Rosier *et al.* 2006; Rillig 2004; Hurisso *et al.* 2018). Hurisso *et al.* (2018) developed methodology extracted protein as autoclave-citrate-extractable-ACE-protein.

Several researches observed positive correlations between soil protein and soil aggregates (Wright and Upadhyaya, 1996; Wright *et al.* 1999; Fine *et al.* 2017; Rillig *et al.* 2002). Soil protein content also observed to be influences by LUS's Halvorson and Gonzalez, (2006) crop management (Wright *et al.* 1999). The relationship ofsoil protein with (potential-net-N-mineralization) yet not established (Hurisso *et al.* 2018). Also found soil protein methodology also extracts humic matter, lipid substances and some inorganic matter Gillespie *et al.* (2011).

Tunsisa et *al*. (2018) reported that the procedure used to measure “glomalin,” was later termed as soil protein as it extractant protein comes from a wide range sources along with glomalin. Therefore the fraction of proteins extract by process should be seen mainly as soil-health-indicator reflecting primary fraction of organic-N and soas also potentially-available-organic nitrogen.

Caitlin *et al*. (2020) observed ACE protein varied 0.73 to 96 mg g^{-1} soil in hay system and varied 0.188 to 532 mg g^{-1} soil in crop system. The hay system more protein in 0 to 5 cm soil layer compared to crop system but observed similar protein in deeper soil depths. Forest LUS had more protein 0 to 5 and 5 to 10 cm soil depths. Roper *et al*. (2017), estimated soil protein value in Carolina and observed no significant variation among different tillage management compared to scores of the soil health with the protein of soil. Hurisso *et al.* (2018b) proposed the use of ACE-soil protein as a indicature of potentially-mineralizable-nitrogenof soil.

Mechanisms of SOC and soil organic-N stabilization are important in climate change scenario and the soil organic-N role in influencing plant productivity. The global soil organic-N pool is around 10^{17} g while 10^{23} g in lithosphere and 10^{21} g in atmosphere (Paul and Clark 1996).

In soil mean residence time of nitrogen N is around50 years while 26 years for soil C (Schlesinger 1991). This difference is due to mainly reprocessing of nitrogen by soil-microbes, the mechanisms may also differ that stabilize nitrogen consisting organic compounds from the stabilize non-nitrogen containing organic compounds. Among the various SOM components, proteins comprises largest fraction of organic nitrogen in soil (Nannipieri and Paul 2009).

2.6 Effect of land use systems on soil quality

Soil Quality Indices assessment is necessary for sustainable LU management for enhancing soil quality to meet demands for food, fiber & fuels Cherubin *et al.* (2016). Soil quality may be defined, capacity of particular soil to function, within the natural or managed ecosystem, sustaining biological productivity and maintaining or enhancing water and air quality thus supporting health and habitation (Karlen *et al.* 1997). Soil quality tool that provide useful information observe adverse/positive fluctuation in physico-chemical and soil biological characteristics induced by different LUS’s and suggesting sustainable land management (McGrath and Zhang 2003) and analysis of soil nutrient importance Chen *et al.* (2013). SQI is decision making tools which efficiently combine information for multi objective of decision-making (Karlen and Stott 1994).

Traditionally soil quality study focused on nutrient capacity of soil and productivity from agricultural land. But now researchers feels that quality of soil not be analysed directly but can be interpreted from various SQ attributes or indicators which depends on external factors like soil management and LUS, ecosystem interaction and also political and socio-economic priorities (Doran *et al.* 1996). These soil quality indicators or soil attributes helps in monitor biomass accumulation, water-use efficiency and soil aeration play in important role for plant growth, water storage flow, protect the soil and environment from hazardous compounds (Larson and Pierce 1991).

Chaudhury *et al.* (2005) suggested for alluvial soils, total soil nitrogen, available phosphorus, DHA and MWD are key indicators. Karlen *et al.* (1992) emphasized on soil biological parameters like SMBC and soil respiration important quality indicators of SQ assessing long duration cropping system and LU managements. Soil quality determination is objective and location specific so indicators vary from site to site (Shukla *et al.* 2006).

Andrews *et al.* (2002) assessed in California different methods of SQI to select best management system for vegetable crop production systems. The alternative processes for soil quality compared were the (EO) expert opinion and PCA techniques for (MDS) of sensitive indicators. The linear and non linear scoring process used for indicator normalization while additive index and weighted additive index and also decision support system (DSS) used for the final SQI calculation. The organic system found significantly more SQI score compared to lower organic input in conventional practice treatment in whole indexing combinations. Comprehensive multivariate method also exhibited similar observation in all indexing combination. It reveals that wisely picked minimum number of soil indicators used in non-linearly score index will deliver the desired information for identification of best management practice.

Guang-Lu and Xiao-Ming (2010) observed LUC from cropland to forest LUS after 23 years of agriculture and into orchard LU after 7 years of agriculture helped soil structure recover by increased soil macro aggregates 9 and 10%, respectively and improved soil soil quality scores.

Mandal *et al*. (2010) evaluated soil quality in Himalayan region considering five soil functions influenced by landscape and LUS's watershed. The proportional change observed in soil functions in terraced croplands at each landscapes position when compared to reference site. Among the upper slope region, maximum change found in habitats of flora & fauna -35% then soil moisture conservation -27.4%, supply of SOM and soil nutrient cycling -24.4%, soil and air infiltration and water -23.8% and the lowest observed in resistance to erosion -9.0%. While in mid slope area maximum change detected in SOM supply and soil nutrient cycling -25.9% followed by habitat of flora-fauna -22.4% and moisture conservation in soil -16.3%. The proportional change observed in soil function lowest valley by -3% habitat of flora & fauna and -13% for OM and soil nutrient cycling.

Mandal *et al.* (2013) determined the SQI to assess impact of LUS's on soil sustainability north western Himalayas and observed significant difference in soil parameters under various LUS. The highest SQI was recorded in sal forest soils 337 and lowest in cropland soils 257, showing forest LUS superior in sustaining better SQI compared to other LUS's.

Lima *et al.* (2013) studied the various indicator sets to develop SQI in 3 rice systems with 4 textural classes and reported all set of 29 indicators resulted better development of SQI, moreover the MDS of indicators showed same results among different rice systems, soil functions and soil texture.

Rahmanipour *et al.* (2014) observed two different methods of determining SQI by including total data-set (TDS) and other by minimum data-set (MDS) through PCA. The better estimation of SQI was obtained by (IQI) integrated quality index compared to the (NQI) nemoro quality index. It revealed that (IQI) derived through MDS more appropriate method in developing SQI while assessing effects of LUS and management on soil quality. MDS procedure also reduced soil analysis cost by limiting lesser number of parameters in indicator data set.

Gelaw *et al*. (2015) studied SQIs under various LUS's and reported agroforestry LUS observed highest score SQI 0.58, irrigated crop system 0.51 and rainfed cultivation LUS 0.47. The integrated SQI was influenced mainly by SOC 26.4 percent, WSA 20%, total porosity 16%, soil total-N 11.2%, SMBC 6.4% percent, and CEC 6.4%. All these 6 soil quality indicators contributed 80 % of SQI.

Nakajima *et al.* (2015) assessed the SQI using scoring function analysis process to observe the consequence of various tillage system and also drainage systems on SQI. The study revealed, saturated hydraulic conductivity, physical properties of soil and SOC compared to other chemical soil properties found most significant indicator for SQI. SQI differed from 0.69 to 0.71 in conventional tillage and no-till and while 0.69 to 0.70 in drainage system and in no-drainage systems but no statistical variation observed between treatments. However, SQIs found significant correlation corn yield (R = 0.62) which suggest SQI is most effective tool for assessing agronomic efficiency.

Kalu *et al.* (2015) determined SQIs for different LUS's in Nepal. The highest SQI's observed in protected forest LUS 0.95 then community forest LU 0.91, pasture LU 0.88, *khet* LU 0.81, and the lowest found in *bari* LUS 0.79. The available nutrient phosphorus and SOC was sensitive SQ indicators which contributed in significant difference in determining SQI's among different LUS's. In forest LUS leads to better SQ whereas in more anthropogenic disturbed activity agricultural LUS deteriorates SQI.

Cherubin *et al.* (2016) evaluated the SQI under prevailing LUC in southern Brazil through (SMAF) Soil Management Assessment Framework and reported, native vegetation LUS had more SQI 0.87 than sugarcane LU 0.74 and pasture LU 0.70. The SQI determined by SMAF significantly correlated with SOC stocks.

Kaushal *et al.* (2016) assessed the SQI in *Grewia optiva* based agroforestry LUS and found highest SQI observed in solo grewia (0.50) then grewia+ finger millet 0.47, grewia+ barn yard millet 0.47 while lowest in fallow LUS 0.32.

Vasu *et al.* (2016) determined SQIs by two methods using soil profile data of soil series in Deccan plateau of India and observed that the weighted method determining SQI using (PCA) and (EO) expert opinion found well correlated to yield of field crop. While SQI derived by EO weighted index process was found comparable both for surface 0-15 cm and soil control sections 0-100 cm soil layer and observed reliable relationship with crop yield that represents superior performance over PCA. Considering soil subsurface properties with surface soil properties in assessing SQI helps to establish a more relationship between SQI and various soil function and management objectives.

Cherubin *et al.* (2017) studied SQI in Brazilian oxisols using (SMAF) soil management assessment framework found conversion process of natural vegetation into agricultural LUS's decreases SQ due to deterioration in soil-physical-biological characteristics. Results showed SMAF best tool for evaluating SQ changes in different LUS's. The SMAF SQI sums up individual indicator scores in comprehensible number which help in assesing the whole soil functioning in a specific LUS. Biswas *et al.* (2017) assessed SQI's and select the sensitive indicators of the soilof rice-rice LUS under Indo-Gangetic plain of India. The study revealed highest SQI was observed in inceptisol value ranged 0.66 to 0.89 than Entisols value ranged 0.23 to 0.76 while in Alfisols value ranged 0.37 to 0.60. Under SQI study 37 parameters assessed and found most sensitive key indicators DTPA Zn, soil BD, β-glucosidase and also soil urease activity in inceptisols while soil DHA activity, soil

WSA, TOC, soil *p*H observed with Entisols and oxidizable SOC, *β*-glucosidase, soil WSA, and also mineralizable carbon found with Alfisols. Observed SQI in the upper and the lower critical limits maximum in inceptisols 0.85 and 0.56 then entisols 0.65 and 0.23 and alfisols 0.56 and 0.37.

Beuschel *et al.* (2018) observed higher SOC, SMBC and related activity were recorded in tree rows when compared from intercropped areas in 0-5 cm soil depth found higher in poplar tree LU than annual crop plants. A significant enhancement in the soil quality indices observed under tree area rows after 5 to 8 years plantation in arable LU alley cropping LUS. Higher SQI recorded in top soil depth and declined with soil depth.

Ghimire *et al.* (2018) evaluated SQI's under different LUS's in Nepal and observed highest SQI was in the forest LUS (0.82), followed declining trend *Bari* (0.66), *Khet* (0.64) and lowest in degraded LUS (0.40). SOM and total nitrogen play important role in developing SQIs under different LUS whereas, higher chemical fertilizers and continuous prolong tillage practices attribute inferior SQI in agricultural LUS. Phosphatic fertilizer enhances the efficiency of no-till system improving soil quality indices (Souza *et al.* 2016).

Ebabu *et al.* (2020) observed that the integrated LU management with proper most effective way for sustaining and restoring soil quality and sustainable through enhancing microbial biomass, soil aggregate stability, soil CO_2 efflux, and diverse microbial population in soil.

2.7 Tree biomass and carbon stock

Naik *et al*. (2019) conducted study on biomass carbon stock accumulation in mango orchard in age 2 to 10 year old plantation. Among all models, Gompertz total estimated biomass differed from 00.53 to 10.50 Mg ha^{-1} and mean annual increment value ranged 0.26 to 1 Mg ha^{-1} in two to ten year old mango orchard. The carbon mitigation potential observed in ten year mango LUS was recorded highest 3.0 Mg ha^{-1} while CO_2 mitigation of 11.04 Mg ha^{-1} in climatic condition hot and sub-humid.

Mango (*Mangifera indica* L.*)* is one of the most common horticulture LUS commonly grown in India also called as "King of fruits". Mango orchard may be used for carbon sequestration into long lived pool, schemes like Clean Development Mechanisms (CDM) by estimating total biomass. Mango has also potential economic value by providing livelihood security by understanding its carbon storage potential. Additionally farmers can also earn from carbon market schemes such as REDD+.

Chisanga *et al.* (2018) estimated tree biomass C-stock in different LUS's is important in curbing global climatic change. In high-altitude and dry temperate LUS's three altitudinal was selected in Himachal Pradesh, India A1, 1900–2170 MSL; A2, 2170–2440 MSL and third A3, 2440–2710 MS and six LUS's *viz*. agriculture LU, horticulture, agri-horticulture LU, agri-horti-silviculture, silvipasture LU, and barren LUS Results revealed that maximum mean AGB 84.65 t ha^{-1} and BGB 19.50 t ha^{-1} while total biomass estimated 104.10 t ha^{-1} was observed in silvipasture LUS's. Total biomass produced in different LUS's followed trend silvipasture then agri-horti-silviculture, agrihorticultur, horticulture, agriculture and last barren LUS, respectively. Highest SOC 1.41% was observed in silvipasture LUS at par horticulture LU. SOC, irrespective of LU increased with the increased altitude and decreased when soil depth increased. Highest C-density 155.77 t ha^{-1} was observed in 0 to 100 cm soil depth agri-horticulture LUS. The trend of C-density under different LUS's was agrihorticulture followed by agri-horti-silviculture, silvipasture, horticulture, agriculture, barren LU.

Rathore *et al.* (2021) developed best fit exponential model predictive estimation model for mango standing C-stocks contained in biomass and entire tree carbon. Biomass accumulation with mango alone 1.4–97.7 t ha^{-1}, intercrops alone 4.9–2.6 t ha^{-1} and mango with intercrops1.4–100.3 t ha^{-1}. It was observed stored carbon ranged 0.70 - 39.7 Mg ha^{-1}, emitted carbon 0.00–8.50 Mg ha^{-1}, mitigated carbon 0.70–31.2 Mg ha^{-1} and total carbon stock 0.70–48.20 Mg ha^{-1} in different selected LUS's in humid climate of Indian Sub-Himalayas.

Kanime *et al*. (2013) estimated tree biomass, carbon storage and CO_2 mitigation potential *Mangifera indica, Eucalyptus tereticornis, Litchi chinensis, Dalbergia sissoo, Populus deltoides* and *Prunus salicina*. The highest total biomass 94.8 Mg ha^{-1} was observed in 10 year age *D. sissoo* plantation, followed by 8-year-old *P. deltoids* plantation 63.0 Mg/ha. C-stocks varied from 4.51 Mg/ha in an 8 year age *P. deltoides* plantation to 43.39 Mg ha^{-1} in *D. sissoo* LU. The C-sequestration rate in *P. deltoids* LUS was 2.75 and 0.43 Mg ha^{-1} year^{-1}. Eucalyptus LU sequestered 0.84 Mg ha^{-1} year^{-1} and *D. Sissoo* LUS sequestered 2.73 Mg ha^{-1} year^{-1}. Among horticulture LU Kanime *et al.* (2013) also observed SOC in mango LUS higher 1.12% while litchi LU 1.03, while bulk density 1.33 g cm^{-3} and soil *p*H 7.4 remained same in both LUS. Tree biomass observed mango LUS (AGB- 51.12 + BGB-9.73 = total biomass -60.85 Mg ha^{-1}) while in litchi LUS (AGB- 14.77 + BGB- 4.24 = total biomass - 18.94 Mg ha^{-1}). Also total carbon stock stored in tree mango LUS 27.02 Mg ha^{-1} while litchi LUS observed 8.42 Mg ha^{-1}.

Sarkar, S and Das, DK . (2022). Conducted experiment on tree based agroforestry systems (AFS) and assessed biomass and carbon stock of (*Anthocephalus cadamba* Miq.) agri-silvicultural, (*Simarouba glauca* DC) agri-silvicultural, (*Litchi chinensis* Sonn.) agri-horticultural system, and one open system (without trees). In was observed that simarouba havin higher long-lived C storage over kadamb trees which were higher long lived carbon storage over litchi trees. Long-lived C stock in tree biomass varied from 1.69 q tree^{-1} in simarouba trees to 1.13 q tree^{-1} in litchi trees.Simarouba trees recorded higher CO_2 mitigation over kadamb trees which were higher CO_2 mitigation over litchi trees. It was also observed CO_2 mitigation by trees varied from 15.13 q tree^{-1} by simarouba trees to 12.11 q tree^{-1} by litchi trees.

* * *

CHAPTER – III

MATERIALS AND METHODS

3. MATERIALS AND METHODS

In the present era, global warming vagaries being faced by world today this is mainly due to elevated level of CO_2 in atmosphere. It is pertinent to understand the effect of different prevailing LUS's on soil carbon and soil quality study which will help policy makers and planners in mitigating CO_2 emission.With this view study undertaken entitled "**Assessing carbon sequestration potential and Soil Quality Index (SQI) under horticulture-based land-use systems in Agro-Climatic Zone-I of Bihar"** with relevant objectives. In this chapter, the various methods adopted to achieve objective are expressed in following sub-headings.

3.1 Selection of representative land-use systems

A survey based approach was undertaken along with participatory tools like observations at different location, transect walk, formal and informal group discussion with farmers, secondary data, reports reviews and opinion from experts scientists was used to select the dominant LUS's in the Agro-Climatic Zone-I of Bihar, India. From the representative LU site primary data on cultivation, planting history, location *etc.* were recorded. Based on the preliminary survey and views of experts, five representative prevailing LUS's in different districts of Agro-Climatic Zone-I of Bihar were selected for the study. The selected representative dominant LUS's descriptions are as follows:

Selected land-use-system:

i. Litchi solo
ii. Litchi intercrop
iii. Mango solo plantation
iv. Rice-wheat
v. Uncultivated

3.1.1 Litchi solo land use:

The litchi (*Litchi chinensis* Sonn.) solo plantation LUS was selected which have attained senior adult bearing stage of growth *i.e.* more than 15 years and above age. The planting distance was observed to be 8 X 8 meter distance which is most commonly followed and recommended for litchi orchard establishment.

Fig 3.1: Agro-Climatic Zone –I of Bihar

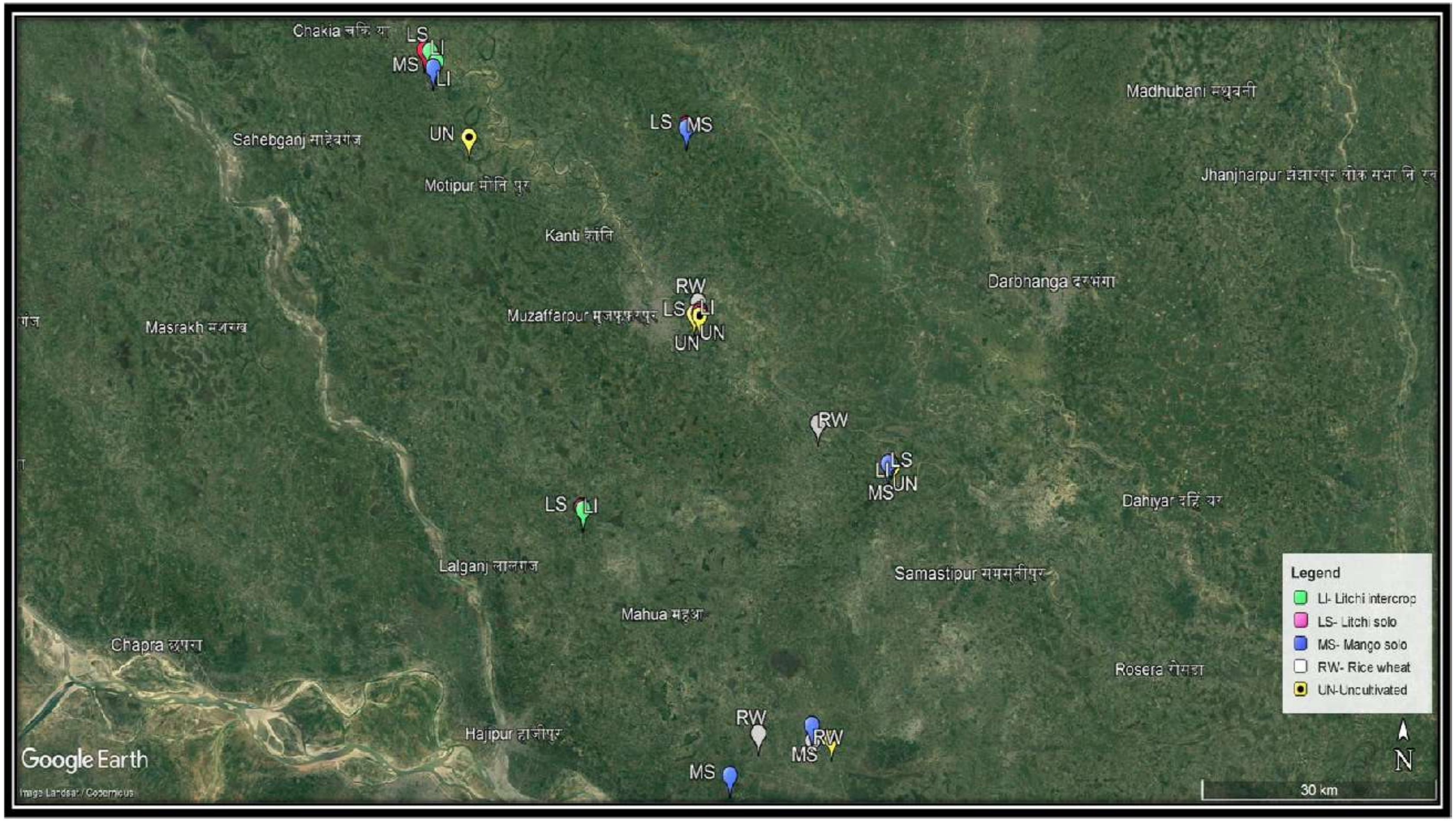


Fig 3.2 GPS location of selected LUS's in ACZ-I of Bihar

3.1.2 Litchi intercrop land use:

Litchi intercrop orchard was also selected where the trees attained 15 years old age and above having planting distance of 8 X 8 m The main intercrops followed by the farmers are turmeric (*Curcuma domestica*) and in some location elephant foot yam (*Amorphophallus campanulatus*) and Arbi (*Colocasia esculenta*) were followed.

3.1.3 Mango solo land use:

Mango *(Mangifira indica)* solo LU was selected at different location having planting distance of 10 X 10 m which have attained senior adult bearing stage of growth *i.e.* more than fifteen years of age.

3.1.4 Rice-wheat land use:

Rice-wheat LUS is one of the most dominant cropping system being followed in Agro-Climatic Zone-I of Bihar. Area where continuous rice-wheat cropping system was being followed for more than 15 years was selected as representative LU.

3.1.5 Uncultivated land use:

The uncultivated LU selected were those land in which no soil disturbance and no inputs applied externally however natural vegetations and volunteer grass species grow. These uncultivated LUs was selected which remained undisturbed for more than 15 years.

3.2 Climate and weather conditions

The Agro-Climatic Zone–I of Bihar lies in middle Gangetic plain region, (Agro-ecoregion 13.1) characterised by sub-region hot dry to moist sub-humid transitional zone; soil- loamy alluvium–derived soils; available water capacity (AWC)-low to medium and length of growing period – 180 to 210 days. ACZ-I North alluvial plain lies in north of river Ganga and are flood prone area of Bihar.

Bihar being situated in between 25º to 27º N latitude, mostly sub-tropical climatic condition prevails in these regions.

The climate of Bihar is characterized by mainly three distinct seasons (i) winter- cool day, (ii) summer-hot day and (iii) monsoon rainy- warm wet season. Winter season extends from October to February with low temperature ranges from 7 ºC to 16 ºC and experiencing very little rain, mostly clear sky and relatively low humidity. Summer-hot dry season extends from March to Mid June experiencing temperatures increases upto 44 - 45 ºC having low humidity. Monsoon warm wet season is the period from mid-June to September month. During this period temperatures varied from 24 to 35 ºC having cloudy sky and relatively high humidity. During winter, daily temperature decreases 7 to 8 ºC during December – January in north Bihar plains. Agro- climatic rainfall zone-I receives mean annual total rainfall 1344.35 mm, while individually season wise rainfall distribution observed that during monsoon 1077.3 mm rainfall, in autumn October-November months receives 35.15 mm.

3.3 Physiography and soil

Agro- Climatic Zone I: The lands of ACZ-I are alluvial plains and are slopy towards the south east direction having very low gradient almost near flatness of the landscape which result vast water logged areas observed in Saran, Vaishali and Samastipur districts gets flooded during rains. The north eastern area of this zone is "Don hills valleys" glacial hills and valley. Except northern area and western area the entire ACZ-I is under the effect of rivers like Gandak, Burhi Gandak and Ghaghra and soils under these rivers are mostly calcareous as these rivers originate from lime rich foothills of the Himalayas.

Land use change

In ACZ-I, during the period 2003 to 2013, the study observed largest LUC of 36.82% in current fallow category while in whole Bihar the current fallow LUC observed to be 50.72% which is mainly due to climate change effect (Sinha *et al.* 2016).

3.4 Agriculture cropping pattern

The most commonly followed agriculture cropping pattern is rice – wheat followed by rice – mustard, rice – sweet potato, rice – maize (*rabi*), maize – wheat, maize –sweet potato, maize – mustard, rice – lentil, rice-linseed.

Horticulture

Bihar has favourable condition for growing almost all the horticultural crops. The major fruit plantation grown in Bihar is mainly mango, litchi, guava, banana *etc*.

3.5 Soil sampling

Soil sampling was carried out at different location selected as representative LU site in different districts of ACZ-I of Bihar as per availability of LUS's. Soil sample were collected from different sites which occupied minimum area of 0.5 ha during spring season. Composite soil sampling was done from 5 to 10 points as per observed homogeneity of LUS's. The sampling sites at different location for each LUS were considered as replication. The composite soil samples collected randomly from five different LUS's with four soil depths, replicated 5 times for each LUS. Total 100 composite soil samples collected from five LUS's, four soil depth 0-15, 15-30, 30-45 and 45-60 cm and five replications. The composit soil samples were air dried in shade. Soil sample was processed by grinding with mortar & pestle and sieved through 2 mm sieve and finally labelled for laboratory analysis. Another set of soil sample was also collected and stored at 4 °C for estimating soil biological properties.

3.6 Soil analysis

The soil samples collected from different LUS's and was analyzed in laboratory for various soil physical, chemical and biological parameters with standard scientific methods as described below:

Table 3.1: Soil parameters and standard analytical methods followed

S.No.	Soil parameters	Standard procedure	Reference
1	Soil reaction (*p*H)	Using pH meter in (1: 2: :soil: water suspension)	Richards (1954)
2	Electrical conductivity	Conductivity meter in (1: 2: :soil: water suspension)	Richards (1954)
3	Available phosphorus	Olsen's method (0.5 M $NaHCO_3$, *p*H 8.5)	Olsen *et al*. (1954)
4	Available potassium	Neutral normal ammonium acetate extraction using flame photometry	Hanway and Heidal (1952)
5	Available Zn, Fe, Mn, and Cu	DTPA extraction method using atomic absorption spectrophotometer	Lindsay and Norvell (1978)
6	Soil organic carbon	Walkley and Black wet digestion method	Walkley and Black (1934)
7	Total organic carbon	Wet-digestion method using potassium dichromate and acid digestion mixture	Snyder and Trofymow (1984)
8	Oxidizable organic carbon fractions	Modified Walkley and black methods by using different concentrations of H_2SO_4	Chan *et al*. (2001)
9	Soil microbial biomass carbon	Chloroform fumigation-extraction method	Vance *et al.* (1987)
10	Available nitrogen	Alkaline permanganate method	Subbiah and Asija (1956)
11	Mineral –N (NH_4^+-N, NO_3^-- N)	Kjeldahl method	Keeney and Nelson (1982)
12	Soil total nitrogen	Kjeldahl method	Kirk P L (1950)
13	Soil microbial biomass nitrogen	Chloroform fumigation-extraction method	Brookes *et al.* (1985)
14	Dehydrogenase activity	Colorimetric determination of TPF (Tri-phenylformazon)	Casida *et al.* (1964)
15	Soil respiration (CO_2 efflux)	Incubation and Alkali Trap	Zibilske (1994)
16	Bulk density	Soil core method	Singh (1980)

S.No.	Soil parameters	Standard procedure	Reference
17	Soil texture	International pipette method	Piper (1960)
18	Soil penetration resistance (*Pr*)	Soil Cone penetrometer	Duiker (2002)
19	Aggregate size distribution	Wet sieving of aggregate	Yoder (1936)
20	Soil protein	Autoclaved Citrate Extractable (ACE)	Wright *et al*. (1996)

3.6.1 Soil texture (particle size distribution)

The soil texture was determined using international pipette method (Piper 1960). First, soil samples treated with hydrogen peroxide 6% for removing organic carbon and then treated with HCl 2% for removing $CaCO_3$ present in the soil. The sodium hexa-metaphosphate (5%) was used to dispers soil seperates. The sand separates were isolated by wet sieving of soil samples through 70-mesh size sieve. After sand separation, volume of suspension of soil and water was made upto one litre by distilled water addition in sedimentation cylinder. The plunger used for thoroughly mixing suspension and 25 ml of soil and water suspension pipetted out at 10 cm depth for silt plus clay and clay according to their settling time and observation recorded along with temperature. The weights of silt + clay and clay recorded after sample drying at 105 ºC for 24 to 48 hrs in oven. The USDA method of textural triangle used to estimate texture class.

3.6.2 Bulk density

Soil core method was used in which cylindrical core sampler was hammered depth wise and soil sample was collected at 15 cm depth interval up to 60 cm depth. Collected soil samples then dried at 105 ºC for 48 hours in oven. Mass of oven dry soil was determined by subtracting weight of core from soil weight. Volume of the core cylinder was calculated by measuring diameter and its height. Bulk density calculated by soil mass upon volume and the BD expressed in Mg m^{-3} (Singh 1980).

3.6.3 Surface hardness:

The surface hardness or penetration resistance was recorded in different LUS by using cone penetrometer instrument whose conical top was pushed into desired soil depth and resistance in penetration got recorded digitally (Duiker 2002).

3.6.4 Mean weight diameter

The clods larger than 8 mm were broken by hand along the natural cleavage. The aggregates of different sizes were separated through wet-sieving process (Yoder 1936). The aggregate retained in each sieve during wet sieving were transferred into Buchner funnel with filter paper. The aggregates with filter paper were oven-dried at 65 ºC then the weight was recorded. The meanweight diameter (MWD) was calculated as an index of aggregation (Kemper and Roseneau 1986) by formula:

$MWD = \Sigma$ Wi Xi

Where, Xi: Arithmetic mean diameter of fraction (mm)

Wi: Proportion of the total weight of sample in the fraction i

3.6.5 Soil reaction (*p*H)

The processed soil sample used for pH determination with 1:2::soil:water suspension using an systronic micro-processor based digital *p*H meter (Rechards 1954).

3.6.6 The electrical conductivity (EC)

The processed soil sample with 1:2::soil:water suspension was prepared and electrical conductivity was recorded in supernatant liquid using conductivity bridge, expressed in unit dS m^{-1} and temperature was also recorded.

3.6.7 Available nutrient

The available nitrogen was determined by alkaline permanganate oxidation process with semi-automatic Kjeldahl distillation unit (Subbiah and Asija 1956). Available phosphorus measured by extraction of soil samples using 0.5 M $NaHCO_3$ at *p*H 8.5 and colour develop blue using reagent ascorbic acid, then finally reading taken in spectrophotometer (Olsen *et al.* 1954). Available potassium was estimated by soil sample extraction with normal neutral ammonium acetate and reading observed in flame photometer (Hanway and Heidal 1952). The available micronutrients zinc, iron, manganese, copper concentration in soil was determined by micronutrient extraction using DTPA-$CaCl_2$-TEA extractant and reading was taken in (AAS) Atomic Absorption Spectrophotometer (Lindsay and Norvell 1978).

3.6.8 Soil respiration (CO_2 efflux)

Soil respiration value indirectly signifies microbial population which releases CO_2 during metabolic activity and was estimated by trapping CO_2 as adapted by Zibilske (1994). Air dried processed soil 100 g was taken in conical flask and water was added to maintain 50% of WHC. A trap of glass beaker filled with 20 ml of 0.1 N KOH was hung inside the flask. The conical flak was sealed with cork and paraffin wax tape and kept in BOD incubator for incubation for 5 days at 28 ºC. After five days of incubation KOH solution was transferred in conical flask and immediately 5 ml of 3 N $BaCl_2$ added to stop further CO_2

absorption. Titration was carried out with 0.1 N standard HCl using 3-4 drops of phenolphthalein indicator.

3.6.9 Soil protein

Soil protein constitutes fractional pool of soil organic nitrogen present in soil. Autoclaved Citrate Extractable (ACE) relates to mineralizable nitrogen available for plant uptake. Wright *et al*. (1996) developed method of ACE protein, at first, 3.00 g of soil sample taken and added 24.00 ml of sodium citrate solution of 20 mM with *p*H 7.0, then shaked on shaker to break soil aggregates for 5 min. The tubes were autoclaved at 121 °C for 30 min and then cooled thereafter centrifuged at 5000- 10,000 rpm. Bradford protein assay used in assessing soil protein and BSA (bovine serum albumin) standard were used in analyzing soil protein. The BSA standard and soil protein absorbance were measured at 595 nm in Eppendorf Bio Spectrometer.

3.6.10 Dehydrogenase activity

The soil microbial DHA activity was estimated by using process of reduction of tri-phenyl tetrazolium chloride (TTC) to tri-phenyl formazan (TPF) as described by Casida *et al.* (1964) and Klein *et al.* (1971). Air-dried soil samples 1 gram placed into screw-capped tube and 0.2 ml of 3% TTC and 0.5 ml of 1 % glucose was added. The content mixed with slight tapping to remove air bubbles. The glass tubes then incubated at 28 ^{o}C for 24 hours in BOD incubator. After the incubation period, the caps glass tube was slowly removed and 10 ml of methanol was added. Then, for the glass tube was shaken for one minute and kept in dark for six hours. The colour intensity developed was measured at 485 nm by calorimetrically using a spectrophotometer. The soil microbial DHA was finally expressed in µg TPF g^{-1}soil 24 h^{-1}.

3.6.11 Metabolic Quotient (qCO_2)

The metabolic quotient (qCO_2) of different LUS's and at various soil depths was determined by the value obtained from ratio of CO_2 efflux upon corresponding SMBC.

3.6.12 Microbial Quotient (MQ)

Microbial quotient is the ratio of SMBC upon total SOC or simply in other word it is percentage of SMBC of total SOC.

3.6.13 Soil organic carbon pools

a) Soil organic carbon

The collected soil sample was processed and passed through 2.0 mm sieve and was used in determined of SOC by wet digestion method of Walkley and Black (1934).

b) Total soil organic carbon

The Walkley and Black (1934) modified process of wet digestion by external heating proposed by Snyder and Trofymow (1984) gives measure of TOC. Soil 0.5 g was taken in conical flask and added 5 ml one normal $K_2Cr_2O_7$ and 5 ml conc. H_2SO_4. The mixture was digested by heating in oven (140 ± 5) °C for one hour, during heating funnel was placed on flask for refluxing digestion mixture during heating. The final digests after cooling added 20 mL distilled water. Titration was done using diphenylamine as indicator 0.5 normal FAS.

c) Microbial biomass carbon

The SMBC was estimated by chloroform fumigation and incubation method Vance *et al.* (1987). In this process, 10 g of soil taken in 100 ml beakers and then fumigated with chloroform in a vaccum desiccator. Incubation was done for 24 hours, and then extraction was done with of 0.5 M 40 ml potassium sulphate (K_2SO_4) on rotary shaker and filtered with whatman no.1. The 8 ml filtered extract digested with 2 ml 0.4 N $K_2Cr_2O_7$, 70 mg HgO and 15 ml acid mixture of conc. H_2SO_4 (two parts) and H_3PO_4 (one part) on hot plate at 150 ^{o}C for 30 min and then cooled. In cooled mixture 20-25 ml distilled water added and transferred into flask then 3 to 4 drops of ferroin indicator added and titrated with 0.033 N FAS recorded. The same process was repeated in non-fumigated soil samples also. The difference in SMBC in fumigated and unfumigated soil sample was divided by 0.45 considering extraction efficiency of the process.

d) Oxidizable organic carbon fractions

Chan *et al.* (2001) categorised different fraction of SOC according to their oxidizing ability into very labile (VLc), labile (Lc), less labile (LLc) and non labile carbon (NLc). All four fractions of TOC under estimated through modified Walkley and Black method which involved the oxidation of soil TOC by different concentration of H_2SO_4 *i.e.* 12 N, 18 N and 24 N.

Fraction I (very labile; **VLc**) :	SOC oxidizable under 12 N H_2SO_4
Fraction II (labile; **Lc**) :	Difference between oxidizable SOC between 18 N and 12 N H_2SO_4
Fraction III (less labile; **LLc**) :	Difference between oxidizable SOC 24 N and 18 N H_2SO_4
Fraction IV (non-labile; **NLc**) :	Difference between oxidizable SOC 24 N H_2SO_4 and TOC

3.6.14 Soil nitrogen pools

a) Total nitrogen

Total nitrogen soil was estimated by digestion and distillation method (Kirk 1950). In this method, 1 g of soil sample taken into 250 ml digestion cum distillation tube and added 10 ml digestion mixture of conc. sulphuric acid and selenium dioxide. A little salicylic acid about 1g added. Digestion was carried till light green colour appears and after cooling the digest was distilled in micro-Kjeldhal set with 40 percent NaOH. During distillation evolved ammonia (NH_3) got absorbed in boric acid 4% containing mixed indicator. Then finally distillate was titrated with 0.02 N H_2SO_4.

b) Microbial biomass nitrogen

Soil microbial biomass nitrogen (SMBN) estimation in soil was analyzed by the chloroform fumigation and extraction method (Brookes *et al.* 1985). In this process, 20 g of soil taken in 100 ml beakers and then fumigated with chloroform in a vaccum desiccator. Incubation was done for 24 hours, then extraction was done with of 0.5 M 1:4 (soil: solution ratio) potassium sulphate (K_2SO_4) on rotary shaker and filtered with whatman no.1. After this 40 ml of extractant taken in 250 ml digestion-cum-distillation tube and added 0.1ml of 0.19 M $CuSO_4$ + 10 ml conc. H_2SO_4 and the mixture refluxed for 3 hours. After cooling of mixture 20 ml distilled water got added in tube. The mixture in digestion-cum-distillation tube steam distilled with 40% NaOH and NH_3 evolved got collected in 20 ml of 0.05 M HCl in micro-Kjeldhal unit. About 100 ml distillate collected in distillation process and then titrated with std. 0.05M NaOH. The SMBN was calculated as follows:

$MBN = (ON_f - ON_{uf})/ K_{Ec}$

Here, ON_f and ON_{uf} are organic nitrogen by fumigated and non- fumigated. KEc is efficiency of the method 0.45.

c) Mineral nitrogen

Ammonium nitrogen NH_4^+-N and nitrate nitrogen NO_3^-- N determined by method described by Keeney and Nelson (1982). Soil sample 5 g taken and extraction was done using 50 ml 2 M KCl solution after shaking for 30 minutes. The extract was steam distilled along with activated magnesium oxide in micro-Kjeldhal distillation set. The NH_3 evolved during steam distillation got collected in 20 ml of 2% boric acid *p*H 4.8 containing mixed indicator. Around 100 ml of distillate collected and was titrated with 0.02N H_2SO_4. The NO_3^-N estimated by again distilling same sample with Devarda's alloy 50% Cu, 45% Al, and 5% Zn. The NO_3^-- N evolved in 2nd distillation collected in flask containing 20 ml of boric acid along with mixed indicator. Finally distillate was titrated with 0.02 N H_2SO_4.

3.6.15 Soil organic carbon and nitrogen stocks

Bhattacharya *et al.* (2011) methodology was used in estimating soil carbon and nitrogen stock. In present study TSOC or total nitrogen and bulk density (BD) of different soil depth was used 0-15, 15-30, 30-45, 45-60 cm used for calculating with formula:

TOC stocks in soil (Mg C ha^{-1}) =

$\{\text{Total SOC}/100\} \text{ X BD } (\text{Mg m}^{-3}) \text{ X soil depth (m) X } 10^4 (\text{m}^2 \text{ ha}^{-1})$

Where, TOC stocks at 0-60 cm soil depth Mg C ha^{-1}, Total SOC expressed in % and BD in Mg m^{-3}. Similarly, soil total nitrogen stock Mg N ha^{-1} was also determined.

3.6.16 Development of soil quality indices

Andrews *et al.* (2002), developing SQI mainly consist of following 3 steps: 1) soil indicators selection 2) Normalization or scoring indicator into 0-1 scale, and 3) Integrating transformed indicators into SQI.

a) Indicators selection (Minimum data set)

The analyzed data of all soil properties under different LUS's were subjected to PCA tool which helps in selecting most sensitive soil quality indicators (Andrews *et al.* 2002; Sharma *et al.* 2005). The PCA of all original observations of soil performed by using software SPSS package. The PCs having eigen values ≥1 were selected for most sensitive soil quality indicator (Kaiser, 1960). Within a particular PC, variables having high weightage retained for MDS (minimum data set) of indicators. High weightage defined as variables having absolute values within 10% of the highest factor loading (Wander and Bollero, 1999, Andrews *et al.* 2002). When variable (soil parameter) retained more than one in a single PC, then multivariate correlation coefficients was performed to eliminate redundant variable from minimum data set of indicators (Andrews and Carrol*,* 2001). If the highly weighted factors found not well correlated, then each was considered significant so retained in the minimum data set of indicators. While in between well correlated variables simply highest weighted factors (absolute value) selected for the MDS of soil quality indicators.

b) Indicator transformation into scores (scoring)

After selection of indicators for MDS from various soil variables, then each indicator was first transformed to unit less score which ranged from 0-1, using the linear scoring method. In this process, selected indicators were grouped based considering good or bad soil function. Mainly 3 mathematical algorithm functions used 1. More is better, 2. Less is better and 3. Optimum is better. Optimums are those properties having positive effect to certain level and beyond which effect considered harmful. The score of 1 indicates highest potential function in particular system for which and 0 being lowest.

1. **More is better:** every observation of indicator was divided by maximum observed value from whole data set so that highest observed value gets a score of one.
2. **Less is better:** in particular indicator the lowest observed value from whole data set was divided by each observation so that lowest observed value receives a score of one.
3. **Optimum is better:** in case of optimum indicators are scored like “more is better” up to a threshold value and above threshold values were scored like “less is better” (for example. soil *p*H up to 5.5 to 7.2 scored “more is better” and *p*H more than 7.2 scored “less is better.”

c) Integration of transformed indicators into indices

The final step in soil quality indexing is integration of transformed indicators into indices. The selected indicators (MDS observations) were transformed into unit less values (scored 0-1), a weighted additive index method was used to integrate into SQIs for each LUS’s. In this process the weightage was given to each observation of the MDS variables using the PCA results. In each principal component (PC) the value of variation in dataset was divided by maximum total variation (cumulative) among all PCs selected to get a weightage value under particular PC. Finally SQI was calculated using equation:

Soil Quality Index (SQI) = $\sum_{i=1}^{n} Wi \times Si$

Si-is score of the subscripted indicator, Wi is weightage derived from PCA results. The hypothesis is higher SQI scores means better soil quality and performance of the soil function.

3.6.17 Biophysical measurements of the trees

The different biophysical parameter was recorded in mango and litchi LUS's at different locations.

a) **Height:** Mango and litchi tree height (m) was measured using instrument optical Clinometer (PM-5/360 PC).

b) **Diameter at breast height (DBH) :**

Orchard tree girth was measured using measuring tape at 1.37 meter above tree base. (DBH = Girth/ 3.14).

c) **Crown width (m):**

Orchard tree mango and litchi crown width measured using measuring tape north south and east west directions.

d) **Tree volume :**

Quarter girth formulae was used to estimate volume of orchard tree

Volume = $(\text{Tree Girth}/4)^2 \times$ Height of tree.

Girth of orchard tree measured at 1.37 m above tree base (Sarkar *et al*, 2020).

e) **Aboveground biomass (AGB)**

The biomass accumulated by mango and litchi tree was estimated using formula

ABG= 10 × specific gravity × timber volume.

Where, specific density of mango was 0.45 g cm^3 and for litchi 0.35 g cm^3 (Kanime *et al*. 2013; and Sarkar *et al*, 2020).

f) **Belowground biomass (BGB)**

The orchard below ground biomass observed to be 15% of the above ground biomass

BGB = AGB × 15% (Marak and Khare 2017).

g) Carbon stock in tree biomass

The carbon stored in litchi and mango tree tree biomass including both above ground biomass and below ground biomass was estimated by assuming 45% carbon stored in total tree biomass

Carbon storage in tree biomass = Tree biomass× 45%

(Magnussen and Reed 2004).

h) Carbon-dioxide mitigation by the tree biomass

In mango and litchi amount of CO_2 mitigated by total tree biomass determined by formula

CO_2 mitigated = Carbon storage × 3.67

(Bhagya *et al*. 2017).

3.6.18 Statistical analysis

During this experiment the data observed in the labrotary and data collected from the experimental field from different location, different LUS and soil depth. In this experiment five different land use system were selected in Agro-Climatic Zone-I of Bihar from different district having dominent Land use system.

Soil sample were collected from representative land use site of different district from a minimum area of 0.5 ha during spring season. Composit soil sampling was done from five to ten points as per observed homoginity of land use system. The sampling site at different location for each land use system considered as replication. The composit soil sample collected randomly from five five different land use system with four soil depth, replicated five times for each land use system. Total 100 composite soil samples collected from five LUS's, four soil depth 0-15, 15-30, 30-45 and 45-60 cm and five replications.

The data so obtained were analysed through excel 2010 software while in for PCA analysis was done through SPSS software (Statistical Package for the Social Science, SPSS, Inc., Chicago, USA). Soil depth was assumed as independent variables *i.e.* (factors) and soil parameters as dependent variables in present study. Mean values was estimated for each the variables, and two way analysis of variance (ANOVA) was used to observe effect of LUS and soil depth on the soil properties. The critical difference (CD) was used for comparing mean of different LUS's and soil depths at 5% probability levels ($p < 0.05$).

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CHAPTER – IV

RESULTS AND DISCUSSION

4. RESULTS AND DISCUSSION

The doctoral research programme was undertaken entitled "**Assessing carbon sequestration potential and Soil Quality Index (SQI) under horticulture-based land-use systems in Agro-Climatic Zone-I of Bihar".** As per approved research programme different prevailing LUS's were selected at different location within ACZ-I of Bihar and accordingly soil samples were collected from four soil depths 0-15, 15-30, 30-45 and 45-60 cm. In horticulture based LUS's the various biophysical parameters were also observed along with their details. The collected soil sample was processed and analyzed for measurable soil physical, chemical and biological properties. The soil data so obtained was used to assess the soil quality index SQI of different LUS. Also the above ground and below ground stored carbon was estimated. The laboratory data obtained wasanalyzed by appropriate statistical tool to assess the effect of LU and soil depth on soil. Tree biophysical parameter data were accordingly also analyzed. The analyzed results of present investigation are presented in form of tables and figures under the following heads:

4.1 Physical properties of soil
4.2 Chemical properties of soil
4.3 Biological properties of soil
4.4 Carbon fractionin soil
4.5 Nitrogen fractionin soil
4.6 Carbon and nitrogen stock in soil
4.7 Metabolic quotient (qCO_2) and microbial quotient (MQ) in soil
4.8 Soil quality index (SQI)
4.9 Tree biomass and carbon storage

4.1 Effect of LUS's and soil depth on soil physical properties

4.1.1 Bulk density (Mg m^{-3})

The bulk density of soil Table 4.1, Fig 4.1 among different LUS's and soil depths found significantly varied while their interaction effect was not significant. Among different LUS's bulk density was found highest in uncultivated LU 1.46 Mg m^{-3} followed by rice-wheat 1.45 Mg m^{-3}, litchi intercrop LU 1.42 Mg m^{-3} while litchi solo LU and mango solo LU recorded least 1.41 Mg m^{-3} *i.e.* it varied from 1.46 to 1.41 Mg m^{-3} among LUs. Irrespective of LU soil bulk density was found to increase with increasing soil depths. Soil bulk density among various depths, recorded the highest value in soil depth of 45-60 cm 1.48 Mg m^{-3}, followed by at 30-45 cm 1.45 Mg m^{-3}, at 15-30 cm 1.42 Mg m^{-3} and the lowest was observed in 0-15 cm soil depth 1.36 Mg m^{-3}. Data reveals when bulk density compared with mango LU found bulk density increased by 0.04% in litchi solo LU, 0.35% in litchi intercrop, 2.41% in rice-wheat and 3.34% increase in uncultivated LU over mango solo LU. Among the different soil depths when bulk density compared with upper soil depth of 0-15 cm was found to increase by 4.09% in 15-30 cm, 6.48% in 30-45 cm and 8.79% in 45-60 cm soil depth over 0-15 cm soil depth.

Effect of LU on bulk density depicts that mango solo and litchi solo horticulture LU varied significantly with uncultivated LU, further it was also observed rice-wheat and uncultivated LU not varied significantly from each other litchi solo and mango solo did not vary significantly. Among soil depths, 0-15 cm bulk density was found to significantly vary with all lower depths.

In the present study, the bulk density was observed lowest in mango solo followed by litchi solo, rice-wheat LU and highest in uncultivated LU, while, with depth bulk density increased. Our result are in conformity with Naik *et al.* (2016) and it was observed that lower bulk density in horticulture LUS of mango and litchi over control. Singh *et al.* (2007), Seyoum (2016) and Meena *et al.* (2018) reported that in natural forest and tree-based LUS's observed to have lower bulk density compared to agricultural LUS's. The reduction in bulk density is mainly due to higher SOC which improves aggregation and consequently, volume enhanced due to increased micro-pores in soil.

In present study it was observed rice-wheat LU having lower bulk density in comparison to uncultivated LU. This might be due to repeated tillage operation followed in rice-wheat LU which temporarily reduces bulk density, similar result observed by Lemenih *et al.* (2005) and Moges and holden (2008).

In line with our observation Stockfisch *et al.* (1999); Bhattacharya *et al.* (2004); Meena *et al.* (2018); Brady and Weil (2002); Moges *et al.* (2013) and Tufa *et. al*. (2019) observed lower bulk density in upper soil depth due to more SOC while in lower depth bulk density increase with depth due to pressure of over laying soil layer due to which soil gets compacted.

Table 4.1: Effect of LUS's and soil depths on soil bulk density (Mg m^{-3}).

Land use systems (L)	**Bulk density (Mg m^{-3})**				
	Soil depth(D) cm				
	0-15	**15-30**	**30-45**	**45-60**	**Mean**
Litchi solo	1.33	1.40	1.44	1.48	**1.41**
Litchi intercrop	1.35	1.42	1.44	1.47	**1.42**
Mango solo	1.34	1.39	1.43	1.49	**1.41**
Rice –wheat	1.38	1.44	1.48	1.50	**1.45**
Uncultivated	1.42	1.45	1.48	1.49	**1.46**
Mean	**1.36**	**1.42**	**1.45**	**1.48**	
SEm±	**L=0.014**	**D=**	**0.012**	**L X D=**	**0.027**
C.D.(P=0.05)	**L=0.04**	**D=**	**0.03**	**LX D=**	**NS**

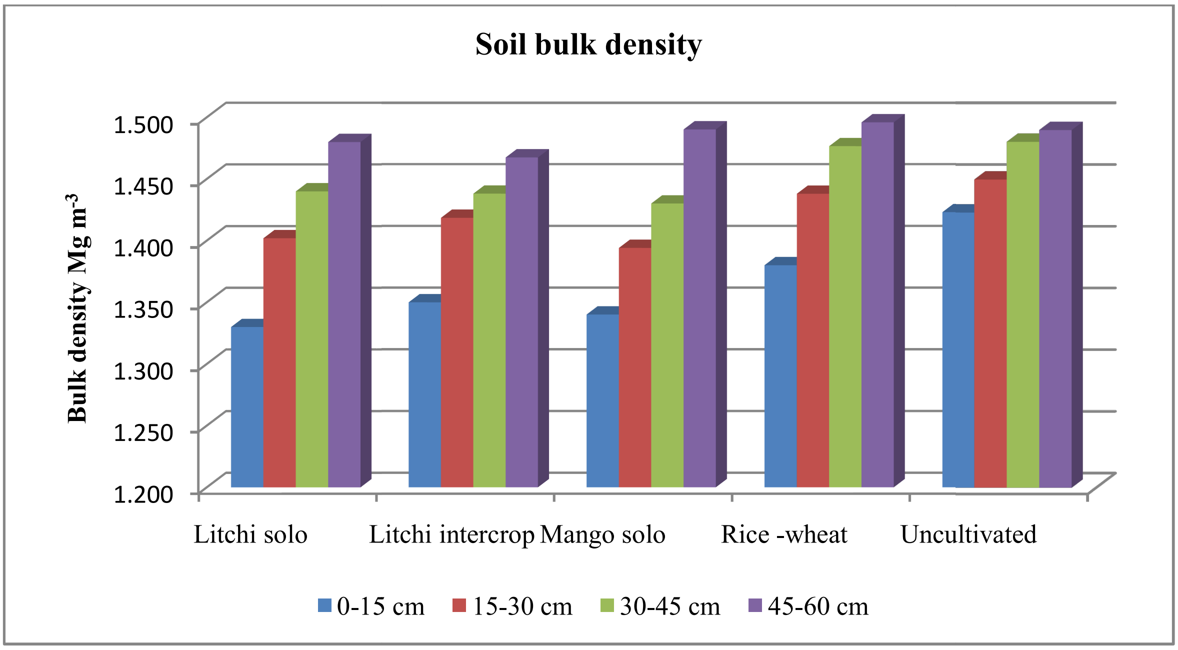

Fig 4.1: Soil bulk density (Mg m^{-3}) in different LUS's and soil depths.

4.1.2 Soil texture (particle size distribution)

The soil separates sand%, silt% and clay% in different LU, soil depth Table 4.2 does not significantly differ and their interaction did not vary significantly. Soil texture of land is the inherent property and does not change over a short period of time it does not get altered even with agriculture management practice and LU. The particle size distribution within soil depth was found insignificant. In the case of sand%, a general trend was observed that with increasing depth sand% decreased, it was observed in soil depth of 0-15 cm that sand% recorded 29.93% whereas in 45-60 cm soil depth it was 25.11%. While in the case of silt and clay%, a general trend was observed that with soil depth increase, silt and clay% also increased. From data silt% in upper soil depth, 0-15 cm was 47.08% while in lowest soil depth 45-60 cm recorded 49.52% *i.e.* silt increased with soil depth, a similar trend observed with clay, at 0-15 cm 22.99% clay and at 45-60 cm 25.38 clay% observed. The analyzed data of sand%, silt%, and clay% showed textural class mainly found silt loam, clay loam and sandy loam in different LU. The soil separates (sand, silt, clay) data revealed no significant variation was observed among LU but through the process illuviation, silt and clay moved to lower soil depth while sand remained at surface soil. The data revealed the highest silt and clay observed in 45-60 cm soil depth whereas the highest sand% was observed at 0-15 cm soil depth among different LU. Although silt and clay movement varied but not enough to bring change in soil texture, a similar trend was observed by Moges *et al.* (2013) that soil texture remained the same. These results are in line with the previous findings of Gilley and Doran (1997); Singh *et al*. (2005); and Chemada *et al*. (2017) for soil texture.

Table 4.2: Effect of LUS's and soil depths on particle size distribution (%).

Land use systems(L)	**Soil depth(D) cm**												**Mean**		
	0-15 cm			**15-30 cm**			**30-45 cm**			**45-60 cm**					
	Sand (%)	**Silt** (%)	**Clay** (%)	**Sand** (%)	**Silt** (%)	**Clay** (%)	**Sand** (%)	**Silt** (%)	**Clay** (%)	**Sand** (%)	**Silt** (%)	**Clay** (%)	**Sand** (%)	**Silt** (%)	**Clay** (%)
Litchi solo	29.26	49.68	21.06	27.76	50.18	22.06	26.24	50.90	22.86	24.14	52.30	23.56	**24.14**	**50.77**	**22.39**
Litchi intercrop	28.76	49.14	22.10	27.70	49.56	22.74	26.06	50.46	23.48	24.16	51.80	24.04	**24.16**	**50.24**	**23.09**
Mango solo	29.56	45.14	25.30	28.04	45.78	26.18	26.34	46.34	27.32	23.96	47.34	28.70	**23.96**	**46.15**	**26.88**
Rice –wheat	33.40	43.74	22.86	32.08	44.76	23.16	30.61	45.79	23.60	29.58	46.54	23.88	**29.58**	**45.21**	**23.38**
Uncultivated	28.66	47.70	23.64	27.34	48.10	24.56	25.68	48.84	25.48	23.70	49.60	26.70	**23.70**	**48.56**	**25.10**
Mean	**29.93**	**47.08**	**22.99**	**28.58**	**47.68**	**23.74**	**26.99**	**48.47**	**24.55**	**25.11**	**49.52**	**25.38**			
SEm±	**Sand L=1.97 D=1.76 LXD=3.93**					**Silt L=2.29 D=2.0 LXD=4.59**					**Clay L=1.19 D=1.06 LXD=2.38**				
C.D.(P=0.05)	**Sand L= NS D=NS LXD=NS**					**Silt L=NS D=NS LXD=NS**					**Clay L=NS D=NS LXD=NS**				

4.1.3 Mean weight diameter

Mean weight diameter Table 4.3 was found to be significantly varied in different LUS. Highest MWD was observed in mango solo LU 3.73 mm followed by litchi solo 3.62 mm, litchi intercrop 3.26 mm, uncultivated LU 3.17 mm and least was observed in rice-wheat LU. From data it is evident that all three horticulture LU significantly differed both with uncultivated and rice-wheat LU. Also litchi solo and mango solo varied significantly similarly from uncultivated and rice-wheat LU differed significantly with each other.

In conformity to our result Shahmir *et al.* (2017) also observed wet aggregate size distribution in different LUS revealed that MWD of aggregate were found higher in grassland and the abandoned apple LUS, than cropland LUS. Also observed soil aggregates were positively correlated with SOC and root biomass of different plants. Concluded that LUS's affect the soil aggregation and its distribution. Small aggregates forms large aggregate fractions when combine with fresh OM thus increase in SOC closely related with macro-aggregates formation.

4.1.4 Penetration resistance (KPa)

Penetration resistance varied significantly among different LU Table 4.3. Highest 1368.20 KPa value was recorded in uncultivated LU followed by rice-wheat LU 1135.80 KPa, litchi intercrop 1063.20 KPa, litchi solo 977.60 KPa and least 974.20 KPa was observed in mango solo LU. Penetration resistance was found significantly varied between litchi solo, mango solo with rice-wheat LU, further observed that rice-wheat and uncultivated LU varied significantly but litchi solo and mango solo not varied significantly.

Penetration resistance is measure of resistance by soil which depends upon hardness or softness of soil and expressed in pound per square inch (Duiker 2002).

In present research it was observed higher *Pr* in agricultural field compared to horticultural LUS primarily due to use of heavy machinery and long tern tillage operation which break down soil aggregates increasing its bulk density (Grzesiak 2009 and Abu-Hamdeh 2003). Similarly, Cherubin *et al.* (2019); Lal *et al.* (1989); and Sinnett *et al.* (2008) observed lower Pr in tree based LUS then cropland and found *Pr* increases with increase in soil depth.

Table 4.3: Effect of LUS's on soil mean weight diameter (MWD) and penetration resistance (*Pr*).

Land use systems (L)	MWD (mm)	*Pr* (KPa)
Litchi solo	3.62	977.6
Litchi intercrop	3.26	1063.2
Mango solo	3.73	974.2
Rice –wheat	2.73	1135.8
Uncultivated	3.17	1368.2
SEm±	0.133	26.94
C.D.(P=0.05)	0.0403	81.46

4.2 Effect of LUS's and soil depths on soil chemical properties

4.2.1 Soil reaction

The analyzed data as given in Table 4.4 reveals that *p*H significantly varied under different LUS's and soil depths while the interaction effect was not significant. The highest *p*H value was recorded in uncultivated LU 8.23 followed by rice-wheat 8.26, litchi intercrop 8.20, litchi solo 8.03 and the lowest 7.91 *p*H was found in mango solo LU *i.e.* *p*H ranged from 8.23 to 7.91. The soil *p*H per cent change among LU compared with rice-wheat LU reveals that in mango solo LU soil *p*H decreased by 4.15%, litchi solo by 2.74%, litchi intercrop by 0.66% and uncultivated LU by 0.34% over rice-wheat LUS. It has also been observed that the soil *p*H value increased with increasing soil depth irrespective of LU. The soil *p*H data within soil depth recorded lowest 7.99 *p*H in upper soil depth 0-15 cm, followed by *p*H 8.12 in 15-30 cm, *p*H 8.16 in 30-45 cm, while highest 8.23 *p*H recorded in 45-60 cm soil depth, *i.e.* there has been increase of 1.69%, 2.17%, 2.9% *p*H in 15-30 cm, 30-45 cm and 45-60 cm, respectively over 0-15 cm soil depth.

The data reveals that both mango and litchi solo LU significantly varied with uncultivated LU. Also, all three horticulture LU significantly varied from each other while uncultivated and rice-wheat LU did not vary significantly. It was observed all soil depths significantly varied from each other. The soil *p*H among different LU and soil depth was found to be moderately alkaline.

In the present study, data depicts horticultural land has lower soil *p*H than rice-wheat LU might be due to more microbial activity which releases organic acids that result in low soil *p*H and another reason is leaching of the base forming cations in horticulture LU more due to lower bulk density and more micropores (Mohammed *et al.* 2005; Chauhan *et al.* 2014). The soil *p*H data shows a trend that there has been increasing soil *p*H with an increase in soil depth, the reason might be due to accumulation of base cations with depth due to leaching of solutes downward resulting in higher carbonate in lower soil depth, a similar finding was also reported by Malo *et al.* (2005). In a similar experiment by Naik *et al.* (2016) observed in lower soil *p*H in horticultural LU mango and litchi compared to control.

Table 4.4: Effect of LUS's and soil depths on soil reaction (*p*H).

Land use systems (L)	**Soil (*p*H) (1:2 : : soil : water)**				
	Soil depth(D) cm				**Mean**
	0-15	**15-30**	**30-45**	**45-60**	
Litchi solo	7.85	8.04	8.10	8.13	**8.03**
Litchi intercrop	8.08	8.21	8.23	8.29	**8.20**
Mango solo	7.78	7.90	7.94	8.03	**7.91**
Rice –wheat	8.14	8.24	8.29	8.35	**8.26**
Uncultivated	8.10	8.23	8.25	8.33	**8.23**
Mean	**7.99**	**8.12**	**8.16**	**8.23**	
SEm±	**L=0.037**	**D=**	**0.0327**	**L X D=**	**0.073**
C.D.(P=0.05)	**L=0.1**	**D=**	**0.09**	**LX D=**	**NS**

4.2.2 Soil electrical conductivity

Soil EC significantly varied under different LU, soil depths and their interaction effect were also found significant Table 4.5. The main effect of LU on EC was recorded highest in uncultivated LU 0.48 dS m^{-1} followed by rice-wheat LU 0.45 dS m^{-1}, litchi intercrop 0.39 dS m^{-1}, litchi solo 0.38 dS m^{-1} and the least observed in mango solo 0.34 dS m^{-1}. Among the different LUS's, EC ranged from 0.48 to 0.34 dS m^{-1}. When among LU EC compared with mango LU, found EC increase by 11.69% in litchi solo, 14.28% litchi intercrop, rice-wheat by 32.37% and uncultivated LU by 40.60% over mango LU, respectively. It has also been observed irrespective of different LU EC decreased with increasing soil depth. The data pertaining to EC among soil depth shows highest EC recorded in upper soil depth (0-15) cm EC 0.69 dS m^{-1}, followed by 15-30 cm EC 0.36 dS m^{-1}, 30-45 cm EC 0.31 dS m^{-1} and least recorded in 0.27 dS m^{-1} in 45-60 cm soil depth. Also recorded when soil depths compared to uppermost soil depth, EC decreased by 47.34% in 15-30 cm soil depth, 55.18% in 30-45 cm soil depth and 60.21% in 45-60 cm over 0-15 cm soil depth. The interaction effect of LU and soil depth on soil EC reveals that the highest EC was recorded in uncultivated LU 0.89 dS m^{-1} in 0-15 cm soil depth while the lowest EC 0.28 dS m^{-1} was observed in mango solo LU.

The main effect of LU depicts that all three horticulture LU varied significantly with both rice-wheat LU and uncultivated LU, further also observed that mango solo was at par with litchi solo similarly uncultivated LU was at par with rice-wheat LU. It was observed all soil depths significantly varied from each other. The analyzed result shows EC varied from 0.48 to 0.34 dS m^{-1} which is below the critical limit without hindering the growth and development of crop or tree species.

In the present study, horticulture LU EC was observed lowest, the reason might be due to lower bulk density and higher permeability in soils of horticulture LU, due to which, soluble salts move down to lower soil depth. In rice-wheat LU evaporative demand is more due to less surface cover resulting in movement of salts to the soil surface, a similar finding also observed by Mesele *et al*. (2006).

Table 4.5: Effect of LUS's and soil depths on electrical conductivity (dS m^{-1}).

Land use systems (L)	**Electrical conductivity (dS m^{-1})(1:2 : : soil : water)**				
	Soil depth(D) cm				
	0-15	**15-30**	**30-45**	**45-60**	**Mean**
Litchi solo	0.47	0.38	0.36	0.32	**0.38**
Litchi intercrop	0.71	0.31	0.29	0.26	**0.39**
Mango solo	0.58	0.29	0.27	0.23	**0.34**
Rice –wheat	0.81	0.41	0.32	0.28	**0.45**
Uncultivated	0.89	0.43	0.32	0.29	**0.48**
Mean	**0.69**	**0.36**	**0.31**	**0.27**	
SEm±	**L=0.011 D= 0.009 L X D= 0.0203**				
C.D.(P=0.05)	**L=0.03 D= 0.03 LX D= 0.06**				

4.2.3 Soil organic carbon (g kg^{-1})

The analyzed laboratory data Table 4.6, Fig 4.2 show that SOC significantly varied among different LU and soil depth but their interaction effect does not differ significantly. The main effect of LU SOC content reveals that the highest observed in the mango LUS 5.55 g kg^{-1} followed by litchi solo 4.73 g kg^{-1}, litchi intercrop 4.07 g kg^{-1}, uncultivated LU while least 2.98 g kg^{-1} SOC was found in rice-wheat LUS. Among various LU, SOC ranged from 5.55 g kg^{-1} to 4.07 g kg^{-1}. . Further data revealed that irrespective of LU SOC decreased with increasing soil depth. Among soil depth, the highest SOC 5.68 g kg^{-1} was observed in 0-15 cm soil depth followed by 94.42 g kg^{-1} in 15-30 cm, 3.56 g kg^{-1} in 30-45 cm while the lowest in 45-60 cm soil depth 3.27 g kg^{-1}. When, among LU the SOC compared with mango solo, it was also observed that SOC decreased by 14.79% in litchi LU then, 26.57% litchi intercrop, 31.19% in uncultivated LU and 46.36% decrease in rice-wheat LU over mango LU. While among soil depth SOC when compared with uppermost soil depth, SOC content decreased with increasing soil depth, at 15-30 cm soil depth SOC decreased by 22.35%, 30-45 cm soil depth by 37.41% and 45-60 cm soil depth SOC decreased by 42.47% over 0-15 cm depth. The interaction effect of LU and soil depth was found to be insignificant.

SOC data revealed that all three selected horticulture LU was found to vary significantly compared to uncultivated LU and the rice-wheat LUS. Among horticulture LU, mango solo significantly differed from both litchi solo and litchi intercrop while uncultivated LU and rice-wheat LU varied significantly from each other. It was observed all soil depths significantly varied from each other.

In conformity to our observation Naik *et al*. (2016) also observed mango LU SOC was higher than litchi LU and both horticulture LUS maintained more SOC over control. Similar observation was also observed by Rajan *et al.* (2019) while assessing effect of different LU in Indo-Gangetic plains observed that horticulture LU (mango) sequestered more SOC compared to rice-wheat LUS.

Higher observed SOC in horticulture LU is due to high above and below ground biomass that adds on as organic ingredients through plant litter fall, root biomass decay. Also microbial diversity dead and decomposed adds carbon to soil. At farmers field it has been observed in horticultural LU tillage operation is less as compared to intensive cropping system (Mandal *et al.* 2020). Another reason for lesser SOC in cultivated soil is that loss of SOC being not compensated with organic input and on the other hand crop residue also removed from the field (Seyoum 2016). It has been also observed in present study that SOC decreases with increase in soil depth, this might be due to more addition of dead and decomposed SOM on upper soil surface which being mineralised by soil microbes, enriching carbon in soil. The quality of organic matter is also important factor, as some are more resistant and some easily gets mineralised enriching more carbon in soil. Tufa *et al.* (2019); Sariyildiz and Anderson (2003). In line with our finding (Meena *et al.* 2018) also observed that in natural forest and tree-based systems SOC content higher compared to agricultural LUS's, further also observed SOC decreased with increasing depth. In horticulture LU Rajan *et al.* (2019) observed mango LU soil organic carbon percentage was higher in comparison with rice-wheat LU further also observed SOC decreased with increasing soil depth. Adak *et al.* (2018) reported in line with our results was that mango LU SOC was higher than litchi LU and SOC also decreased with soil depth.

Table 4.6: Effect of LUS's and soil depths on soil organic carbon (g kg^{-1}).

Land use systems (L)	**Soil organic carbon (g kg^{-1})**				
	Soil depth(D) cm				**Mean**
	0-15	**15-30**	**30-45**	**45-60**	
Litchi solo	6.28	4.98	4.01	3.64	**4.73**
Litchi intercrop	5.49	4.23	3.41	3.16	**4.07**
Mango solo	7.32	5.93	4.69	4.25	**5.55**
Rice –wheat	4.10	3.00	2.48	2.32	**2.98**
Uncultivated	5.21	3.91	3.18	2.97	**3.82**
Mean	**5.68**	**4.41**	**3.56**	**3.27**	
SEm±	**L=0.096**	**D=**	**0.086**	**L X D=**	**0.192**
C.D.(P=0.05)	**L=0.27**	**D=**	**0.24**	**LX D=**	**NS**

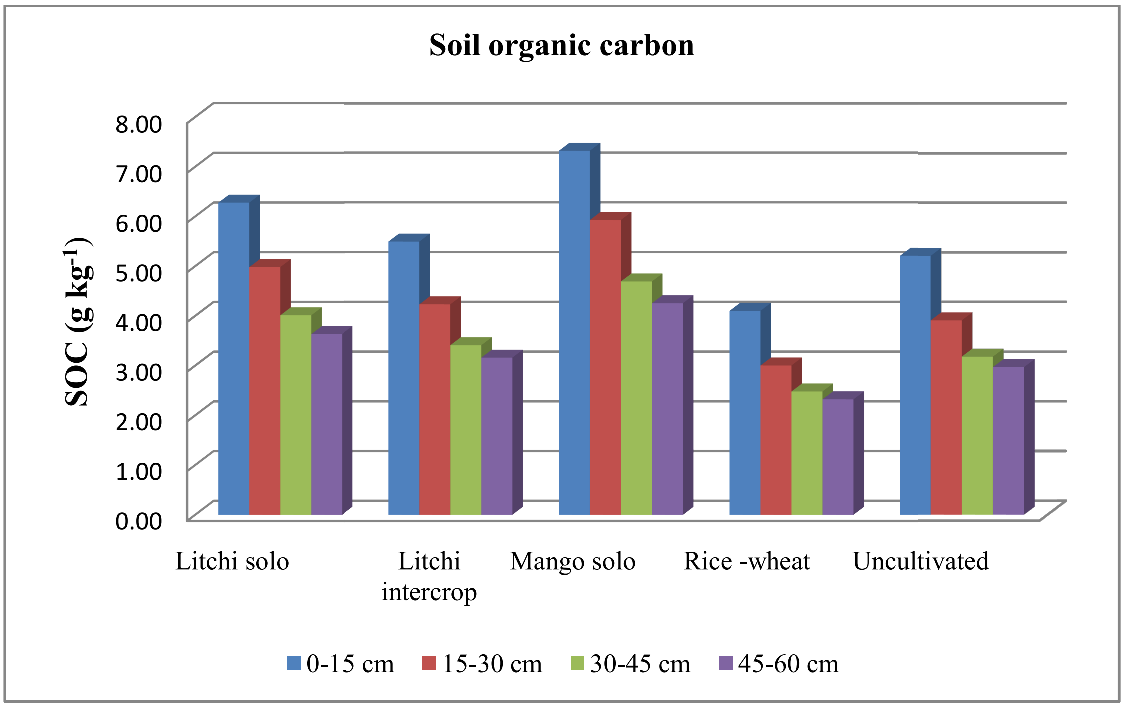

Fig 4.2: Soil organic carbon in different LUS's and soil depths

4.2.4 Available nitrogen (kg ha^{-1})

Available nitrogen significantly varied in different land and soil depth while their interaction effect varied significantly Table 4.7. Among the different LU highest available nitrogen was recorded in mango solo LU 241.25 kg ha^{-1} followed by litchi solo LU 225.25 kg ha^{-1}, litchi intercrop 205.05 kg ha^{-1}, uncultivated LU 190.30 kg ha^{-1} and least recorded in rice-wheat LU 164.25 kg ha^{-1}, *i.e.* it varied from 241.25 to 164.25 kg ha^{-1}. Within the soil depth it was observed highest available nitrogen content observed 230 kg ha^{-1}, was observed in the upper soil layer 0-15 cm followed by 219.60 kg ha^{-1} in 15-30 cm soil depth, 204.08 kg ha^{-1} in

30-45 cm soil depth while least observed 167.20 kg ha^{-1} in 45-60 cm soil depth. The perusal data reveals that among different LU it was observed that there was a decrease in available nitrogen by 6.63%, 15.01%, 21.12%, and 31.92% in namely LU litchi solo, litchi intercrop, uncultivated LU and rice-wheat LU, respectively when compared with mango LU. Further also data depicts that available nitrogen decreased by 4.52%, 11.27%, 27.30% in soil depth 15-30 cm, 30-45 cm, 45-60 cm, respectively over 0-15 cm soil depth.

The interaction effect of LU and soil depth depicts that the highest available nitrogen content was observed in 0-15 cm soil depth in mango LU 120.09 kg ha^{-1} followed by litchi LU 112.86 kg ha^{-1}, litchi intercrop 102.32 kg ha^{-1}, uncultivated LU 94.64 kg ha^{-1} and rice-wheat LU 83.48 kg ha^{-1} while least value 54.46 kg ha^{-1} observed in 45-60 cm soil depth in rice-wheat LU.

Available nitrogen data reveals all three LU horticulture-based LU significantly differed with both rice-wheat and uncultivated LU whereas mango solo LU and litchi solo LU varied significantly, similarly rice-wheat and uncultivated land varied significantly *i.e* all LU significantly varied from each other, similarly, all soil depths significantly differed from each other.

In the present study available nitrogen in soil followed decreasing trend mango solo> litchi solo> litchi intercrop> uncultivated land> rice-wheat LU *.i.e* highest in horticulture LU than agriculture rice-wheat LU which is mainly due to higher litterfall and root biomass accumulation enhancing nitrogen mineralization in the soil.

In conformity to our finding Naik *et al.* (2016) observed higher available nitrogen in mango LU then litchi LU while least in control. (Emiru and Gebrekidan 2013) observed in agricultural soil due to more tillage operation there is more oxidation of organic matter resulting in low nitrogen availability in soil. Pal *et al.* (2013); Kaur and Bhat (2017); and Mandal *et al.* (2018) reported that lower available nitrogen in agriculture land in comparison to horticulture intercrop and horticulture LU is due to lesser vegetation surface cover and nitrogen leaching loss during irrigation and rainfall. Similar to our finding Chen *et al.* (2016) also reported a decrease in available nitrogen with depth due to immobilisation of nitrogen and decreasing organic carbon with depth.

Table 4.7: Effect of LUS's and soil depths on available nitrogen (kg ha $^{-1}$).

Land use systems (L)	Available nitrogen (kg ha^{-1})				
	Soil depth(D) cm				Mean
	0-15	15-30	30-45	45-60	
Litchi solo (T1)	252.80	240.00	219.20	189.00	**225.25**
Litchi intercrop (T2)	229.20	219.00	205.00	167.00	**205.05**
Mango solo (T3)	269.00	255.00	237.00	204.00	**241.25**
Rice -wheat (T4)	187.00	180.00	168.00	122.00	**164.25**
Uncultivated (T5)	212.00	204.00	191.20	154.00	**190.30**
Mean	**230.00**	**219.60**	**204.08**	**167.20**	
SEm±	**L=0.95**	**D=**	**0.8481**	**L X D=**	**1.8964**
C.D.(P=0.05)	**L=2.67**	**D=**	**2.39**	**LX D=**	**5.34**

4.2.5 Available phosphorus (kg ha^{-1})

The main effect of different LU and soil depth was found to be varied significantly whereas the interaction effect did not vary significantly Table 4.8. Available phosphorus among different LUS's was found highest 23.71 kg ha^{-1} in mango solo LU followed by litchi solo LU 22.2 kg ha^{-1} litchi intercrop 20.89 kg ha^{-1} rice-wheat LU 19.96 kg ha^{-1} and least recorded in uncultivated LU 14.85 kg ha^{-1} *i.e.* it varied from 8.91 to 14.85 kg ha^{-1} in LU. Within various soil depths available phosphorus was found highest (26.25 kg ha^{-1}) in the upper soil layer 0-15 cm followed by 20.84 kg ha^{-1} in 15-30 cm soil depth, 17.91 kg ha^{-1} in 30-45 and 16.28 kg ha^{-1} in 45-60 cm soil depth. Available phosphorus soil in different LU, when compared to mango LU, was found to decrease by 6.38%, 11.89%, 15.82%, and 37.38% in LU *viz.* litchi solo, litchi intercrop, rice-wheat LU and uncultivated LU, respectively over mango LU. The analysed data among soil depth available phosphorus when compared with upper 0-15 cm available phosphorus decreased by 20.62%, 31.77%, and 37.97% in soil depth 15-30 cm, 30-45 cm, 45-60 cm, respectively over upper soil depth 0-15 cm.

The data depicts that all three horticulture LU and rice-wheat LU significantly varied with uncultivated LU, further also observed that mango and litchi solo did not vary significantly. While uncultivated and rice-wheat varied significantly. All soil depths significantly varied from each other. In conformity to our result Naik *et al.* (2016) also observed similar trend that mango LU available phosphorus was more in mango LU then litchi LU and both horticultural LU was higher over control.

The availability of phosphorus in the soil is from organic sources *i.e.* from organic residue mineralization and inorganic phosphatic fertilizer addition to soil. In the present study highest available phosphorus was observed in mango solo LU while least in uncultivated LU. In line with our findings, Weldeamlak and Stroosnjder (2003); Mohammadi *et al.* (2009) reported higher phosphorus availability in horticulture and agri-horticulture LU compared to uncultivated LU due to more organic matter in horticulture LU which on mineralisation increase available phosphorus, also on other hand more organic substrate in horticulture LU supports more beneficial microorganism like phosphorus solubilising bacteria which releases organic acid that helps in solubilizing unavailable phosphorus. Also, observed higher phosphorus in agricultural soil compared to uncultivated LU due to the continuous addition of phosphatic fertilizer resulting phosphorus buildup in the soil which is in conformity to our result. Sepehya *et al.* (2012) observed in horticulture LU more availability of phosphorus due to organic acids released during the decomposition of organic matter which makes chelates with Al, Mg, Ca, Fe cations inhibiting phosphorus fixation in soil. Dadhwal *et al.* (2012) also reported higher phosphorus availability at surface soil and decreased with soil depth.

Table 4.8: Effect of LUS's and soil depth on soil available phosphorus (kg ha^{-1})

Land use systems (L)	Available phosphorous (kg ha^{-1})				
	Soil depth(D) cm				
	0-15	15-30	30-45	45-60	Mean
Litchi solo (T1)	28.32	22.47	20.11	17.90	**22.20**
Litchi intercrop (T2)	27.30	20.96	18.68	16.62	**20.89**
Mango solo (T3)	30.12	24.86	20.66	19.20	**23.71**
Rice -wheat (T4)	26.08	20.43	17.02	16.31	**19.96**
Uncultivated (T5)	19.44	15.47	13.09	11.38	**14.85**
Mean	**26.25**	**20.84**	**17.91**	**16.28**	
SEm±	**L=0.637**	**D= 0.5699**		**L X D=**	**1.27**
C.D.(P=0.05)	**L=1.79**	**D= 1.61**		**LX D=**	**NS**

4.2.6 Available potassium (kg ha^{-1})

The analysed data of soil available potassium in different LU and soil depth varied significantly and their interaction effect also differed significantly Table 4.9. The soil available potassium value among different LU was found highest in mango solo LU (128.29 kg ha^{-1}) followed by litchi solo LU 123.35 kg ha^{-1}, litchi intercrop 118.86 kg ha^{-1}, uncultivated LU 95.88 kg ha^{-1} and least recorded in rice-wheat LU 83.47 kg ha^{-1} *i.e.* it varied from 128.29 to 83.47 kg ha^{-1} in LU. Soil carbon stock among various soil depths, recorded the highest value 164.05 Kg ha^{-1} in the upper soil layer 0-15 cm followed by 125.63 kg ha^{-1} in

15-30 cm soil depth, 89.34 kg ha^{-1} in 30-45 cm soil depth while least observed 60.85 kg ha^{-1} in 45-60 cm soil depth. Soil available potassium in different LU when compared to mango solo found decreased by 3.85%, 7.35%, 25.27%, and 37.36% in LU *viz.* litchi solo, litchi intercrop, uncultivated LU and rice-wheat LU, respectively over mango LUS. The analysed data among soil depth when compared with 0-15 cm soil depth reveals available potassium decreased by 23.42%, 45.54%, and 62.91% in soil depth 15-30 cm, 30-45 cm, 45-60 cm, respectively over upper soil depth 0-15 cm.

The data depicts that all three horticulture LU varied significantly with both uncultivated and rice-wheat LU, also found mango solo litchi solo and litchi intercrop varied significantly, similarly, rice-wheat and uncultivated LU varied significantly. It was also observed all soil depths varied significantly varied with each other.

In the present study, it was observed highest available potassium in mango solo LU was followed by litchi solo, litchi intercrop, uncultivated LU and least in rice-wheat LU. In a similar study by Naik *et al.* (2016) also observed horticulture LU mango and litchi LU available phosphorus was higher over control. Mandal *et al.* (2018); Moges *et al.* 2013) reported higher available potassium in natural forest and horticultural LU compared to other LU due to higher litterfall and root deposition in soil which helps in organic residue enrichment which helps solubilising unavailable form and release of bounded potassium. Whereas in agricultural soil lesser available potassium is due to low organic input and apart from this loss of potassium is due to leaching and erosion. Waken (2001) studied different LUS's and found higher available potassium on surface soil which gradually decreased with depth.

Table 4.9: Effect of LUS's and soil depth on soil available potassium (kg ha^{-1})

Land use systems (L)	Available potassium (kg ha^{-1})				
	Soil depth(D) cm				
	0-15	15-30	30-45	45-60	Mean
Litchi solo (T1)	182.26	142.10	99.44	69.60	**123.35**
Litchi intercrop (T2)	169.30	137.20	101.62	67.30	**118.86**
Mango solo (T3)	191.18	144.42	103.78	73.78	**128.29**
Rice -wheat (T4)	117.20	93.70	71.12	51.84	**83.47**
Uncultivated (T5)	160.30	110.72	70.76	41.72	**95.88**
Mean	**164.05**	**125.63**	**89.34**	**60.85**	
SEm±	**L=1.37**	**D= 1.226**		**L X D=**	**2.74**
C.D.(P=0.05)	**L=3.86**	**D= 3.45**		**LX D=**	**7.72**

4.2.7 DTPA extractable zinc (mg kg^{-1})

The DTPA extractable zinc content found significantly varied among various LU and soil depth while their interaction effect significantly varied Table 4.10. The highest available zinc in different LU was observed in mango solo LU 0.49 mg kg^{-1} followed by litchi solo use (0.44 mg kg^{-1}), litchi intercrop LU 0.38 mg kg^{-1}, uncultivated LU 0.36 mg kg^{-1} and in rice-wheat least 0.33 mg kg^{-1} value was observed *.i.e.* it ranged from 0.49 mg to 0.36 mg kg^{-1} among LU. Available zinc content, when compared with mango solo within LU, was found to decrease by 10.32% in litchi solo, 23.28% in litchi intercrop, 28.04% in uncultivated and 33.60% in rice-wheat over mango solo LU. The analyzed data also revealed that among soil depths highest 0.65 mg kg^{-1} available zinc was recorded in upper 0-15 cm followed by 0.41mg kg^{-1} in 15-30 cm , 0.30 mg kg^{-1} in 30-45 cm and least 0.24 mg kg^{-1} observed in 45-60 cm soil depth while analyzing percent change in available zinc content within soil depth, found it decreased by 36.41%, 54.31%, and 63.35% in soil depth 15-30 cm, 30-45 cm, 45-60 cm, respectively over 0-15 cm soil depth.

The available zinc data of LU revealed that litchi solo, litchi intercrop and mango solo significantly varied with rice-wheat LU further also observed that litchi solo and mango solo significantly differed from each other similarly rice-wheat and uncultivated LU varied, significantly.

The interaction effect depicts that the highest value of available zinc was observed in mango solo 0.79 mg kg^{-1} in 0-15 cm soil depth followed by litchi solo 0.72 mg kg^{-1}, litchi intercrop 0.61 mg kg^{-1}, uncultivated LU 0.59 mg kg^{-1} and rice-wheat LU 0.54 mg kg^{-1} while least was found 0.19 mg kg^{-1} in 45-60 cm soil depth in rice-wheat LUS.

In the present study, it was observed higher available nutrients in horticulture LU compared to rice-wheat land, as there is more addition of SOM from the leaf litter and root exudates which promotes healthy microbial activity. The organic acids released by soil microbes enhance nutrient availability Dhaliwal and Singh (2013). In an intensive cultivation system, there is more soil disturbance and less organic input and more removal of nutrients by crop resulting in lesser available nutrients than in horticulture and agri-horticulture LUS as observed by Mandal *et al.* (2018) in line with our finding. In present study observed that with an increase in depth decrease in micronutrients was observed, similar findings were also observed by Abate and Kibert (2016); Patel *et al.* (2015); and Jiang *et al.* (2006).

Table 4.10: Effect of LUS's and soil depths on DTPA extractable zinc (mg kg^{-1}).

Land use systems (L)	DTPA extractable zinc (mg kg^{-1})				
	Soil depth(D) cm				
	0-15	15-30	30-45	45-60	Mean
Litchi solo	0.72	0.46	0.33	0.26	**0.44**
Litchi intercrop	0.61	0.39	0.28	0.24	**0.38**
Mango solo	0.79	0.51	0.38	0.30	**0.49**
Rice –wheat	0.54	0.34	0.24	0.19	**0.33**
Uncultivated	0.59	0.37	0.26	0.20	**0.36**
Mean	**0.65**	**0.41**	**0.30**	**0.24**	
SEm±	**L=0.007**	**D= 0.006**		**L X D=**	**0.014**
C.D.(P=0.05)	**L=0.02**	**D= 0.02**		**LX D=**	**0.04**

4.2.8 DTPA extractableiron (mg kg^{-1})

The available iron in different LUS's and soil depths Table 4.11 significantly differed and their interaction effect was also observed significant. It is evident from observed data that among LU highest mean value was observed in mango LU 5.38 mg kg^{-1} followed by litchi solo LU 5.01 mg kg^{-1}, litchi intercrop 4.64 mg kg^{-1}, uncultivated LU 4.53 mg kg^{-1} and least found in rice-wheat LU 4.53 mg kg^{-1} *i.e.* among LU ranged from 5.38 to 4.53 mg kg^{-1}. Within the soil depth highest available iron in the upper soil layer 0-15 cm soil depth 7.46 mg kg^{-1} followed by 5.03 mg kg^{-1} in 15-30 cm, 3.63 mg kg^{-1} in 30-45 cm and least observed 2.85 mg kg^{-1} in 45-60 cm soil depth. Available iron in different LUS's when compared with mango solo was found to decrease by 6.88% in litchi solo, 13.85% litchi intercrop, 15.89% uncultivated and 22.77% in rice-wheat LU over mango solo LUS whereas when per cent change in available iron content analyzed with 0-15 cm soil depth, found decrease of 32.60%, 51.37% and 61.82% in soil depth 15-30 cm, 30-45 cm, 45-60 cm, respectively over 0-15 cm soil depth.

The main effect of LU revealed that all the three horticulture-based LU found to have significantly differed with rice-wheatalso it was observed that rice-wheat and uncultivated LU differed significantly, similarly litchi LU and mango LU and litchi intercrop significantly varied with each other. The interaction effect of LU and soil depth depicts that the highest value of available iron was observed in mango solo 8.60 mg kg^{-1} in 0-15 cm soil depth followed by litchi solo 7.80 mg kg^{-1}, litchi intercrop 7.32 mg kg^{-1}, uncultivated LU 7.08 mg kg^{-1} and rice-wheat LU 6.50 mg kg^{-1} while least was found 2.40 mg kg^{-1} in 45-60 cm soil depth in rice-wheat LUS.

Table 4.11: Effect of LUS's and soil depths on DTPA extractable iron (mg kg^{-1}).

Land use systems (L)	DTPA extractable iron (mg kg^{-1})				
	Soil depth(D) cm				Mean
	0-15	15-30	30-45	45-60	
Litchi solo	7.80	5.30	3.92	3.02	**5.01**
Litchi intercrop	7.32	4.92	3.50	2.80	**4.64**
Mango solo	8.60	5.70	4.02	3.20	**5.38**
Rice –wheat	6.50	4.42	3.30	2.40	**4.16**
Uncultivated	7.08	4.80	3.40	2.82	**4.53**
Mean	**7.46**	**5.03**	**3.63**	**2.85**	
SEm±	**L=0.069**	**D= 0.0619**		**L X D= 0.1385**	
C.D.(P=0.05)	**L=0.2**	**D= 0.17**		**LX D= 0.39**	

4.2.9 DTPA extractablecopper (mg kg^{-1})

The data presented in Table 4.12 reveals that in different LU and soil depth available copper significantly differed whereas their interaction was observed also significant. . Among different LU highest available copper was observed in mango LU 0.66 mg kg^{-1} followed by litchi solo LU 0.62 mg kg^{-1}, litchi intercrop 0.57 mg kg^{-1}, uncultivated LU 0.56 mg kg^{-1} and least observed in rice-wheat LU 4.53 mg kg^{-1} *i.e.* within LU available copper ranged from 5.38 to 4.53 mg kg^{-1}.

Among the different soil depth available iron observed to be highest in upper soil layer 0-15 cm soil depth 0.83 mg kg^{-1} followed by 0.68 mg kg^{-1} in 15-30 cm, 0.46 mg kg^{-1} in 30-45 cm and least observed 0.38 mg kg^{-1} in 45-60 cm soil depth. Irrespective of different land there has been decrease in available copper with increasing depth. Analyzed data depicts that among soil depth available copper when compared with 0-15 cm soil depth found to decrease by 18.82%, 44.42%, 54.10% in soil depth 15-30 cm, 30-45 cm, 45-60, respectively over 0-15 cm soil depth. Among the different LU it was observed when compared with mango solo there was a decrease in available copper by 6.12%, 13.29%, 15.41%, and 20.24% in namely LU litchi solo, litchi intercrop, uncultivated LU and rice-wheat LU when compared with mango LU.

Within different LU, it was observed that all three horticulture-based LU significantly differed from the rice-wheat LUS also observed litchi LU and mango LU and litchi intercrop significantly varied from each other similarly rice-wheat and uncultivated LU also varied significantly. Further, it was also observed that all soil depths significantly varied with each other.

The interaction effect depicts that the highest value of available copper content highest was observed in mango LU 0.93 mg kg^{-1} followed by litchi LU 0.88 mg kg^{-1}, litchi intercrop 0.81 mg kg^{-1}, uncultivated LU 0.79 mg kg^{-1} and rice-wheat LU 0.75 mg kg^{-1} while least value 0.34 mg kg^{-1} observed in 45-60 cm soil depth in rice-wheat LU.Within different LU, it was observed that all three horticulture-based LU significantly differed from the rice-wheat LUS also observed litchi LU and mango LU and litchi intercrop significantly varied from each other similarly rice-wheat and uncultivated LU also varied significantly. Further, it was also observed that all soil depths significantly varied with each other.The interaction effect depicts that the highest value of available copper content highest was observed in mango LU 0.93 mg kg^{-1} followed by litchi LU 0.88 mg kg^{-1}, litchi intercrop 0.81 mg kg^{-1}, uncultivated LU 0.79 mg kg^{-1} and rice-wheat LU 0.75 mg kg^{-1} while least value 0.34 mg kg^{-1} observed in 45-60 cm soil depth in rice-wheat LU.

Table 4.12: Effect of LUS's and soil depths on DTPA extractable copper (mg kg^{-1}).

Land use systems (L)	**DTPA extractable copper (mg kg^{-1})**				
	Soil depth(D) cm				
	0-15	**15-30**	**30-45**	**45-60**	**Mean**
Litchi solo	0.88	0.71	0.49	0.40	**0.62**
Litchi intercrop	0.81	0.66	0.45	0.37	**0.57**
Mango solo	0.93	0.76	0.52	0.44	**0.66**
Rice –wheat	0.75	0.61	0.41	0.34	**0.53**
Uncultivated	0.79	0.64	0.45	0.36	**0.56**
Mean	**0.83**	**0.68**	**0.46**	**0.38**	
SEm±	**L=0.009**	**D= 0.008**		**L X D=**	**0.017**
C.D.(P=0.05)	**L=0.02**	**D= 0.02**		**LX D=**	**NS**

4.2.10 DTPA extractable manganese (mg kg^{-1})

Available manganese analyzed data presented in Table 4.13 varied significantly in different LU at various soil depths while their interaction effect was found non-significant. The data reveals that among different LU highest available Mn was recorded in mango solo LU 2.34 mg kg^{-1} followed by litchi solo 2.10 mg kg^{-1}, litchi intercrop 1.87 mg kg^{-1}, uncultivated LU 1.80 mg kg^{-1} and least value observed in rice-wheat LU1.80 mg kg^{-1} *i.e.* it ranged from 2.34 to 1.80 mg kg^{-1} in different LU. Available Mn content among different LU, when compared with mango solo in terms of percentage change, it was observed to decrease by 10.24%, 20.9%, 22.95% and 27.82% in LU of *viz.* litchi solo, litchi intercrop, uncultivated LU and rice-wheat LU, respectively over mango LU. The data depicts that among different LU highest Mn content was observed in the upper soil layer 0-15 cm soil depth 3.25 mg kg^{-1}

followed by 2.10 mg kg^{-1} in 15-30 cm, 1.38 mg kg^{-1} in 30-45 cm and least 1.11 mg kg^{-1} observed in 45-60 cm soil depth.

Analyzed data, when compared with 0-15 cm soil depth, depicts available Mn decreased by 35.24%, 57.42%, 65.84% in soil depth 15-30 cm, 30-45 cm, 45-60 cm, respectively over 0-15 cm soil. Also, it was observed with an increase in soil depth available Mn decreased in all LU.

Among the different LU, all three horticulture LU significantly differed from the rice-wheat LUS and it was also observed litchi LU significantly varied from mango LU but rice-wheat not varied significantly with uncultivated LU.

Table 4.13: Effect of LUS's and soil depths on DTPA extractable manganese (mg kg^{-1}).

Land use systems (L)	**DTPA extractable manganese (mg kg^{-1})**				
	Soil depth(D) cm				
	0-15	**15-30**	**30-45**	**45-60**	**Mean**
Litchi solo	3.50	2.20	1.50	1.20	**2.10**
Litchi intercrop	3.10	2.08	1.30	1.00	**1.87**
Mango solo	3.80	2.50	1.70	1.36	**2.34**
Rice –wheat	2.81	1.83	1.15	0.96	**1.69**
Uncultivated	3.02	1.91	1.26	1.02	**1.80**
Mean	**3.25**	**2.10**	**1.38**	**1.11**	
SEm±	**L=0.06**	**D=**	**0.053**	**L X D=**	**0.119**
C.D.(P=0.05)	**L=0.17**	**D=**	**0.15**	**LX D=**	**NS**

4.3 Effect of different LUS's and soil depths on soil biological properties

4.3.1 Soil dehydrogenase acticity (µg TPF g^{-1} soil 24 hr^{-1})

The analyzed data predented in Table 4.14 reveals among different LU and soil depths DHA activity varied significantly and also interaction effect varied significantly. The DHA activity among different LU was marked highest in mango solo LU (13.64 µg TPF g^{-1} soil 24 hr^{-1}) followed by litchi solo LU (11.91 µg TPF g^{-1} soil 24 hr^{-1}), litchi intercrop (9.63 µg TPF g^{-1} soil 24 hr^{-1}), uncultivated LU (8.87 µg TPF g^{-1} soil 24 hr^{-1}) and least recorded in rice-wheat LU (7.44 µg TPF g^{-1} soil 24 hr^{-1}), *i.e.* it varied from (13.64 to 7.44 µg TPF g^{-1} soil 24 hr^{-1}). Among the various soil depth it was recorded highest DHA activity (18.22 µg TPF g^{-1} soil 24 hr^{-1}) in the upper soil layer (0-15 cm) followed by (12.04 µg TPF g^{-1} soil 24 hr^{-1}) in 15-30 cm soil depth, (6.59 µg TPF g^{-1} soil 24 hr^{-1}) in 30-45 cm soil depth while least observed (4.32 µg TPF g^{-1} soil 24 hr^{-1}) in 45-60 cm soil depth. DHA activity in different LU was when compared to mango solo found to decrease by 12.69%, 29.38%, 34.92%, and 45.48% in LU *viz.* litchi solo, litchi intercrop, uncultivated LU and rice-wheat LU over mango LU. The DHA activity data among soil depth when compared to 0-15 cm soil depth reveals a decrease of 33.92%, 63.82%, and 76.28% in soil depth 15-30 cm, 30-45 cm, 45-60, respectively over 0-15 cm soil depth.

The analyzed data shows that all the three horticulture-based LU significantly differed from rice-wheat LU and also found litchi solo, litchi intercrop and mango solo significantly differed, similarly uncultivated and rice-wheat LU significantly differed from each other. Among soil depths DHA activity significantly differed in all soil depths from each other.

The interaction effect indicates that the highest value of DHA activity was observed in 0-15 cm soil depth and within this soil depth highest was observed in mango LU 23.38 µg TPF g^{-1} soil 24 hr^{-1} followed by litchi LU 21.22 µg TPF g^{-1} soil 24 hr^{-1}, litchi intercrop 17.42 µg TPF g^{-1} soil 24 hr^{-1}, uncultivated LU 15.66 µg TPF g^{-1} soil 24 hr^{-1} and rice-wheat LU 13.44 µg TPF g^{-1} soil 24 hr^{-1} while least value 3.02 µg TPF g^{-1} soil 24 hr^{-1} observed in 45 cm soil depth with rice-wheat LU.

The present study shows the highest DHA recorded in horticultural LU compared to other LU similar results were also observed by (Kalambukattu *et al.*2013) that higher DHA in agri-horticulture due to higher SOC enhancing better microbial environment thus more DHA activity whereas in agricultural land less organic carbon and use of agrichemical inhibit microbial activity. Kuwano *et al.* (2014); Blonska *et al.* (2017) also reported higher DHA activity in horticultural LU and higher accumulation of SOM from litterfall which increases substrate for soil microbes enhancing DHA activity. In present study observed lower DHA activity with increasing soil depth which is due to the low organic substrate for microbes resulting in a lower microbial population and consequently low DHA activity Maini *et al.* (2020); and Bhavya *et al.* (2018) also obtained similar results.

Table 4.14 : Effect of LUS's and soil depths on dehydrogenase activity (DHA) (µg TPF g^{-1} soil 24 hr^{-1}).

Land use systems (L)	**Dehydrogenase activity (µg TPF g^{-1} soil 24 hr^{-1})**				
	Soil depth(D) cm				**Mean**
	0-15	**15-30**	**30-45**	**45-60**	
Litchi solo	21.22	13.67	7.85	4.87	**11.91**
Litchi intercrop	17.42	11.39	6.14	3.56	**9.63**
Mango solo	23.38	15.62	9.16	6.38	**13.64**
Rice –wheat	13.44	8.64	4.64	3.02	**7.44**
Uncultivated	15.66	10.89	5.17	3.78	**8.87**
Mean	**18.22**	**12.04**	**6.59**	**4.32**	
SEm±	**L=0.377**	**D= 0.34**		**L X D=**	**0.75**
C.D.(P=0.05)	**L=1.06**	**D= 0.95**		**LX D=**	**2.12**

4.3.2 Soil respiration CO_2 efflux (mg CO_2-C 100 g^{-1} day^{-1})

The soil respiration in different LU and soil depth varied significantly but their interaction effects not differ significantly. The soil respiration value among different LU was observed highest in mango solo LU 0.49 mg CO_2-C 100$g^{-1}$$day^{-1}$ followed by litchi solo LU 0.48 mg CO_2-C 100g^{-1} day^{-1}, litchi intercrop 0.46 mg CO_2-C 100g^{-1} day^{-1}, uncultivated LU 0.41 mg CO_2-C 100g^{-1} day^{-1} and least was recorded in rice-wheat LU 0.33 mg CO_2-C 100g^{-1} day^{-1}, *i.e.* it varied from 0.49 to 0.33 mg CO_2-C 100g^{-1} day^{-1}. Soil respiration among various soil depth highest value recorded 0.72 mg CO_2-C 100g^{-1} day^{-1} in upper soil layer 0-15 cm followed by 0.53 mg CO_2-C 100g^{-1} day^{-1} in 15 - 30 cm soil depth, 0.30 mg CO_2-C 100g^{-1} day^{-1} in 30-45 cm soil depth while least observed 0.18 mg CO_2-C 100g^{-1} day^{-1} in 45-60 cm soil depth.

Soil respiration data when compared to mango solo LU in different LU was found to decrease by 1.29%, 6.29%, 14.66%, and 32.01% in LU *viz.* litchi solo, litchi intercrop, uncultivated LU and rice-wheat LU over mango LU. The soil respiration data among soil depth when compared to 0-15 cm soil depth decreased by 26.55%, 58.89%, 75.42% in soil depth 15-30 cm, 30-45 cm, 45-60, respectively over upper soil depth 0-15 cm soil depth.

The analyzed data expressed that all the three horticulture-based LU significantly differed from rice-wheat LU and also observed that litchi solo and mango solo did not significantly differ, whereas uncultivated and rice-wheat LU significantly differed from each other.

In the present study, soil respiration was observed highest in mango solo LU and least in rice-wheat LU. Soil respiration is highly related to microbial population in LU Kuwano *et al.* (2014); Blonska *et al.* (2017) reported microbial population in horticulture LU more compared to agricultural LU due to more organic substrate availability. In our study also observed more microbial population in horticulture LU compared to rice-wheat LU, consequently more respiration in horticulture LU compared to others. In rice -wheat LU less microbial population was observed due to inorganic fertilizer and agrichemical use which inhibits microbial population. In conformity to our result, Maini *et al.* (2020) and Costa *et al.* (2018) also observed a higher microbial population in surface soil while in lower depth less microbial population was observed due to low organic carbon substrate availability.

Table 4.15: Effect of LUS's and soil depths soil respiration (CO_2 efflux) (mg CO_2-C $100g^{-1}$ day^{-1}).

Land use systems (L)	Soil respiration (CO_2 efflux) (mg CO_2-C $100g^{-1}$ day^{-1})				
	Soil depth(D) cm				Mean
	0-15	15-30	30-45	45-60	
Litchi solo	0.82	0.58	0.34	0.19	**0.48**
Litchi intercrop	0.76	0.55	0.31	0.19	**0.45**
Mango solo	0.86	0.59	0.34	0.19	**0.49**
Rice –wheat	0.56	0.41	0.21	0.14	**0.33**
Uncultivated	0.69	0.52	0.28	0.17	**0.41**
Mean	**0.74**	**0.53**	**0.30**	**0.18**	
SEm±	**L=0.013**	**D= 0.012**		**L X D=**	**0.027**
C.D.(P=0.05)	**L=0.04**	**D= 0.03**		**LX D=**	**0.07**

4.3.3 Autoclave citrate extractable (ACE) soil protein (mg g^{-1})

The soil protein data presented in Table 4.16 reveals in different LU and soil depth varied significantly but their interaction effect did not differ significantly. The soil protein content among different LU was found highest in mango solo LU 1.88 mg g^{-1} followed by litchi solo LU 1.75 mg g^{-1}, litchi intercrop 1.47 mg g^{-1}, uncultivated LU 1.21 mg g^{-1} and least recorded in rice-wheat LU 1.10 mg g^{-1}, *i.e.* it varied from 1.88 to 1.10 mg g^{-1} in LU. Soil protein content among various soil depths, recorded the highest value 1.66 mg g^{-1} in the upper soil layer 0-15 cm followed by 1.54 mg g^{-1} in 15-30 cm soil depth, 1.49 mg g^{-1} in 30-45 cm soil depth while least observed 1.25 mg g^{-1} in 45-60 cm soil depth. Soil protein value in different LU when compared with mango solo was found to decrease by 7.04%, 21.80%, 35.58%, and 41.40% in LU *viz.* litchi solo, litchi intercrop, uncultivated LU and rice-wheat LU, respectively over mango LU. The analyzed data reveals among soil depth when compared with 0-15 cm soil depth it by 6.97%, 10.37%, 24.60% in soil depth 15-30 cm, 30-45 cm, 45-60 cm, respectively over upper soil depth 0-15 cm soil depth.

Analyzed soil protein data depicts that all the three horticulture LU significantly differed with both rice-wheat LU and uncultivated LU, further also found litchi solo and mango solo LU significantly differed similarly uncultivated and rice-wheat LU significantly differed with each other. Among soil depth soil protein all soil depths differed significantly from each other.

Soil proteins are components of soil nitrogen soil which on mineralization released into the soil. Soil proteins are related to soil total nitrogen in our study highest TN was observed in mango solo LU and least in rice-wheat cropping system similarly in our experiment soil protein was observed highest in mango solo compared to agriculture LU.

Table 4.16: Effect of LUS's and soil depths on autoclave citrate extractable (ACE) soil protein (mg g^{-1}).

Land use systems (L)	Autoclave citrate extractable (ACE) soil protein (mg g^{-1})				
	Soil depth(D) cm				
	0-15	15-30	30-45	45-60	Mean
Litchi solo	1.96	1.82	1.72	1.50	**1.75**
Litchi intercrop	1.64	1.53	1.48	1.24	**1.47**
Mango solo	2.10	1.93	1.88	1.62	**1.88**
Rice –wheat	1.24	1.17	1.11	0.89	**1.10**
Uncultivated	1.35	1.26	1.24	1.00	**1.21**
Mean	**1.66**	**1.54**	**1.49**	**1.25**	
SEm±	**L=0.013**	**D=**	**0.012**	**L X D=**	**0.026**
C.D.(P=0.05)	**L=0.04**	**D=**	**0.03**	**LX D=**	**NS**

4.4 Effect of different LUS's and soil depths on soil carbon fractions

4.4.1 Total soil organic carbon (g kg^{-1})

The statistical data presented in Table 4.17 depicts that the main effect of various LU and soil depth on total SOC was significantly influenced while the interaction effect does not differ significantly. Among the different LU the highest 8.48 g kg^{-1} total SOC was observed in mango solo LU, followed by litchi solo 7.32 g kg^{-1}, litchi intercrop 6.40 g kg^{-1}, uncultivated LU 6.01 g kg^{-1} while 5.19 g kg^{-1} least recorded in the rice-wheat LUS. *i.e.* it ranged from 8.48 to 5.19 g kg^{-1} among various LU. Total SOC among soil depth, recorded highest 8.61 g kg^{-1} in upper soil depth 0-15 cm depth followed by 6.90 g kg^{-1} in soil depth 15-30 cm, 5.74 g kg^{-1} in soil depth 30-45 cm, 5.47 g kg^{-1} in soil depth 45-60 cm, respectively. Total SOC irrespective of different LU was found to decline with soil depth increase. While comparing different LUS's with mango solo LU, the total SOC content in litchi solo decreased 13.69%, litchi intercrop by 24.46%, uncultivated LU by 29.11% and rice-wheat LU decreased by 38.73% over mango LUS, respectively. Among soil depth, it was observed that total SOC content decreased with decreasing depth. While comparing total SOC among soil depth, compared with 0-15 cm soil depth, a marked 19.81% decrease in 15-30 cm, 33.35% in 30-45 cm and 36.51%, decrease in total SOC in 45-60 cm soil depth.

The analyzed data reveals that among LU, all three horticulture LU significantly varied with rice-wheat LU. Further, it was also observed mango solo and litchi solo significantly varied from each other similarly rice-wheat and uncultivated LU also significantly varied.

In the present study more organic carbon in horticulture LU was observed, due to higher organic matter in horticulture LU added in the soil through leaf litter fall and higher root biomass, root exudates which on decay adds carbon to the soil, as also observed in tree-based LU by Jha *et al.* (2012); Chauhan *et al.* (2011). Total organic carbon dynamics in soil depends on the balance between organic input from plant litter, external manures and degradation of carbon by heterotrophic micro-organism present in the soil. The quality of organic matter also governs total SOC. The leaf litter structural carbohydrate is more resistant to decomposition *i.e.* decay rate is slower due resulting in more

Mfilinge *et al.* (2002) studied carbon accumulation in tree-based LUS and observed more tillage operation in intensive cultivation reduces total SOC when compared to other less soil disturbed LU, this finding is in line with our result that higher total SOC in horticulture LU Yeasmin *et al.* (2020); Sayer (2006) and Thangavel *et al.* (2018). Grigal and Berguson (1998); and Sayer (2006) reported in horticulture intercropping system resulted in more loss of carbon due to soil disturbance as compared to solo horticulture LU. An intensive cropping system was found to decrease around 71% of the added carbon and the remaining 29% stabilises in agriculture soil Meena *et al.* (2018) and Sharma *et al.* (2014). In horticulture LU, due to canopy effect temperature inside is lower, additionally mulching effect of leaf litter results in slower mineralization loss of carbon Anantha *et al.* (2018). Total SOC decreases with an increase in soil depth due to lesser incorporation of organic residue in lower soil depth similar results were also observed by Heluf and Waken (2006); John *et al.* (2005); and Dawit *et al.* (2002).

Table 4.17: Effect of LUS's and soil depths on total soil organic carbon (g kg^{-1}).

Land use systems (L)	**Total soil organic carbon (g kg^{-1})**				
	Soil depth (D) cm				**Mean**
	0-15	**15-30**	**30-45**	**45-60**	
Litchi solo	9.32	7.62	6.30	6.02	**7.32**
Litchi intercrop	8.30	6.56	5.45	5.30	**6.40**
Mango solo	10.68	8.95	7.37	6.90	**8.48**
Rice –wheat	6.93	5.20	4.44	4.20	**5.19**
Uncultivated	7.82	6.18	5.12	4.91	**6.01**
Mean	**8.61**	**6.90**	**5.74**	**5.47**	
SEm±	**L=0.167**	**D=**	**0.149**	**L X D=**	**0.334**
C.D.(P=0.05)	**L=0.47**	**D=**	**0.42**	**LX D=**	**NS**

4.4.2 Non-labile carbon (g kg^{-1})

Non-labile carbon NLC fraction significantly varied in different LU and soil depth but the interaction effect not varied significantly Table 4.19. The analyzed data reveals that in different LU highest NLC content was observed in mango solo LU 2.93 g kg^{-1}, followed by litchi solo 2.59 g kg^{-1}, litchi intercrop 2.33 g kg^{-1} rice-wheat LU 2.22 g kg^{-1} while least 2.19 g kg^{-1} recorded in uncultivated LUS. Among LU, NLC content varied from 2.93 to 2.19 g kg^{-1}. The LU data, when compared to mango solo, reveals that the NLC fraction decreased by 11.6% in litchi solo, 20.46% in litchi intercrop, 24.28% in rice-wheat and 25.17% in uncultivated LU, respectively over mango LU. when different soil depths were compared with the uppermost 0-15cm soil depth NLC decreased by 14.88% in 15-30 cm, 25.47% in 30-45 cm and 24.94% in 45-60 cm soil depth, respectively. Irrespective of LU NLC decreased with soil depth, also observed in different soil depths NLC varied from 2.93 to 2.20 g kg^{-1}

From the analyzed data it is evident that there is a significant difference between horticulture solo LU and both rice-wheat and uncultivated LU. Also, observed litchi solo NLC significantly varied with mango solo LU while rice-wheat and uncultivated LU did not vary significantly from each other.

In our study horticulture LU observed to be higher NLC than rice-wheat and uncultivated LU which is due to more quantity of organic carbon being added in soil due to litterfall where as rice-wheat recorded higher NLC as faster oxidation active fraction *i.e.* easily decomposable SOC fractions due to more soil disturbance, similar observation was observed by Benbi *et al*. (2014) that rice-wheat LU recorded more non labile carbon.

4.4.3 Very labile carbon (g kg^{-1})

The laboratory analyzed data presented in Table 4.18 depicts that a significant difference in very labile carbon (VLC) was observed among various LU and soil depth while the interaction effect was found insignificant. The main effect of LU reveals that the highest value of VLC content was found in mango solo LU 3.01 g kg^{-1} followed by litchi solo 2.53 g kg^{-1}, litchi intercrop 1.94 g kg^{-1}, uncultivated 1.91 g kg^{-1} and least 1.30 g kg^{-1} in rice-wheat LUS *i.e.* it ranged from 3.01 to 1.30 g kg^{-1}. Among the different soil depth VLC fraction found highest 2.98 g kg^{-1} in upper 0-15 cm uppermost soil while 2.24, 1.74, 1.58 g kg^{-1} was observed in 15-30 cm, 30-45 cm, 45-60 cm soil depth, respectively. VLC fraction, when compared with mango solo LU, observed VLC decreased by 16.1%, 35.75%, 36.59% and 56.78% in litchi solo, litchi intercrop, uncultivated LU and rice-wheat LU, respectively over mango solo LU. Among soil depth VLC compared with uppermost soil found VLC decreased by 24.80%, 41.63% and 46.97% in soil depth 15-30 cm, 30-45 cm and 45-60 cm over the 0-15 cm soil depth.

It is clear from VLC data that mango LU and litchi LU significantly differed, also further observed all three horticulture-based LU significantly differed from rice-wheat LU. Further also observed mango solo and litchi solo significantly vary from each other similarly uncultivated and rice-wheat LU varied significantly. Among soil depths, the uppermost 0-15 cm soil depth varied significantly from all lower soil depths. In conformity to our result Benbi et al. 2014 also observed in tree based LUS more very labile carbon fraction compared to rice-wheat LUS.

4.4.4 Labile carbon (g kg^{-1})

The perusal data of LC fraction in different LUS's and soil depths were found to influence significantly but the interaction effect does not vary significantly Table 4.18. The analyzed data of LU reveals that the highest value of LC fraction was found in mango solo LU 1.53 g kg^{-1} followed by litchi solo 1.29 g kg^{-1}, litchi intercrop 1.04 g kg^{-1}, uncultivated 1.03 g kg^{-1} and least 0.82 g kg^{-1} in rice-wheat cropping system *i.e.* among LU it varied from 1.53 to 0.82 g kg^{-1}. Among soil depth LC fraction data revealed that the highest value 1.59 g kg^{-1} found at 0-15 cm while 1.21g kg^{-1}, 0.94g kg^{-1} and 0.82 g kg^{-1} at soil depth 15-30 cm, 30-45 cm, 45-60 cm, respectively.The observed data reveals that irrespective of LULC decreased with an increase in soil depth. When LC fraction of mango solo LU was compared with other LU found LC decrease by 15.79%, 32.17%, 33.08% and 46.69% in litchi solo, litchi intercrop, uncultivated LU and rice-wheat LU, respectively. Within soil depths when LC fractions were compared to 0-15 cm soil depth was found to decrease by 23.68%, 41.04% and 48.40% at soil depths 15-30 cm, 30-45 cm and 45-60 cm over the 0-15 cm soil depth.

Labile carbon data depicts that mango solo and litchi solo significantly differed from the rice-wheat LUS and further also observed that mango solo and litchi solo significantly differed from each other similarly uncultivated vary significantly with rice-wheat LU. All four soil depths found significantly vary from each other.

4.4.5 Less labile carbon (g kg^{-1})

The data expressed that LLC fraction significantly varied in different LU and soil depth while their interaction effect does not differ significantly Table 4.19. Among different LU mean value was found to be highest in mango solo LU 1.09 g kg^{-1} followed by litchi intercrop 1.03 g kg^{-1}, litchi solo 0.97 g kg^{-1}, uncultivated LU 0.89 g kg^{-1} and least in rice-wheat 0.84 g kg^{-1} *i.e.* it varied from 1.09 to 0.84 g kg^{-1} in LUS's. The analyzed data expressed, that among different soil depths highest LLC fraction observed in 0-15 cm soil depth 1.08 g kg^{-1} while in soil depth 15-30 cm, 30-45 cm and 45-60 cm LLC found to be 0.98 g kg^{-1}, 0.90 g kg^{-1} and 0.91 g kg^{-1}, respectively. Amid different LUS's when compared with mango solo LLC observed a decrease of 11.10%, 5.40%, 18.28% and 23.60% in LU litchi solo, litchi intercrop, uncultivated LU and rice-wheat LUS's over mango LU Similarly among soil depths when LLC of 0-15 cm compared with soil depths (15-30) cm, (30-45) cm and (45-60) found a decrease in LLC value by 9.52%, 16.67%, and 15.22%, respectively over the top 0-15 cm soil depth Less labile carbon fraction of LU reveals that mango solo and litchi solo significantly varied from rice-wheat LU. It was also observed, that mango solo and litchi solo varied significantly while rice-wheat and uncultivated not differed significantly. Among soil depth LLC in 0-15cm, soil depth significantly varied with all lower soil depths.

Table 4.18: Effect of LUS's and soil depths on very labile (VLc) and labile (Lc) organic carbon (g kg^{-1}).

Land use systems (L)	Soil depth(D) cm									
	0-15		15-30		30-45		45-60		Mean	
	VLc	Lc	VLc	Lc	VLc	Lc	VLc	Lc	VLc	Lc
Litchi solo	3.46	1.76	2.67	1.42	2.08	1.08	1.90	0.90	2.53	1.29
Litchi intercrop	2.74	1.49	2.02	1.10	1.55	0.82	1.43	0.75	1.94	1.04
Mango solo	4.06	2.03	3.21	1.66	2.52	1.32	2.26	1.12	3.01	1.53
Rice -wheat	2.01	1.17	1.33	0.83	1.01	0.66	0.86	0.61	1.30	0.82
Uncultivated	2.66	1.50	1.98	1.06	1.55	0.82	1.46	0.73	1.91	1.03
Mean	**2.98**	**1.59**	**2.24**	**1.21**	**1.74**	**0.94**	**1.58**	**0.82**		
SEm±	**VLc: L=0.08 D=0.071 L X D= 0.16**					**Lc: L=0.04 D=0.036 L X D= 0.08**				
C.D.(P=0.05)	**VLc:L=0.23 D=0.02 LX D= NS**					**Lc: L=0.11 D=0.1 LX D= NS**				

Table 4.19: Effect of LUS's and soil depths on non labile (NLc) and less labile (LLc) organic carbon (g kg^{-1}).

Land use systems (L)	Soil depth(D) cm									
	0-15		15-30		30-45		45-60		Mean	
	NLc	LLc	NLc	LLc	NLc	LLc	NLc	LLc	NLc	LLc
Litchi solo	3.04	1.12	2.64	0.98	2.29	0.87	2.39	0.91	2.59	0.97
Litchi intercrop	2.80	1.08	2.33	0.97	2.04	1.05	2.14	1.04	2.33	1.03
Mango solo	3.36	1.27	3.02	1.18	2.68	0.95	2.64	0.98	2.93	1.09
Rice -wheat	2.83	0.98	2.20	0.82	1.96	0.75	1.88	0.80	2.22	0.84
Uncultivated	2.61	0.94	2.27	0.93	1.94	0.87	1.94	0.84	2.19	0.89
Mean	**2.93**	**1.08**	**2.49**	**0.98**	**2.18**	**0.90**	**2.20**	**0.91**		
SEm±	**NLc:L=0.077 D=0.069 L X D= 0.153**					**LLc: L=0.031 D=0.028 L X D= 0.064**				
C.D.(P=0.05)	**NLc: L=0.22 D=0.19 LX D= NS**					**LLc: L=0.09 D=0.08 LX D= NS**				

4.4.6 Effect of LUS's and soil depths on active and passive carbon pool (g kg^{-1})

The different oxidizable fractions of SOC *i.e.* very labile carbon (VLc), labile carbon (Lc), less labile carbon (LLc), and non- labile carbon (NLc) pools are categorised according to oxidising capability Chan *et al.* (2001) and presented in Table 4.20 and Fig 4.3. These different fractions of SOC are sensitive indicators of LU and vary according to management practices being followed as observed by Blair *et al.* (1995); and Purakayastha *et al.* (2008). In the present study, we have observed in the general average magnitude of different carbon fractions among different LUfollowed a sequence of NLc> VLc> Lc> LLc constituting around 37.09% > 31.45% >16.95% >14.67% of the total SOCwhile in mango land followed VLc > NLc > Lc> LLc. In our study, we have observed total SOC in different LU followed the general sequence mango solo> litchi solo > litchi intercrop> uncultivated LU > rice-wheat LU. Active carbon proportion was observed more in mango solo and litchi solo where as in other LU proportion of passive pool was more than active pool similar observation also observed by Naik *et al*, (2016) that mango solo and litchi solo contained more active pool than passive pool. In the present study, found that the active pool (Vlc +Lc) which is easily assimilated by the soil microbial population constitutes around 48% whereas the passive pool more resistant to microbial assimilation constitutes around 52% of the total SOC.

In conformity to our result Benbi *et al.* (2012); Datta *et al.* (2015); and Signor *et al.* (2018) also observed more SOC accumulation in horticulture LU in comparison to agri-horticulture, agriculture land and fallow land system. It was also observed lability of SOC more in horticulture LU due to more leaf litter turnover in soil and a higher amount of root exudates in the horticulture LUS.. In agricultural soil SOC fraction, both active and passive carbon pool observed low due to low addition of organic residue input and more loss of carbon due to erosion and soil disturbance Jha *et al.* (2012); Thorburn *et al.* (2012) and Hu *et al.* (1997). Poorly managed LUS affects the labile and non-labile pools of carbon affecting carbon sequestration in soil. Chen *et al.* (2007) also observed a decline in SOC with increasing depth due to less input of organic matter in lower depths. Moreover, study results indicated that land-use systems affected both active and passive carbon pools in the different soil layers, whereby the losses in poorly managed agricultural systems may have imposed a negative impact on SOC sequestration.

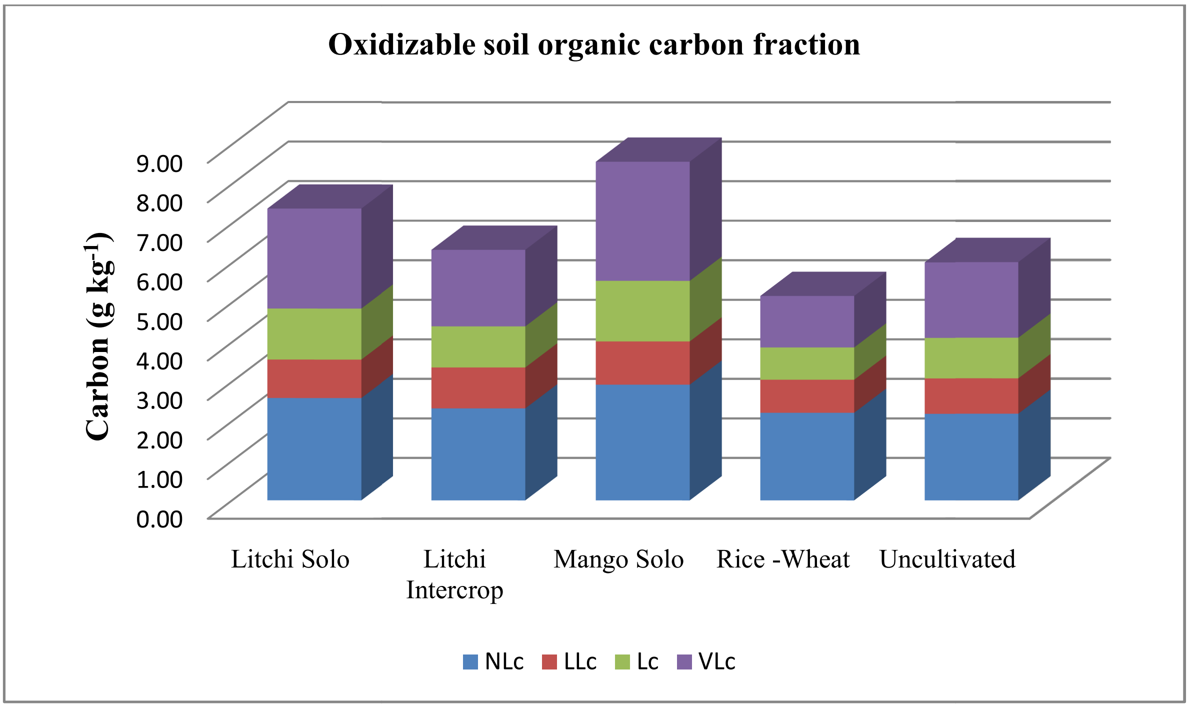

Fig 4.3: Oxidizable soil organic carbon fractions in different LUS's

4.4.7 Soil microbial biomass carbon (mg kg^{-1})

The analyzed data revealed that SMBC varied significantly among various LU and soil depth while the interaction effect did not vary significantly Table 4.20. The highest MBC in different LU was recorded in mango solo LU 146.73 mg kg^{-1}, followed by litchi solo 118.93 mg kg^{-1}, litchi intercrop 92.57 mg kg^{-1}, uncultivated LU 85.97 mg kg^{-1} and least recorded in rice-wheat LU 70.50 mg kg^{-1} *i.e.* among LU it varied from 146.73 to 70.50 mg kg^{-1}. Among all LU, MBC content was found to decline when soil depth increased. Within different soil depths highest value of MBC was recorded 170.62 mg kg^{-1} in upper topsoil 0-15 cm followed by 123.04 mg kg^{-1}, 71.06 mg kg^{-1} and 47.03 mg kg^{-1} at 15-30 cm, 30-45 cm and 45-60 cm soil depth, respectively. *i.e.* within soil depth, MBC ranged from 123.04 to 47.03 mg kg^{-1}. Among LU, MBC data when compared with mango solo revealed that MBC content decreased by 18.95%, 36.91%, 41.41% and 51.95%, in LU namely litchi solo, litchi intercrop, uncultivated and rice-wheat LU over mango solo LU, respectively. Similarly, among different soil depths, MBC content compared with topsoil 0-15 cm showed MBC decreased by 27.89%, 58.35% and 72.43% in 15-30 cm, 30-45 cm and 45-60 cm soil depth, respectively over 0-15 cm soil depth. The interaction effect of different LU and soil depth revealed that the highest MBC observed 246.24 mg kg^{-1} in 0-15 cm soil depth followed by litchi solo 195.68 mg kg^{-1}, litchi intercrop 150.44 mg kg^{-1}, uncultivated land 142.51 mg kg^{-1}

and rice-wheat 118.25 mg kg^{-1} LU, while least value was observed 34.12 mg kg^{-1} in rice-wheat LU at 45-60 cm soil depth.

Further, it was also observed that all three horticulture-based LUS's significantly differed from rice-wheat LU; further also found all three horticulture-based LUS's varied significantly from each other. Among the soil depths, all soil depths significantly vary from each other.

In the present study higher SMBC was observed in horticulture LU, the result is in line with Lepcha and Devi (2020) finding that more litter fall and deep rooted system permits more microbial activity *i.e* more rhizospheric zone in horticulture LUs when compared to other LU. The lowest SMBC was recorded in rice-wheat LU which is due to less addition of organic residue and more loss of organic substrate due to intensive cultivation management practices Van Leeuwen *et al.* (2017) and Soleimani *et al.* (2019). Lepcha and Devi (2020) found that SMBC found higher SMBC in uppermost soil depth observed more due to more availability of organic residue and nitrogen making favourable environment for microbial growth, the finding is in line with our observation. In litchi intercrop LU higher SMBC was observed compared to rice-wheat LU as tree litter fall organic residue addition, more soil moisture due to mulching effect, the lower temperature under tree canopy overall makes a favourable environment for the microbial population. The quality and quantity of organic residue, soil properties, management activity followed and climatic conditions govern SMBC in soil, as observed by Kaiser *et al.* (1992); Grisi *et al.* (1998); Heisler and Kaiser (1995); and Weigand *et al.* (1995). Similar finding were also observed by Naik *et al.* (2016) that mango SMBC was more compare to litchi solo LU and also both horticultural LU higher over control.

Table 4.20: Effect of LUS's and soil depths on soil microbial biomass carbon (mg kg^{-1}).

Land use systems (L)	**Soil microbial biomass carbon (mg kg^{-1})**				
	Soil depth(D) cm				
	0-15	**15-30**	**30-45**	**45-60**	**Mean**
Litchi solo	195.68	142.65	82.35	55.02	**118.93**
Litchi intercrop	150.44	111.78	64.99	43.08	**92.57**
Mango solo	246.24	172.89	105.36	62.42	**146.73**
Rice –wheat	118.25	83.86	45.77	34.12	**70.50**
Uncultivated	142.51	104.02	56.83	40.52	**85.97**
Mean	**170.62**	**123.04**	**71.06**	**47.03**	
SEm±	**L=2.68**	**D= 2.40**		**L X D= 5.36**	
C.D.(P=0.05)	**L=7.55**	**D= 6.75**		**LX D= 15.09**	

4.5 Effect of different LUS's and soil depth on nitrogen fractions

4.5.1 Total nitrogen (mg kg^{-1})

Total soil nitrogen significantly differed among LU and soil depth while the interaction effect was found not significant Table 4.21. The highest mean value among LU was recorded in mango solo LU 642.15 mg kg^{-1} followed by litchi solo LU 560.68 mg kg^{-1}, litchi intercrop 497.22 mg kg^{-1}, uncultivated LU 472.37 mg kg^{-1} and least recorded in rice-wheat LU 438.07 mg kg^{-1}, *i.e.* it varied from 642.15 to 438.07 mg kg^{-1}. Among soil depths, the highest total nitrogen content 659.92 mg kg^{-1}, was observed in the upper soil layer 0-15 cm followed by 535.99 mg kg^{-1} in 15-30 cm soil depth, 457.79 mg kg^{-1} in 30-45 cm soil depth while least observed 434.68 mg kg^{-1} in 45-60 cm soil depth.

Total nitrogen content among different LU when compared in terms of percentage change with mango solo it was observed to decrease by 12.69%, 22.57%, 26.44% and 31.78% in LU *viz.* litchi solo, litchi intercrop, uncultivated LU and rice-wheat LU, respectively over mango solo LU. Among the soil depth total nitrogen when compared with 0-15 cm soil depth, a decrease was observed by 18.78%, 30.63% and 34.13% in 15-30cm, 30-45 cm and 45- 60 cm, respectively over 0-15 cm upper soil depth.

The analysed data depicts significant variation observed between all three horticulture-based LU with both uncultivated and rice-wheat LU, also marked significant variation was observed between litchi solo, litchi intercrop and mango LU. Among soil depths, all four soil depths significantly differed from each other. The interaction effect between soil depth and LU was found insignificant.

In the present study total nitrogen in soil followed decreasing trend mango solo> litchi solo> litchi intercrop> uncultivated land> rice-wheat LU *.i.e* highest in horticulture LU than agriculture land. It was also observed total nitrogen and total organic carbon followed a similar trend as both are structural components of organic matter. In conformity with our result Abera and Belachew (2011) also observed there was a significant decrease in TN in agriculture soil and horticulture intercropping system when compared to forest, horticulture LU and grassland which is mainly due to increase oxidation of SOM because of intensive tillage and less organic residue input. Also Malo *et al.* (2005) observed that in agricultural land application of inorganic fertilizer is not able to substitute nitrogen bening removed by crop and TN losses due to erosion and leaching loss, similar result observed in our experiment. It has been observed to decrease TN with an increase in soil depth, similar trend was observed by Meena *et al.* (2018); Tisdale *et al.* (2002); Gebreselassie (2002) and Abera and Belachew (2011) reported lower TN due to low humus content with increasing depth because of lesser organic input in the soil.

Table 4.21: Effect of LUS's and soil depths on soil total nitrogen (mg kg^{-1}).

Land use systems (L)	Total nitrogen (mg kg^{-1})				
	Soil depth(D) cm				Mean
	0-15	15-30	30-45	45-60	
Litchi solo	700.45	580.22	489.12	472.91	**560.68**
Litchi intercrop	633.86	508.17	445.33	401.51	**497.22**
Mango solo	791.28	674.07	566.84	536.39	**642.15**
Rice –wheat	572.43	435.83	378.98	365.01	**438.07**
Uncultivated	601.58	481.69	408.66	397.55	**472.37**
Mean	**659.92**	**535.99**	**457.79**	**434.68**	
SEm±	**L=12.65**	**D= 11.32**		**LXD=**	**25.31**
C.D.(P=0.05)	**L=35.65**	**D= 31.88**		**LX D=**	**NS**

4.5.2 Ammonium nitrogen (mg kg^{-1})

The analyzed ammonium nitrogen data presented in Table 4.22 reveals that among different LU and soil depth significant variation was observed while their interaction effect did not significantly differ. The observed data depicts that among different LUs highest ammonium nitrogen was recorded in mango solo LU 88.80 mg kg^{-1} followed by litchi solo LU 77.26 mg kg^{-1}, litchi intercrop 67.04 mg kg^{-1}, uncultivated LU 63.69 mg kg^{-1} and least recorded in rice-wheat LU 56.90 mg kg^{-1}, *i.e.* it varied from 88.80 to 56.90 mg kg^{-1}. Within the various soil depths it was observed the highest ammonium nitrogen content 90.02 mg kg^{-1} in the upper soil layer 0-15 cm followed by 72.67 mg kg^{-1} in 15-30 cm soil depth, 61.17 mg kg^{-1} in 30-45 cm soil depth while least observed 59.09 mg kg^{-1} in 45-60 cm soil depth. Ammonium nitrogen content in different LU when compared with mango LU was found to decrease by 13.0%, 24.50%, 28.28%, and 35.93% in LU *viz.* litchi solo, litchi intercrop, uncultivated LU and rice-wheat LU over mango LU. The Analyzed data depicts that ammonium nitrogen among soil depth when compared to 0-15 cm soil depth found decreased by 19.28%, 32.05%, 34.36% in soil depth 15-30 cm, 30-45 cm, 45-60 cm, respectively over 0-15 cm soil depth.

The data reveals that all three horticulture-based LU significantly varied with rice-wheat LU while mango solo and litchi solo significantly differed similarly uncultivated and rice-wheat LU varied significantly with each other. Among soil depths, data revealed that all soil depths varied significantly from each other.

Table 4.22: Effect of LUS's and soil depths on ammonium nitrogen (mg kg^{-1})

Land use systems (L)	Ammonium nitrogen (mg kg^{-1})				
	Soil depth(D) cm				Mean
	0-15	15-30	30-45	45-60	
Litchi solo	97.36	80.09	66.90	64.69	**77.26**
Litchi intercrop	85.57	68.12	57.60	56.87	**67.04**
Mango solo	110.38	93.37	77.81	73.63	**88.80**
Rice –wheat	74.99	56.69	48.86	47.05	**56.90**
Uncultivated	81.81	65.05	54.69	53.20	**63.69**
Mean	**90.02**	**72.67**	**61.17**	**59.09**	
SEm±	**L=1.78**	**D= 1.60**		**L X D= 3.56**	
C.D.(P=0.05)	**L=5.02**	**D= 4.49**		**LX D= NS**	

4.5.3 Nitrate nitrogen (mg kg^{-1})

The main effect of different LU and soil depth varied significantly while their interaction effect not varied significantly Table 4.23. The nitrate nitrogen among different LU was recorded highest in mango solo LU 17.22 mg kg^{-1} followed by litchi solo LU 14.81 mg kg^{-1}, litchi intercrop 12.79 mg kg^{-1}, uncultivated LU 12.25 mg kg^{-1} and least recorded in rice-wheat LU 11.58 mg kg^{-1}, *i.e.* it varied from 11.58 to 17.22 mg kg^{-1}. Within the various soil depths it was recorded highest nitrate nitrogen content 17.71 mg kg^{-1} in upper soil layer 0-15 cm followed by 14.24 mg kg^{-1} in 15-30 cm soil depth, 11.86 mg kg^{-1} in 30-45 cm soil depth while least observed 11.11 mg kg^{-1} in 45-60 cm soil depth. Nitrate nitrogen content in different LU found decrease by 13.96%, 25.70%, 28.85%, and 32.76% in LU *viz*. litchi solo, litchi intercrop, uncultivated LU and rice-wheat LU when compared with mango LU. The nitrate nitrogen data depicts that nitrate decreased by 19.57%, 33.03%, 37.25% in soil depth 15-30 cm, 30-45 cm, 45-60 cm, respectively over 0-15 cm soil depth.

The data depicts that all the three horticulture LU significantly differed with rice-wheat LU, also litchi solo and mango solo significantly differed whereas uncultivated LU was observed at par with rice-wheat LU.

Table 4.23: Effect of LUS's and soil depths on nitrate nitrogen (mg kg^{-1})

Land use systems (L)	Nitrate nitrogen (mg kg^{-1})				
	Soil depth(D) cm				
	0-15	15-30	30-45	45-60	Mean
Litchi solo	18.91	15.51	12.81	12.02	**14.81**
Litchi intercrop	16.54	13.13	10.98	10.52	**12.79**
Mango solo	21.68	18.28	15.07	13.83	**17.22**
Rice –wheat	15.46	11.65	9.93	9.27	**11.58**
Uncultivated	15.94	12.64	10.51	9.91	**12.25**
Mean	**17.71**	**14.24**	**11.86**	**11.11**	
SEm±	**L=0.34**	**D= 0.30**		**L X D=**	**0.68**
C.D.(P=0.05)	**L=0.95**	**D= 0.85**		**LX D=**	**NS**

4.5.4 Total mineral nitrogen (mg kg^{-1})

The total mineral nitrogen (NH_4^+ -N + NO_3^- -N) among different LU and soil depth varied significantly while their interaction effect did not vary significantly Table 4.24. The total mineral nitrogen among different LU was recorded highest in mango solo LU 106.02 mg kg^{-1} followed by litchi solo LU 92.07 mg kg^{-1}, litchi intercrop 79.83 mg kg^{-1}, uncultivated LU 75.94 mg kg^{-1} and least recorded in rice-wheat LU 68.48 mg kg^{-1}, *i.e.* it varied from 106.02 to 68.48 mg kg^{-1}. Within the various soil depth it was recorded highest total mineral nitrogen content 107.73 mg kg^{-1} in the upper soil layer 0-15 cm followed by 86.91 mg kg^{-1} in 15-30 cm soil depth, 73.03 mg kg^{-1} in 30-45 cm soil depth while least observed 70.2 mg kg^{-1} in 45-60 cm soil depth. Total mineral nitrogen content in different LU when compared to mango solo LU was found to decrease by 13.15%, 24.70%, 28.37%, and 35.41% in LU *viz.* litchi solo, litchi intercrop, uncultivated LU and rice-wheat LU when compared with mango LU. The data depicts that among soil depth when total mineral nitrogen compared with 0-15 cm soil depth found decreased by 19.33%, 32.21%, 34.84% in soil depth 15-30 cm, 30-45 cm, 45-60 cm, respectively over 0-15 cm soil depth.

The data depicts that all the three horticulture-based LU significantly differed from rice-wheat LU, also observed litchi solo and mango solo and litchi intercrop significantly differed from each other, similarly uncultivated and rice-wheat significantly differed. The present study showed the highest mineral nitrogen observed in horticulture LU and the least in rice-wheat LU, similar observation by Urra *et al.* (2018) reported a higher amount of mineral nitrogen in forest and horticulture LU due to higher availability of SOC and TN which stimulates more soil microbial population enhancing mineral nitrogen fraction. In the rice-wheat cropping system, the lowest mineral nitrogen was observed may be due to leaching loss during irrigation and rainfall and another reason the addition of a wider C/N ratio of organic residue may reduce mineral nitrogen, a similar finding reported by Aranguren *et al.* (2018). In soil nitrogen mineralization is influenced by many factors, higher organic carbon will enhance microbial population which will enhance ammonification and nitrification in soil, also the C/N ratio is an important factor Mohanty *et al.* (2013). If soil nitrogen is below 2% nitrogen immobilisation will take place and above 2% net mineralization of nitrogen in soil takes place as reported by Seneviratne *et al.* (2000) reason for lower mineral nitrogen in agriculture soil compared to horticulture LU and agri-horticultural LU. Mikha *et al.* (2005) observed a similar finding that if more carbon substrate is available in the soil while lesser nitrogen available will influence the immobilisation process.

Table 4.24: Effect of LUS's and soil depths on total mineral nitrogen (NH_4^+ -N + NO_3^--N) (mg kg^{-1}).

Land use systems (L)	**Total mineral nitrogen (NH_4^+ -N + NO_3^--N) (mg kg^{-1})**				
	Soil depth(D) cm				
	0-15	**15-30**	**30-45**	**45-60**	**Mean**
Litchi solo	116.27	95.60	79.72	76.70	**92.07**
Litchi intercrop	102.11	81.25	68.58	67.39	**79.83**
Mango solo	132.07	111.66	92.88	87.47	**106.02**
Rice –wheat	90.44	68.34	58.78	56.33	**68.48**
Uncultivated	97.76	77.69	65.20	63.12	**75.94**
Mean	**107.73**	**86.91**	**73.03**	**70.20**	
SEm±	**L=2.11**	**D= 1.9**		**L X D=**	**4.23**
C.D.(P=0.05)	**L=5.97**	**D= 5.34**		**LX D=**	**NS**

4.5.5 Soil microbial biomass nitrogen (mg kg^{-1})

The statistical result depicts that SMBN content significantly varied among various LU and their interaction effect was also found significant Table 4.25. The highest MBN mean within LU was expressed in mango solo LU 13 mg kg^{-1} followed by litchi solo use 10.57 mg kg^{-1}, litchi intercrop LU 9.11 mg kg^{-1}, uncultivated LU 9.03 mg kg^{-1} while least observed in rice-wheat LU 8.58 mg kg^{-1}. *i.e.* among LU varied from 13 to 8.58 mg kg^{-1}. Within soil depths highest MBN mean value observed 16.65 mg kg^{-1} in 0-15 cm soil depth followed by 12.08 mg kg^{-1} in 15-30 cm, 6.90 mg kg^{-1} in 30-45 cm and least 4.60 mg kg^{-1} in 45-60 cm soil depth. Microbial biomass nitrogen when compared with mango solo LU found to decrease by 18.64%, 29.93%, 30.52% and 34.0% within LU *viz*. litchi solo, litchi intercrop, uncultivated LU and rice-wheat LU, respectively over mango solo LU, whereas among soil depth when compared with 0-15 cm soil depth MBN decreased by 27.44%, 58.55%, 72.35% in soil depth 15-30 cm, 30-45 cm, 45-60 cm, respectively over 0-15 cm soil depth. Irrespective of LU MBN was found to decline when soil depth increased.

The interaction effect of LU and soil depth reveals that the highest MBN was observed in mango solo 21.74 mg kg^{-1} in 0-15 cm soil depth followed by litchi solo 17.43 mg kg^{-1}, uncultivated LU 14.97 mg kg^{-1} and litchi intercrop 14.73 mg kg^{-1}, rice-wheat LU 14.37 mg kg^{-1} while least value was observed in rice-wheat LU at 45-60 cm soil depth.

Among the different LU, it was observed mango solo and litchi solo horticulture LU significantly differed from rice-wheat LU. Also all three horticulture-based LUS's significantly varied from each other, similarly rice-wheat and uncultivated LU varied significantly from each other. Among soil depth, it was observed all soil depth MBN significantly varied with each other.

The dynamics of soil nitrogen and soil carbon are closely related in soil, mostly nitrogen in the form of organic compounds and soil micro-organism biomass heterotrophic micro-organisms utilising soil carbon for energy. Soil microorganism plays important role in nutrient recycling and energy in the soil ecosystem. Microbial biomass nitrogen is an important source of available nitrogen in the soil Merino *et al.* (2004) and Powlson *et al.* (1987).

In the present study higher MBN was observed in horticultural LU compared to rice-wheat LU, this is mainly due to higher microbial biomass in horticulture LU. In conformity with our result (Kara and Bolat 2008; and Detwiler, 1986) observed more MBN observed in natural forest and horticultural LU, the factor influencing mainly better soil moisture, the low temperature under the tree canopy, higher organic input due to litterfall and root deposition, less soil disturbance, less soil erosion, higher organic carbon and nitrogen in the soil making favourable condition for the microbial population thus more MBN accumulation in soil. Kara and Bolat (2008) also observed less MBN in agricultural land compared to horticultural LU.

In the present study, we observed a decrease in MBN with an increase in soil depth which is mainly due to less availability of labile carbon and nitrogen pool with increasing depth, similar result was observed by Agnelli *et al.* (2004).

Table 4.25: Effect of LUS's and soil depths on soil microbial biomass nitrogen (mg kg^{-1})

Land use systems (L)	Soil microbial biomass nitrogen (mg kg^{-1})				
	Soil depth(D) cm				Mean
	0-15	15-30	30-45	45-60	
Litchi solo	17.43	12.75	7.33	4.78	**10.57**
Litchi intercrop	14.73	11.06	6.35	4.29	**9.11**
Mango solo	21.74	15.37	9.35	5.52	**13.00**
Rice –wheat	14.37	10.25	5.52	4.18	**8.58**
Uncultivated	14.97	10.97	5.94	4.24	**9.03**
Mean	**16.65**	**12.08**	**6.90**	**4.60**	
SEm±	**L=0.198 D= 0.1769 L X D= 0.3956**				
C.D.(P=0.05)	**L=0.56 D= 0.50 LX D= 1.11**				

4.6 Effect of different LUS's and soil depths on soil carbon and nitrogen stock

4.6.1 Carbon stock in soil (Mg C ha^{-1})

The analysed data of soil carbon stock in different LU and soil depth Table 4.26 and Fig 4.4 varied significantly but their interaction effect was found non-significant. The soil carbon stock among different LU was found highest in mango solo LU 17.83 Mg C ha^{-1} followed by litchi solo LU 15.33 Mg C ha^{-1}, litchi intercrop 13.55 Mg C ha^{-1}, uncultivated LU 13.08 Mg C ha^{-1} and least recorded in rice-wheat LU 11.17 Mg C ha^{-1} *i.e.* it varied from 15.33 to 11.17 Mg C ha^{-1} in LU. Soil carbon stock among various soil depths, recorded the highest 17.55 Mg C ha^{-1} in the upper soil layer 0-15 cm followed by 14.65 Mg C ha^{-1} in 15-30 cm soil depth, 12.44 Mg C ha^{-1} in 30-45 cm soil depth while least observed 12.14 Mg C ha^{-1} in 45-60 cm soil depth. Soil carbon stock in different LU when compared to mango solo found decreased by 14.02%, 24.03%, 26.64%, and 37.36% in LU *viz.* litchi solo, litchi intercrop, uncultivated LU and rice-wheat LU, respectively over mango solo LU. The analysed data when compared to 0-15 cm soil depth revealed that among soil depth, soil carbon stock decreased by 16.48%, 29.09%, and 30.83% in soil depth 15-30 cm, 30-45 cm, 45-60 cm, respectively over upper soil depth 0-15 cm.

Analyzed soil protein data depicts that all the three horticulture LU significantly differed from rice-wheat LU, further also found litchi solo and mango solo LU significantly differed similarly uncultivated and rice-wheat LU significantly differed from each other. Also observed 0-15 cm soil depth significantly differed from all lower depths.

In the present study, it was observed highest soil carbon stock was observed in mango solo LU followed by litchi solo LU, litchi intercrop, and uncultivated land while least in rice-wheat LU, the results are in line with findings of Rajan. K. *et al.* (2019) observed in horticulture mango LUS more carbon stock accumulated compared to rice-wheat LUS, similar finding also observed by Naik *et al.* (2016) where mango sequestered more carbon than litchi LU and also observed decrease in carbon with increase in soil depth. Sharma *et al.* (2014); Hussain *et al.* (2019); Meena *et al.* (2018); Venkanna *et al.* (2014); Manjaiah *et al.* (2000); Smith (2007); and Mandal *et al.* (2020) reported highest soil carbon stock in forest and horticulture LUS sequestered more carbon compared to agricultural LU due to higher above and below biomass which enriches soil through leaf litterfall deposition in horticulture LU also observed in agricultural LU less carbon input and more soil disturbance due to which more oxidation of SOC. In horticulture LU soil is more enriched with soil carbon which enhances soil aggregation resulting in more carbon preserved inside soil aggregates. It has been also observed that uncultivated LU having grasses with fibrous root systems and very less soil disturbance might be the reason for more carbon stock compared to rice-wheat LU. Also in rice-wheat erosion of organic clay complex with water causes considerable loss of organic carbon. In horticulture solo, more carbon being sequestered compared to horticulture intercrop reason might be due to more tillage operation causing rapid decomposition of SOM, exposing soil carbon for oxidation. Sahoo *et al.* (2019) in line with our finding observed that soil carbon dynamics in the soil is mainly governed by LU, climate, management practices followed and vegetation composition. Also, Mandal *et al.* (2020) observed the highest soil organic 0- 90 cm soil depth in horticulture LU, 1.5 and 2 times more in comparison to agriculture LU and uncultivated land. In rice-wheat LU least carbon stock was observed due to less organic substrate input and repeated tillage operation which breaks down soil aggregates exposing SOC to microbial oxidation. Beare *et al.* (1994); and Baker *et al.* (2007) also reported a similar finding. In the present study, we observed SOC stock decreased with increasing soil depth due to lesser organic carbon input in lower depth moreover higher SOC stock in lower depth observed in horticulture LU compared to rice-wheat LU might be due to a deep-rooted system which deposits more carbon in lower depth similar finding observed by Brevik (2013); and Garcia *et al.* (2016).

Table 4.26: Effect of LUS's and soil depths on carbon stock soil (Mg C ha^{-1}).

Land use systems (L)	Carbon stock soil (Mg C ha^{-1})				
	Soil depth(D) cm				
	0-15	15-30	30-45	45-60	Mean
Litchi solo	18.49	16.00	13.58	13.26	**15.33**
Litchi intercrop	16.78	13.98	11.73	11.71	**13.55**
Mango solo	21.46	18.69	15.77	15.42	**17.83**
Rice –wheat	14.33	11.18	9.79	9.38	**11.17**
Uncultivated	16.67	13.42	11.33	10.91	**13.08**
Mean	**17.55**	**14.65**	**12.44**	**12.14**	
SEm±	**L=0.316**	**D=**	**0.283**	**L X D=**	**0.632**
C.D.(P=0.05)	**L=0.89**	**D=**	**0.80**	**LX D=**	**NS**

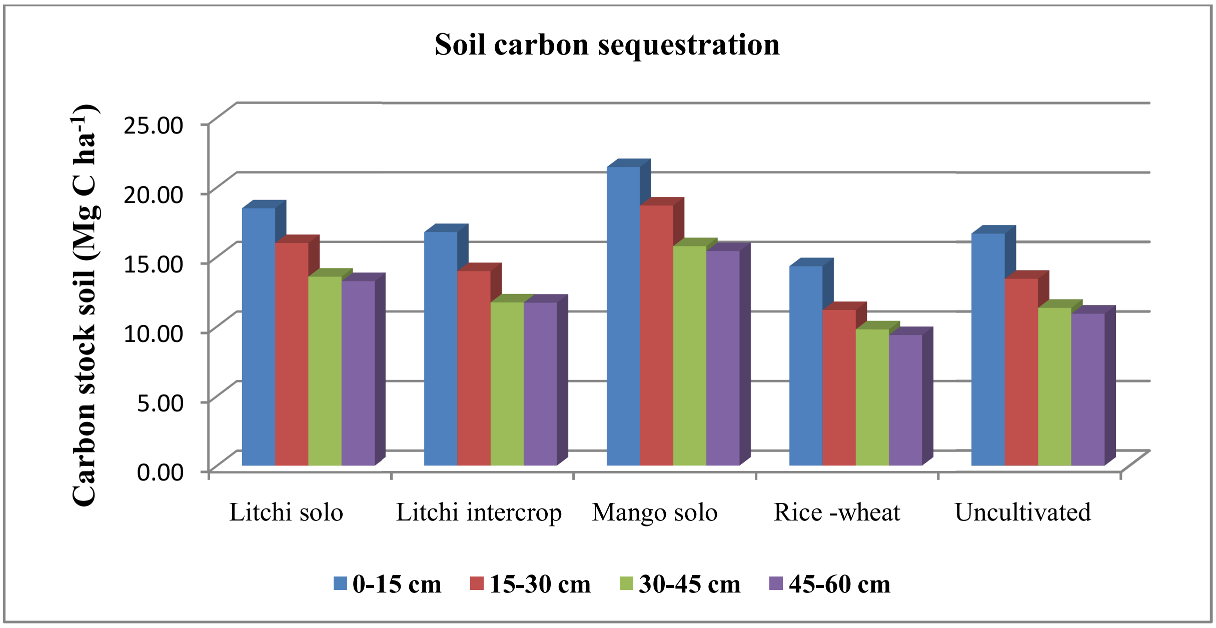

Fig 4.4: Soil carbon sequestration in different LUS's and soil depths.

4.6.2 Cumulative carbon stock in soil (Mg C ha^{-1})

The cumulative C-stock Table 4.27, Fig 4.5 in 0-60 cm soil depth was significantly influenced under different LUS's. The highest cumulative C-stock was observed under mango solo 71.34 Mg C ha^{-1} followed by litchi solo 61.34 Mg C ha^{-1}, litchi intercrop 54.19 Mg C ha^{-1}, uncultivated 52.33 Mg C ha^{-1}, while least was observed in rice –wheat 44.69 Mg C ha^{-1} LUS .*i.e.* varied from 61.34 to 44.69 Mg C ha^{-1}.

When cumulative C-stock compared with uncultivated LUS, the data revealed that highest 36.3% increase in mango solo followed by litchi solo 17.2% increase, litchi intercrop 3.6% increase observed while in rice-wheat LUS a decline by 14.6% over uncultivated LUS.

Table 4.27: Effect of LUS's and soil depths on soil cumulative carbon stock in (Mg C ha^{-1}).

Land use systems (L)	Soil depth (0-60) cm		
	Carbon sequestration (Mg C ha^{-1})	Carbon sequestration over uncultivated (Mg C ha^{-1})	Carbon sequestration over rice-wheat (Mg C ha^{-1})
Litchi solo	61.34	9.00	16.65
Litchi intercrop	54.19	1.86	9.51
Mango solo	71.34	19.01	26.65
Rice –wheat	44.69	-7.64	0.00
Uncultivated	52.33	0.00	7.64
SEm±	**5.36**	**5.30**	**6.13**
C.D.(P=0.05)	**1.77**	**1.70**	**1.97**

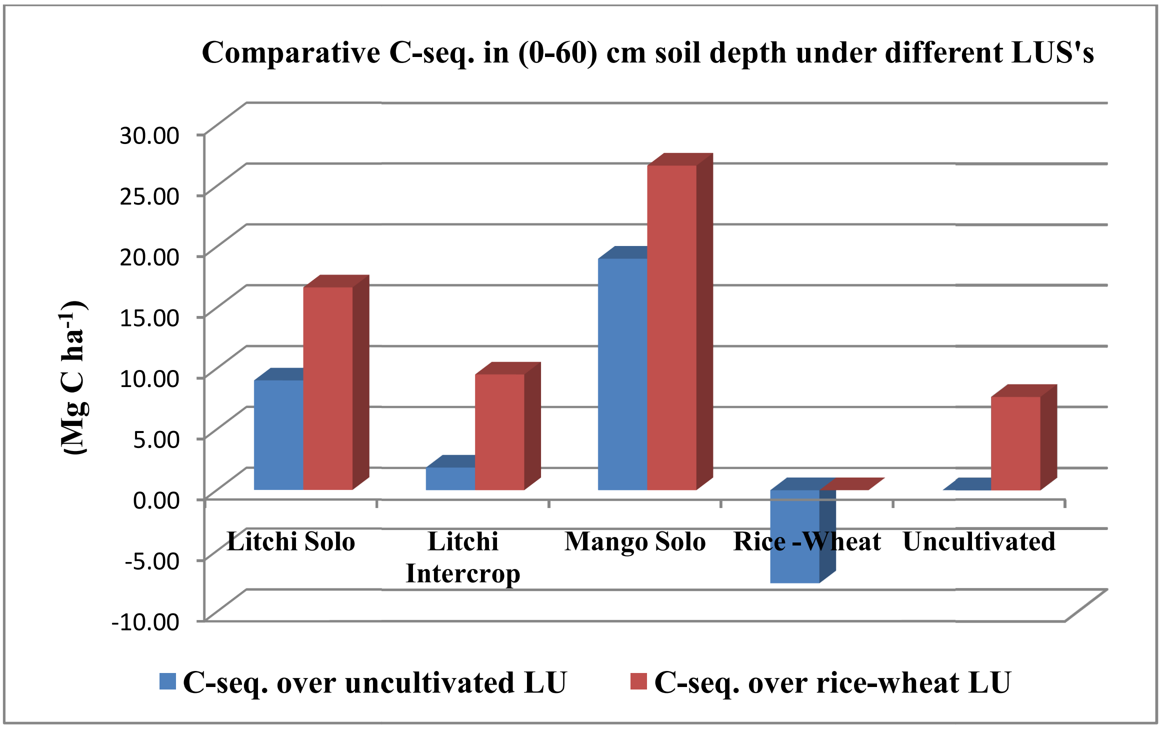

Fig 4.5: Comparative carbon sequestration in (0-60) cm soil depth under different LUS's over uncultivated and rice-wheat LUS's.

4.6.3 Nitrogen stock in soil (kg N ha^{-1})

The analysed data presented in Table 4.28 and Fig 4.6 reveals different LU and soil depth varied significantly but their interaction effect was not significant. The data depicts that among different LU soil nitrogen stock was found highest in mango solo LU 1352 kg N ha^{-1} followed by litchi solo LU 1175 kg N ha^{-1}, litchi intercrop 1052.33 kg N ha^{-1}, uncultivated LU 1028.82 kg N ha^{-1} and least recorded in rice-wheat LU .942.88 kg N ha^{-1} *i.e.* it varied from 1352 to 942.88 kg N ha^{-1} in LU. Soil nitrogen stock among various soil depths, recorded the highest value 1345.48 kg N ha^{-1} in the upper soil layer 0-15 cm followed by 1138.09 kg N ha^{-1} in 15-30 cm soil depth, 993.16 kg N ha^{-1} in 30-45 cm soil depth while least observed 964.8 kg N ha^{-1} in 45-60 cm soil depth. Soil nitrogen stock in different LU when compared to mango solo LU found decreased by 13.03%, 22.17%, 23.9%, and 30.26% in LU *viz*. litchi solo, litchi intercrop, uncultivated LU and rice-wheat LU, respectively over mango LU. Irrespective of LU soil nitrogen stock decreased with increasing soil depth. The analysed data reveals that nitrogen stock among soil depth when compared with 0-15 cm soil depth decreased by 15.41%, 26.19%, and 28.29% in soil depth 15-30 cm, 30-45 cm, 45-60, respectively over upper soil depth 0-15 cm.

Analyzed soil nitrogen stock data depicts that all the three horticulture LU significantly differed from rice-wheat LU, further also found litchi solo and mango solo and litchi intercrop LU significantly differed from each other similarly uncultivated and rice-wheat LU significantly differed from each other. Among soil depths, upper soil depth significantly differed from all lower soil depths.

In the present study, it was observed highest nitrogen stock in mango solo LU was followed by litchi solo LU, litchi intercrop, uncultivated land and least in rice-wheat LU. The pattern of nitrogen stock and carbon stock in soil followed a similar trend as both are integral components of SOM. The differences observed in soil nitrogen stock are mainly due to differences in nitrogen content because differences in nitrogen content are larger compared to the differences in bulk density among LU.

The highest nitrogen content observed in horticulture LUs mainly due to more above and below ground biomass which enriches surface soil with SOM and also less tillage operation being followed in horticultural LU at farmer field. Also, in the horticultural LU tree canopy and mulching enhances soil nitrogen by modifying hydrothermal conditions which reduces volatilization loss of nitrogen. A positive relation has been observed between litter fall, organic residue, and total soil nitrogen. Also, in horticulture LU enhanced SOC promotes soil aggregate formation which in turn reduces leaching loss compared to the rice-wheat LUS also observed by Finzi *et al.* (1998); Poirier *et al.* (2018); Anh *et al.* (2014); and Wang *et al.* (2016). It has been observed that uncultivated LU has higher nitrogen stock than rice-wheat LU might be due to the fibrous root system of grasses which deposit more carbon and no-till condition in uncultivated LU. In rice-wheat LU nitrogen loss through leaching and erosion is also a major factor for lesser nitrogen stock (Meena *et al.* 2018 and Nabais *et al.* (2011). The higher nitrogen uptake by agricultural LU and prolonged cultivation are reasons for low nitrogen stock in agricultural land-use soil observed by Lal (2018) and Lal (2004).

In our study, observed lower nitrogen stock in litchi intercrop than in litchi solo LU mainly due to cultivation operations being carried out in intercrop and also due to removal of litterfall and crop harvest, also observed by Meena *et al.* (2018) and Yadav *et al.* (2016); Andrade *et al.* (2020) observed in line with our finding. In the present study mango solo LU was found to sequester more nitrogen than litchi might be due to mango solo having more above and below biomass thus adding more carbon input to soil.

Soil nitrogen stock was observed to be highest in upper soil and was observed to decline when soil depth increasedmainly due to a decline in organic input similar findings were also reported by Lal (2008); Ghosh *et al.* (2016); Wang *et al.* (2016) and Meena *et al.* (2018). Soil nitrogen stock higher was observed in horticulture LU than rice-wheat due to the well-developed root system in horticulture LU which helps in the nutrient movement to deeper layer as also observed by Poirier *et al.* (2018).

Table 4.28: Effect of LUS's and soil depths on soil nitrogen stock (kg N ha^{-1}).

Land use systems (L)	**Soil nitrogen stock (kg N ha^{-1})**				
	Soil depth(D) cm				
	0-15	**15-30**	**30-45**	**45-60**	**Mean**
Litchi Solo	1390.52	1217.74	1053.59	1041.71	**1175.89**
Litchi Intercrop	1281.98	1082.60	959.35	885.38	**1052.33**
Mango Solo	1589.35	1407.57	1212.20	1198.89	**1352.00**
Rice -Wheat	1183.31	937.39	835.50	815.30	**942.88**
Uncultivated	1282.22	1045.18	905.14	882.74	**1028.82**
Mean	**1345.48**	**1138.09**	**993.16**	**964.81**	
SEm±	**L=23.6**	**D= 21.11**		**L X D=**	**47.20**
C.D.(P=0.05)	**L=66.47**	**D= 59.46**		**LX D=**	**NS**

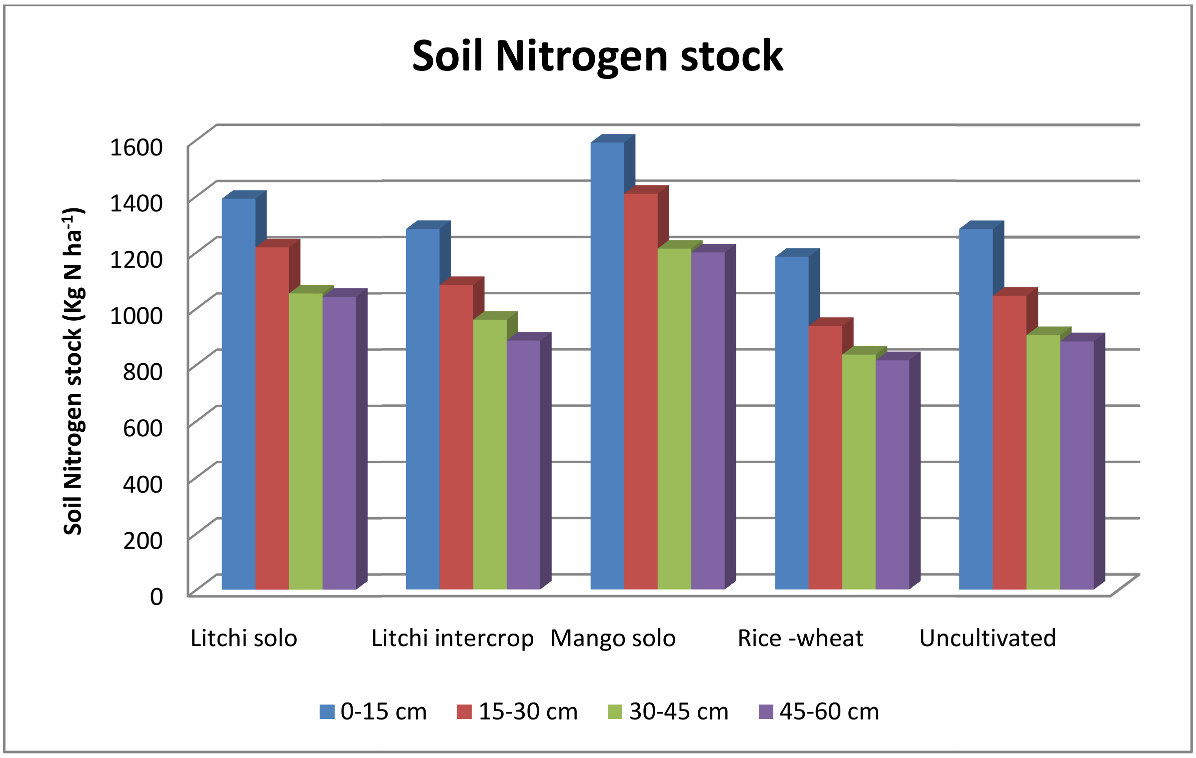

Fig 4.6: Soil nitrogen stock in different LUS's and soil depths.

4.7 Effect of different LUS's and soil depths on soil metabolic quotient (qCO_2) and microbial quotient (MQ) in soil.

4.7.1 Metabolic Quotient (qCO_2) of soil

The metabolic quotient value Table 4.29 and Fig 4.7 in different LU and soil depth varied significantly but their interaction effect was not significant. Among the different LU, the metabolic quotient was observed highest in litchi intercrop 4.87 followed by 4.82 in uncultivated LU, 4.64 rice-wheat LU, 4.04 litchi solo and least 3.32 observed in mango solo. Within different soil depths observed highest 4.50 in 15-30 cm soil depth followed by 4.45 cm in 0-15 cm soil depth, 4.38 in 30-45 cm soil depth and least observed in 4.02 in 45-60 cm soil depth. The analyzed metabolic quotient data when compared to mango solo LU it was observed that litchi solo LU increased by 21.60%, followed by 39.55% rice-wheat LU, 45.21% and 46.52% increase over mango solo LU. While microbial quotient among LU compared to 45-60 cm soil depth observed increase by 8.9% in 30-45 cm soil depth, 10.61% in 0-15 cm soil depth, and 11.84% increase in 15-30 cm soil depth over 45-60 cm soil depth. The analyzed data revealed that both mango solo and litchi solo significantly differed with both litchi intercrop and uncultivated LU while uncultivated and rice-wheat LU did not differ significantly. Among soil depth metabolic quotient in soil depth 45-cm significantly varied with all above soil depth

The metabolic quotient can be expressed as a rate of soil respiration per unit MBC in soil *i.e.* it signifies the ability of soil microbes in decomposing soil organic residue (Jenkinson and Powlson 1976). Also, it depends on microbial diversity, traits and the adaptability of microbes in particular LU. Silva *et al.* (2007) reported a higher microbial quotient in stressed soil due to the response of factors LU change, human interference or climate change *etc.* in a particular terrestrial eco system. Also reported higher qCO2 in forest LU compared to agricultural LU.

Yan *et al.* (2003); and Saggar *et al.* (2001) reported in tree base LUS's lesser qCO_2 compared to others due to the quality and quantity of organic matter, decomposition rate and management practices followed it is in conformity to our finding the lower microbial quotient in horticulture solo LU. In the present study, observed a higher microbial quotient value in litchi intercrop and uncultivated LU due to more stressed conditions in these LU. In conformity to our finding Maia *et al.* (2007); Xu *et al.* (2007) and Notaro *et al.* (2014) found a higher metabolic quotient in upper soil depth compared to lower soil depth.

When forest land used for agricultural and plantation LUS's may lead to a reduction in SOC and microbial biomass and a decline in the substrate utilization efficiency of the microbial community

Table 4.29: Effect of LUS's and soil depths on metabolic Quotient (qCO_2).

Land use systems (L)	**Metabolic Quotient (qCO_2)**				
	Soil depth(D) cm				
	0-15	**15-30**	**30-45**	**45-60**	**Mean**
Litchi solo	4.16	4.06	4.08	3.86	**4.04**
Litchi intercrop	5.04	4.99	4.84	4.61	**4.87**
Mango solo	3.48	3.45	3.24	3.12	**3.32**
Rice –wheat	4.75	4.98	4.66	4.16	**4.64**
Uncultivated	4.82	5.01	5.09	4.37	**4.82**
Mean	**4.45**	**4.50**	**4.38**	**4.02**	
SEm±	**L=0.124**	**D= 0.1091**		**L X D= 0.2440**	
C.D.(P=0.05)	**L=0.35**	**D= 0.31**		**LX D= NS**	

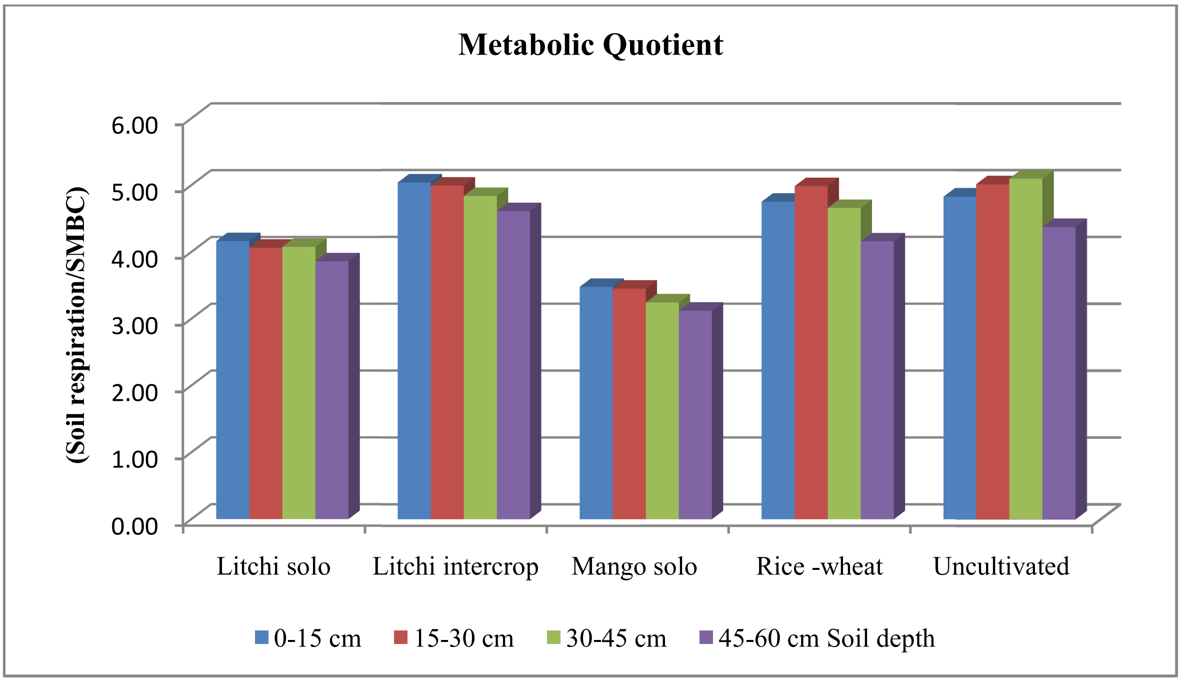

Fig 4.7: Metabolic quotient in different LUS's and soil depths.

4.7.2 Microbial Quotient (MQ)

The microbial quotient varied significantly among different LU and soil depth while interaction effect not varied significantly Table 4.30 and Fig 4.8. Microbial quotient among different LU was found highest 1.64 in mango solo LU followed by litchi solo LU 1.54, litchi intercrop 1.38, uncultivated LU 1.36 and least recorded in rice-wheat LU 1.29 *i.e.* it varied from 1.64 to 1.29 in LU. Among various soil depth, recorded highest value 1.95 in upper soil layer 0-15 cm followed by 1.76 in 15-30 cm soil depth, 1.21 in 30-45 cm soil depth while least observed 0.85 in 45-60 cm soil depth. Microbial quotient in different LU found decrease by 15.91%, 15.85%, 17.38%, and 21.61% in LU *viz*. litchi solo, litchi intercrop, uncultivated LU and rice-wheat LU, respectively over mango LU. The analyzed data reveals that among soil depth, metabolic quotient decrease by 9.87%, 38.05%, and 56.45% in soil depth 15-30 cm, 30-45 cm, 45-60, respectively over upper soil depth 0-15 cm.

The data depicts that all the three horticulture LU significantly differed with rice-wheat LU, further also found litchi solo and mango solo LU significantly differed similarly uncultivated and rice-wheat LU significantly differed with each other.

Soil microbial quotient is the ratio of soil microbial biomass and total SOC expressed in percentage or simply it is the percentage of soil microbial biomass carbon percentage out of total SOC. In general soil microbial biomass carbon ranges from 2 to 3% of total organic carbon. In conformity to our result Naik *et al*. (2016) also observed higher microbial quotient in mango LU compared to litchi LU while both recorded higher over control. Maia *et al.* (2007) also observed in tree-based LUS's had higher microbial population hence more microbial quotient where in traditional intensive farming systems as there is less microbial population due to more tillage operation and use of inorganic fertilizers. In present study it was observed decrease in microbial quotient with increasing depth due to low organic matter deposition in deeper soil layer, similar observation also reported by Maia *et al.* (2007); and Notaro *et al.* (2014).

Table 4.30: Effect of LUS's and soil depths on microbial quotient (MQ).

Land use systems (L)	Microbial Quotient (MQ)				
	Soil depth(D) cm				
	0-15	15-30	30-45	45-60	Mean
Litchi solo	2.11	1.87	1.30	0.89	**1.54**
Litchi intercrop	1.81	1.70	1.19	0.82	**1.38**
Mango solo	2.30	1.93	1.42	0.90	**1.64**
Rice –wheat	1.70	1.61	1.02	0.81	**1.29**
Uncultivated	1.82	1.68	1.10	0.82	**1.36**
Mean	**1.95**	**1.76**	**1.21**	**0.85**	
SEm±	**L=0.017**	**D=**	**0.015**	**L X D=**	**0.034**
C.D.(P=0.05)	**L=0.05**	**D=**	**0.04**	**LX D=**	**0.09**

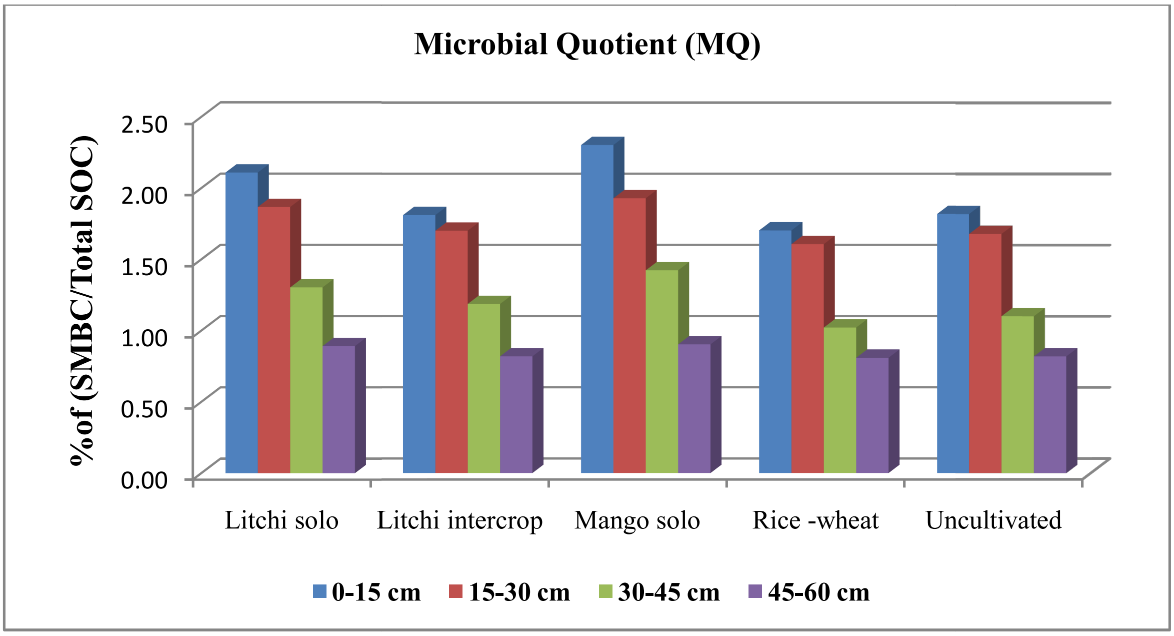

Fig 4.8: Microbial quotient in different LUS's and soil depths.

4.8 Soil Quality Indices (SQIs) development under different LUS's.

4.8.1 Indicators selection to create minimum data set (MDS) from Principal Component Analysis (PCA).

The various parameter physical chemical and biological parameters were screened through principal component analysis and the factor loading (eigen vector) factor loading given in Table 4.31.The parameters were selected having eigen value ≥1. From the table PCs having higher eigen vector value selected and from PCs variable having higher factor loading selected.

The variability observed in PC-1 (40.29%), in PC-2 (38.01%), in PC-3 (6.30%), in PC-4 (4.48%) as shown in Table 4.31.

From each PC highest factor loading variable was selected and again within each PC highly weighted variables within 10% absolute value of the highest factor loading were selected for the (MDS) minimum data set. The multivariate correlation was performed among MDS selected parameters to determine significant well-correlated parameters ($r > 0.60$) and the variable having highest factor selected while the rest was eliminated from each PC. If highly weighted variable not well correlated then retained in MDS. Following well correlation assumption from PC-1 to PC-4 finally representative variable indicator selected was (PC-1, Soil carbon stock and and metabolic quotient), (PC-2, soil respiration), (PC-3, Sand%), (PC-4, Clay%).

Table 4.31: Principal component analysis (PCA) result of variables under different LUS's.

Statistics	PC 1	PC 2	PC 3	PC 4
Eigen Value	12.49	11.78	1.95	1.50
Percent of Variance	40.29	38.01	6.30	4.84
Cumulative%	40.29	78.30	84.60	89.44
Eigen vector or factor loading				
SOC	**0.805**	0.576	-0.028	0.005
TOC	**0.836**	0.536	0.026	0.016
NLc	**0.836**	0.38	0.162	0.043
VLc	**0.794**	0.531	-0.053	-0.091
Lc	0.711	0.61	0.000	-0.09
LLLc	0.599	0.255	-0.031	0.221
SMBC	0.64	0.743	0.017	0.056
SMBN	0.51	**0.832**	0.063	0.04
Av.Zinc	0.516	**0.833**	0.047	0.101
Av.Iron	0.411	**0.896**	0.05	0.102
Av.Copper	0.437	**0.879**	0.062	0.123
Manganese	0.471	**0.85**	0.086	0.151
Soil total N	**0.828**	0.531	0.067	0.037
Av. Nitrogen	0.708	0.522	-0.094	0.000
Ammonium-N	**0.844**	0.519	0.043	0.021
Nitrate-N	**0.811**	0.563	0.07	0.035
Soil *p*H	-0.8	-0.256	-0.044	-0.318
Av.Phosphorus	0.605	0.57	0.17	0.36
Av. Potassium	0.489	**0.834**	-0.002	0.109
DHA	0.533	**0.821**	0.024	0.135
Soil respiration	0.382	**0.898**	0.013	0.134
Soil protein	0.825	0.306	-0.09	0.062
Sand%	0.001	0.125	**0.953**	0.085
silt%	-0.029	-0.049	**-0.909**	0.389
clay%	0.052	-0.109	0.191	**-0.873**
Bulk density	-0.459	-0.55	-0.215	-0.344
Soil C stock	**0.853**	0.476	-0.008	-0.064
Soil N stock	**0.848**	0.463	0.033	-0.051
Metabolic quotient	**-0.822**	0.334	-0.109	0.178
EC	-0.083	**0.818**	0.095	-0.057
Microbial quotient	0.421	**0.843**	0.038	0.073

Table 4.32: Correlation between highly weighted variables under principal components-1.

PC-1 Variables	SOC	TOC	NLc	VLc	Tot. N	Ammo.N	Nitrate.N	Soil Protein	C-Stock	N-Stock	Meta.Q
SOC	1										
TOC	.990**	1									
NLC	.870**	.931**	1								
VLC	.954**	.943**	.826**	1							
Tot. N	.974**	.995**	.954**	.922**	1						
Ammo.N	.983**	.999**	.944**	.936**	.998**	1					
Nitrate.N	.975**	.992**	.943**	.924**	.997**	.995**	1				
Soil Protein	.847**	.825**	.689**	.840**	.785**	.813**	.791**	1			
C-Stock	.973**	.983**	.917**	.925**	.975**	.982**	.971**	.812**	1		
N-Stock	.954**	.977**	.943**	.900**	.979**	.980**	.974**	.765**	.994**	1	
Meta.Q	-.457**	-.507**	-.587**	-.455**	-.519**	-.529**	-.502**	-.473**	-.572**	-.594**	1

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

Table 4.33: Correlation between highly weighted variables under principal components 2, 3 and 4.

PC-2 Variables	MBN	Zn	Fe	Cu	Mn	Av.K	DHA	Co$_2$ efflux	EC	Micro.Q
MBN	1									
Zn	.962**	1								
Fe	.964**	.987**	1							
Cu	.974**	.966**	.979**	1						
Mn	.956**	.984**	.986**	.975**	1					
Av.K	.940**	.950**	.950**	.959**	.937**	1				
DHA	.960**	.978**	.971**	.974**	.977**	.958**	1			
Co$_2$ efflux	.944**	.945**	.966**	.978**	.956**	.965**	.968**	1		
EC	.624**	.657**	.723**	.654**	.675**	.581**	.577**	.632**	1	
Micro.Q	.961**	.908**	.921**	.963**	.907**	.941**	.926**	.944**	.562**	1

PC-3 Variable	Sand%	silt%
Sand%	1	
Silt%	-.849**	1

PC-4 Variable	Clay%
Clay%	1

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

4.8.2 Scoring/ normalization of indicator selected (0-1 scale)

Linear scoring was performed on MDS on (scale 0-1) as suggested by Andrews *et al.* (2002). The selected parameters were grouped into more is better (good) or less is better (bad).

4.8.3 Weighted factor to transformed indicators

The selected indicators after being scored into 0-1 scale are being multiplied by weighted factor. The weighted factor was calculated by dividing % variation of each PC with the % cumulative variation of selected PC >1 eigenvalue. In our study weighted factor obtained for PC-1 (0.226), PC-2 (0.425), PC-3 (0.070), and PC-4 (0.054).

Soil quality index (SQI) obtained by using equation:

$$\textbf{Soil Quality Index (SQI)} = \sum_{i=1}^{n} WiXSi$$

Where S is the score of indicator, W is the weightage from principal component analysis. The SQI value obtained indicates higher value better is soil quality.

4.8.4 Soil quality index (SQI).

The main effect of different LU and soil depth on SQI was found to vary significantly whereas the interaction effects did not vary significantly Table no 4.34 and Fig 4.9.

Soil quality index among different LU was found highest 1.15 in mango solo LU followed by litchi solo LU 1.09, litchi intercrop (1.04), uncultivated LU 1.02 and least recorded in rice-wheat LU 0.94 *i.e.* it varied from 1.15 to 0.94 in LU. Among various soil depths, recorded highest SQI 1.16 in the upper soil layer 0-15 cm followed by 1.07 in 15-30 cm soil depth, 0.98 in both 30-45 and 45-60 cm soil depth.

Soil quality index in different LU, when compared to mango solo LU, was found to decrease by 5.62%, 9.97%, 11.56%, and 18.25% in LU *viz*. litchi solo, litchi intercrop, uncultivated LU and rice-wheat LU respectively over mango LU. The analysed data revealed that among soil depth when compared to 0-15 cm soil depth found SQI decreased by 7.92%, 15.55%, and 15.55% in soil depth 15-30 cm, 30-45 cm, 45-60 cm, respectively over upper soil depth 0-15 cm.

The data depicts that all the three horticulture LU significantly differed from rice-wheat LU, further also found litchi solo and mango solo LU not significantly differed but uncultivated and rice-wheat LU significantly differed with each other. Soil depth 45-60 cm significantly varied with 0-15 and 15-30 cm soil depth.

In line with our observation Biswas *et al.* (2017); and Cherubin *et al.* (2016) also observed higher SQI in horticultural LU than the agricultural LU. These differences might be due to differences in dynamic balance in physical chemical and biological parameters which depend upon also management practices being followed in LU. The horticulture LUS revealed higher SQI due to higher plant litter addition and less soil disturbance which reflects in SQI.

In the present study, the sensitive parameters selected may be used for future SQI estimation for the ACZ -I of Bihar. Similar to our finding Ebabu *et al.* (2020) found microbial biomass, soil respiration, and aggregate stability are important indicators and suggested suitable land management be followed to improve soil quality. Velmourougane *et al.* (2014) observed similar to our finding that SQI decreases with an increase in soil depth due to less SOM and consequently lower microbial activity in lower soil.

Table 4.34: Effect of LUS's and soil depthson soil quality index (SQI).

Land use systems (L)	**Soil quality index (SQI)**				
	Soil depth(D) cm				**Mean**
	0-15	**15-30**	**30-45**	**45-60**	
Litchi solo	1.21	1.12	1.01	1.01	**1.09**
Litchi intercrop	1.15	1.06	0.97	0.97	**1.04**
Mango solo	1.28	1.17	1.07	1.07	**1.15**
Rice –wheat	1.03	0.95	0.89	0.90	**0.94**
Uncultivated	1.13	1.04	0.94	0.96	**1.02**
Mean	**1.16**	**1.07**	**0.98**	**0.98**	
SEm±	**L=0.0234**	**D=**	**0.0210**	**L X D=**	**0.0468**
C.D.(P=0.05)	**L=0.07**	**D=**	**0.06**	**LX D=**	**NS**

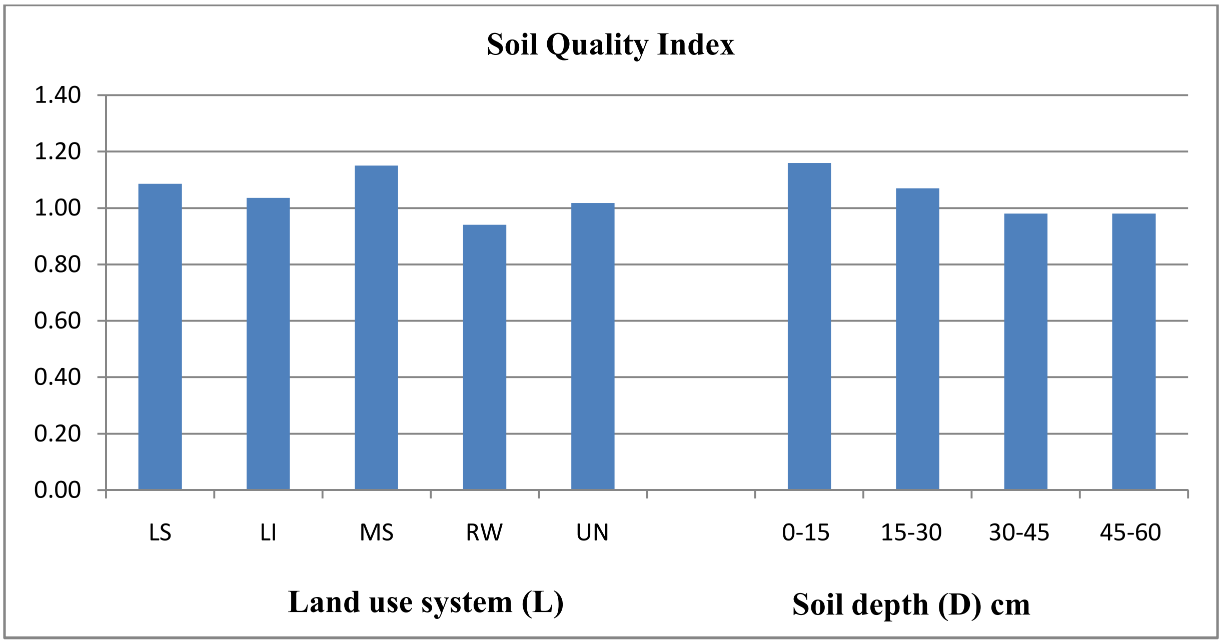

Fig 4.9: Soil Quality Index (SQI) under different LUS's and soil depths.

4.9 Tree biomass and carbon storage

4.9.1 Horticulture tree biophysical parameter

Horticulture based LUS's namely litchi solo, litchi intercrop, mango solo was selected and data recorded presented in Fig 4.10 and Fig 4.11 revealed that significantly highest tree height was observed in mango solo 11.18 m while litchi solo 8.75 m was at par non-significantly from litchi intercrop 8.69 m. Similarly tree girth was observed significantly highest in mango solo 1.76 m followed by litchi solo 1.25 m and litchi intercrop 1.24 m.

Tree volume was observed to be more in mango solo 2.21 m^3 significantly Table 4.35 higher 145.8% when compared with litchi solo while litchi solo recorded 0.9.1 m^3 and least observed in litchi intercrop 0.874 m^3 *.i.e.* almost 3% lower than litchi solo LU.

Above ground-biomass includes tree parts stem, branches, bark, seeds, foliage all above parts, while below ground-biomass (BGB) includes roots of plant (IPCC 2006). Mango solo LUS recorded AGB 99.7 q $tree^{-1}$ Table 4.35 while litchi solo LUS recorded 31.53q $tree^{-1}$ and least AGB recorded in litchi intercrop 30.57q $tree^{-1}$ which is 226% less compared to mango solo LUS. Similarly BGB was observed highest in mango solo LUS 14.95 q $tree^{-1}$ while litchi solo LU 4.73 q $tree^{-1}$ and litchi intercrop least recorded 4.59 q $tree^{-1}$. In present study AGB and BGB variations observed, similar different also reported by Sohrabi *et al.*

(2016); Gebrewahid *et al.* (2018); and Yadav *et al.* (2019) that AGB contributed 86.7% average of total tree biomass while remaining 13.3% contributed by BGB.

Table 4.35: Effect of horticulture-based LUS's on tree biomass and carbon

Land use systems	Tree volume (m^3)	AGB (q $tree^{-1}$)	BGB (q $tree^{-1}$)	Tree carbon (q $tree^{-1}$)	CO_2mitigation (q $tree^{-1}$)
Litchi Solo	0.901	31.53	4.73	16.32	59.89
Litchi Intercrop	0.87	30.57	4.59	15.82	58.07
Mango Solo	2.21	99.70	14.95	51.59	189.34
SEm±	0.038	1.63	0.25	0.85	3.11
C.D.(P=0.05)	0.109	4.65	0.70	2.40	8.83

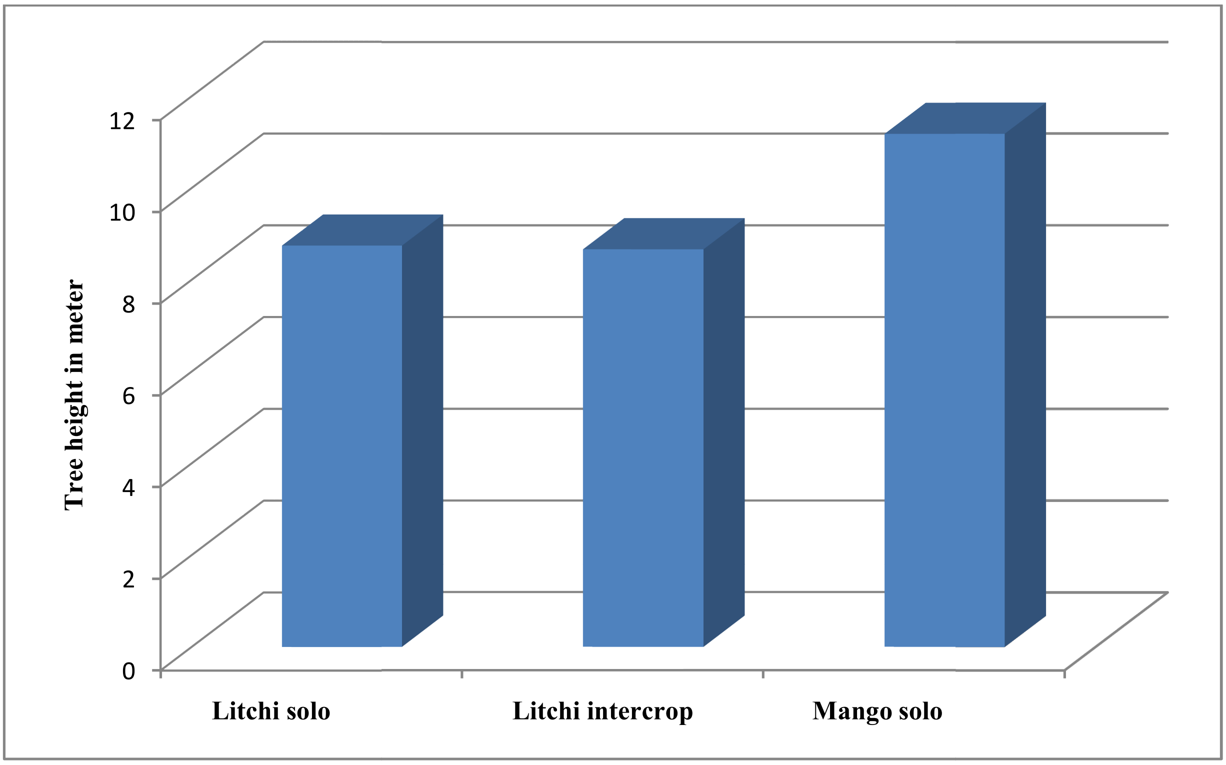

Fig 4.10: Tree height under different horticulture-based LUS's.

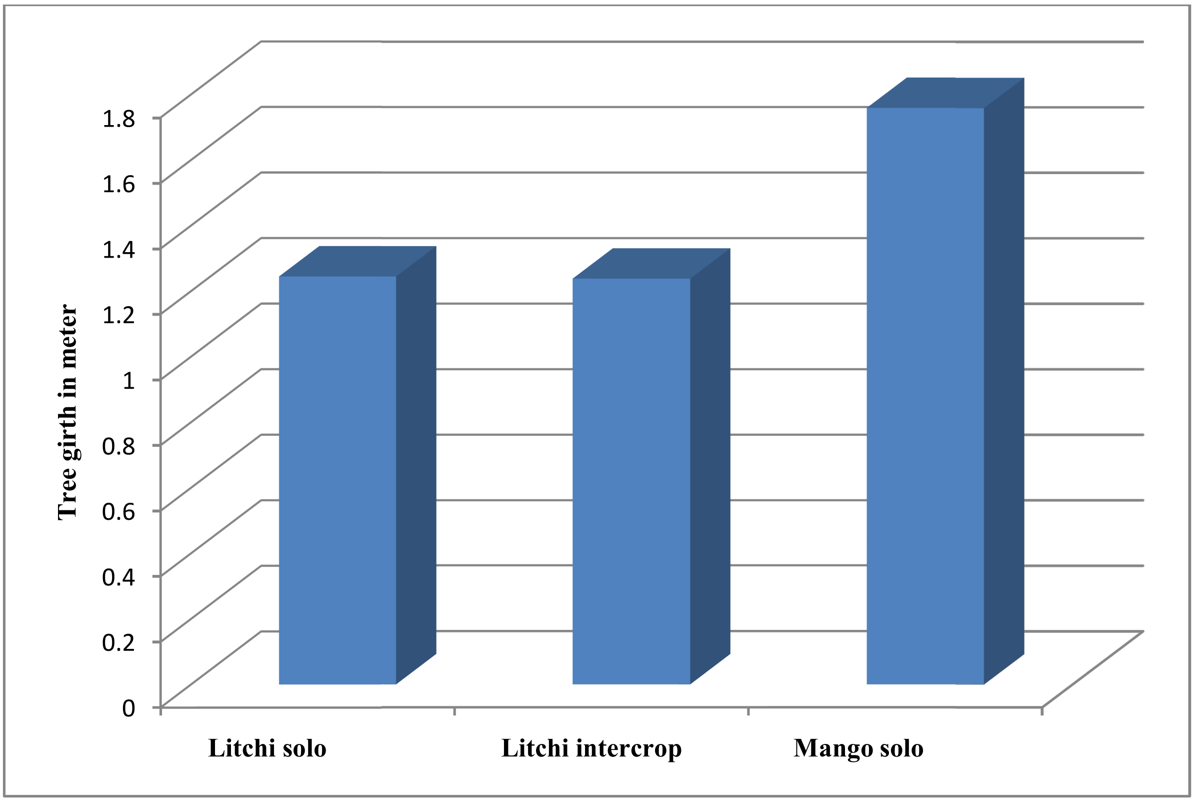

Fig 4.11: Tree girth under different horticulture-based LUS's.

4.9.2 Horticulture tree carbon stock

Horticulture LUS total tree biomass adding both AGB and BGB accounts for total carbon stored in tree biomass. In present study mango remained highest Table 4.35 significantly in total biomass carbon storage 51.59 q tree^{-1} which is about 216% higher than litchi solo LUS 16.32 q tree^{-1} least observed in litchi intercrop 15.82 q tree^{-1}, about 3% less than litchi solo LUS.

The CO_2 mitigation Table 4.35 by the mango LUS was observed to be 189.34 q tree^{-1} followed by litchi solo 59.89 q tree^{-1} and litchi intercrop mitigated least 58.07 q tree^{-1}.
Similar observation horticulture LUS was observed by Naik *et al.* (2018); Adak *et al*. (2018); Grote (2009); and Costa *et al*. (2018).

* * *

CHAPTER – V

SUMMARY AND CONCLUSION

5. SUMMARY AND CONCLUSION

The research was conducted in ACZ-I of Bihar entitled **“Assessing carbon sequestration potential and Soil Quality Index (SQI) under horticulture based LUS’s in Agro-Climatic Zone-I of Bihar”**. The main objective of this study was to estimate the carbon sequestered in prevailing dominant LUS’s and assess related soil properties. In agro-climatic –zone-I, there is a need of research to understand soil carbon dynamics which would help in mitigating increased level of CO_2 in atmosphere. In selected LUS’s, soil quality was assessed for sustainable production with efficient utilization of existing resources. To accomplish these objective five dominant LUS’s were selected in ACZ-I of Bihar and accordingly soil samples were collected from four soil depth upto 60 cm. In horticulture based LUS’s both above and below ground biomass of tree was estimated and accordingly biomass carbon was also calculated. The soil samples were analysed for various physical, chemical and biological properties and the data so obtained were processed for developing SQI of different LUS’s. In present research, attempt has been made to assess LUS’s that influence the soil properties which would help in formulating strategies for enhancing soil quality in ACZ-I of Bihar. The relevant results obtained are described below.

5.1 Soil physical properties

- Soil bulk density among LUS’s varied from 1.46 to 1.41 Mg m^{-3}, the uncultivated LUS observed significantly highest BD of 1.46 Mg m^{-3} while the lowest recorded in mango solo with LUS 1.41 Mg m^{-3}. Irrespective of LUS’s, BD increased with increasing of soil depth.
- Mean weight diameter was observed significantly higher in horticulture solo plantation *i.e.* mango solo 3.73 mm followed by litchi solo LUS 3.62 mm while least was observed in rice-wheat LUS 2.73 mm.
- Soil surface hardness was observed significantly higher in uncultivated LUS 1368.2 KPa followed by rice-wheat 1135 KPa and the least was estimated in mango solo LUS 974.2 KPa.
- Soil mechanical composition revealed that sand, silt clay% not significantly influenced by different LUS’s and the textural class so observed was mostly silt loam, clay loam and sandy loam. Higher sand% was observed in surface soil at 0-15 cm depth while in subsurface soil higher silt and clay% was observed at 45-60 cm soil depth but the difference was found non-significant.

5.2 Soil chemical properties

- Soil *p*H in different LUS's ranged from 7.91 to 8.26 while the significantly highest *p*H value was observed in rice-wheat LUS 8.26 and the lowest *p*H was observed in mango solo LUS 7.91. A general trend was observed that soil *p*H increased with increasing depth among all LUS's.
- Soil electrical conductivity was observed significantly highest in uncultivated LUS 0.48 dS m^{-1} followed by rice-wheat 0.45 dS m^{-1} while lowest EC was observed in mango solo LUS 0.34 dS m^{-1}. Among soil depths, EC significantly decreased with increasing soil depth and the lowest EC was observed 0.27 dS m^{-1} in 45-60 cm.
- SOC was observed significantly highest in mango solo 5.55 g kg^{-1} followed by litchi solo 4.73 g kg^{-1}, litchi intercrop 4.07 g kg^{-1}, uncultivated LU 3.82 g kg^{-1} while least SOC was found in rice-wheat LUS's 2.98 g kg^{-1}. In rice-wheat LUS, SOC decreased significantly by 46.36% compared to mango solo LUS. Among soil depths, highest SOC observed in 0-15 cm 5.68 g kg^{-1} and there after decreased by 42.47% in lowest soil depth and significantly decreased in lower soil depths.
- Highest available N was recorded in mango solo 241.25 kg ha^{-1} among different LUS's while it decreased significantly by 31.92% in rice-wheat LUS 164.25 kg ha^{-1} which was the lowest. Available N decreased significantly with increasing soil depth.
- Available phosphorus in soil varied from 23.71 to 14.85 kg ha^{-1} among different LUS's. Significantly lowest available P was observed in uncultivated LUS while highest recorded in horticulture solo LUS's *i.e.* in mango solo 23.71 kg ha^{-1} followed by litchi solo 22.20 kg ha^{-1}. Upper soil layer of 0-15 cm observed 26.25 kg ha^{-1} of available P and it decreased with increasing soil depth.
- Available potassium in different LUS's recorded highest in mango solo 128.29 kg ha^{-1} and significantly lower available K was recorded in in rice-wheat LUS's 83.47 kg ha^{-1}. Irrespective of LUS's, available potassium was observed to decline when soil depth increased. Upper soil depth of 0-15 cm observed 164.05 kg ha^{-1} of available K and thereafter it decreased significantly.
- The DTPA extractable micronutrient Zn, Fe, Cu and Mn were found significantly influenced by LUS effect. Among different LUS's micronutrient was found highest in mango solo followed by litchi solo, litchi intercrop and least observed in rice-wheat LUS. In present study DTPA extractable micronutrient a declining trend was observed with increasing soil depth.

5.3 Soil biological properties

- The DHA activity was observed highest in mango solo LU 13.64 µg TPF g^{-1} soil 24 hr^{-1} and then decreased by decrease by 12.69%, 29.38%, 34.92%, and 45.48% in LU *viz*. litchi solo, litchi intercrop, uncultivated LU and rice-wheat LU compared to mango LU. Among the soil depths it was recorded highest DHA activity 18.22 µg TPF g^{-1} soil 24 hr^{-1} in upper 0-15 cm soil depth and it decreased by 76.28% significantly to lowest depth 45-60 cm soil depth.
- Soil respiration significantly influenced by different LUS's and observed highest in mango solo 0.49 mg CO_2-C $100g^{-1}day^{-1}$ and least decreased by 32% recorded in rice-wheat LU 0.33 mg CO_2-C $100g^{-1}$ day^{-1}, *i.e.* it varied from 0.49 to 0.33 mg CO_2-C $100g^{-1}$ day^{-1}. While in upper soil depth 0.72 mg CO_2-C $100g^{-1}$ day^{-1} was observed in 0-15 cm soil depth and thereby decreased by about 75% in 45-60 cm soil depth.
- Soil protein significantly varied from 1.88 to 1.10 mg g^{-1}, among different LUS observed in highest in mango solo LU 1.88 mg g^{-1} followed by litchi solo LU1.75 mg g^{-1} and least recorded in rice-wheat LU 1.10 mg g^{-1}.The upper soil depth recorded significantly highest soil protein value 1.66 mg g^{-1} and decreased with increasing soil depth.

5.4 Effect of different LUS's and soil depths on soil carbon fractions

- Total SOC observed significantly influenced by LUS and varied from 8.48 to 5.19 g kg^{-1}. The highest TSOC observed in mango 8.48 g kg^{-1} LUS and thereby decreased in litchi solo 13.69%, litchi intercrop by 24.46%, uncultivated LU 29.11% and rice-wheat LU decreased by 38.73%, respectively. Among soil depth highest TSOC was observed highest in 0-15 cm soil depth 8.61 g kg^{-1} and thereby decreased by 36.51% 45-60 cm in lowest soil depth.
- The average magnitude of different oxidizable fractions of SOCamong different LU observed followed a sequence of NLc> VLc> Lc> LLc constituting around 37.09% > 31.45% >16.95% >14.67% of the total SOC
- Active carbon proportion was observed more in mango solo and litchi solo LUS's where as in other LU proportion of passive pool was more than active pool

- In the present study, observed active pool (Vlc +Lc) constitutes around 48% whereas the passive pool more resistant to microbial assimilation constitutes around 52% of the TSOC.
- Oxidizable SOC fractions averaged across the LUS's with soil depths observed in the order of NLc (2.45 g kg^{-1}) > VLc (2.14 g kg^{-1}) >Lc (1.14 g kg^{-1}) > LLc (0.97 g kg^{-1}). Irrespective of LUS's SOC fractions significantly declined with the soil depth
- Soil MBC varied significantly among LUS's and observed highest in mango solo LU 146.73 mg kg^{-1}, followed by litchi solo 118.93 mg kg^{-1} while least recorded in rice-wheat 70.50 mg kg^{-1} *i.e.* among LU it varied from 146.73 to 70.50 mg kg^{-1}. Among soil depth observed significantly highest 170.62 mg kg^{-1} in 0-15 cm soil depth and thereby it decreased significantly with increasing soil depth.

5.5 Effect of different LUS's and soil depths on soil nitrogen fractions

- Total soil N significantly observed more in horticulture LUS's and the highest recorded in mango solo LUS 642.15 mg kg^{-1} followed by litchi solo 560.68 mg kg^{-1} while least decreased by 31.78% in rice-wheat LUS 438.07 mg kg^{-1}. Among soil depths, the highest total soil N content 659.92 mg kg^{-1}, was observed in the upper soil layer 0-15 cm and thereby decreased significantly.

- The total mineral nitrogen NH_4^+ -N + NO_3^- -N varied significantly among different LUS and recorded highest in mango solo 106.02 mg kg^{-1} while least recorded in rice-wheat LU 68.48 mg kg^{-1} which decreased by 35.41%. Within soil depth highest total mineral nitrogen content recorded 107.73 mg kg^{-1} in the upper soil layer 0-15 cm while least observed in 70.2 mg kg^{-1} in 45-60 cm soil depth.

- The soil MBN value observed more in horticulture LUS in which mango solo LU recorded significantly highest 13 mg kg^{-1} while least in rice-wheat LUS which decreased by 34%. Among soil depths significantly highest observed 16.65 mg kg^{-1} in upper soil depth 0-15 cm while with increasing soil depth SMBN decreased.

5.6.1 Effect of LUS's and soil depths on soil carbon stock and nitrogen stock

- The soil C-stock significantly varied in different LUS's and observed highest in mango solo 17.83 Mg C ha^{-1} followed by litchi solo 15.33 Mg C ha^{-1}, litchi intercrop 13.55 Mg C ha^{-1}, uncultivated LU 13.08 Mg C ha^{-1} and least recorded in rice-wheat LU 11.17 Mg C ha^{-1}, recorded the highest 17.55 Mg C ha^{-1} in the upper soil layer (0-15 cm) and decreased by 30.83% in 45-60 cm soil depth.

- Cumulative soil C-stock of 0-60 cm soil depth in different LUS's revealed that significantly highest recorded in mango solo 71.34Mg C ha^{-1} LU followed by litchi solo 61.34 Mg C ha^{-1}, litchi intercrop 54.19 Mg C ha^{-1}, uncultivated LU 52.33 Mg C ha^{-1} and significantly least observed in rice-wheat LUS 54.19 Mg C ha^{-1}.

- Soil N-stock in different LUS's varied significantly observed highest in mango solo 1352 kg N ha^{-1} followed by litchi solo 1175.89 kg N ha^{-1} and least observed in litchi intercrop 1052.33 kg N ha^{-1}, uncultivated LU 1028.82 kg N ha^{-1} and least recorded in rice-wheat LU 942.88 kg N ha^{-1} *i.e.* it varied from 1352 to 942.88 kg N ha^{-1}. Among soil depths recorded highest value 1345.48 kg N ha^{-1} while least observed 964.81 kg N ha^{-1} in 45-60 cm soil depth.

5.7 Effect of LUS's metabolic quotient (qCO_2) and microbial quotient (MQ) in soil

- The metabolic quotient value in different LUS varied significantly and.observed highest in litchi intercrop 4.87 followed by 4.82 in uncultivated LU while least observed 3.32 observed in mango solo. Within different soil depths observed highest 4.50 in 15-30 cm least observed in 4.02 in 45-60 cm soil depth.

- Microbial quotient varied significantly and found highest 1.64 in mango solo LU followed by litchi solo 1.54, while least recorded in rice-wheat LU 1.29. Among soil depth, recorded highest value 1.95 in upper soil layer 0-15 cm there after followed decreasing trend with increase soil depth and observed 0.85 in 45-60 cm soil depth.

5.8 Soil quality indices

- Soil quality index among different LUS's was observed highest 1.15 in mango solo followed by litchi solo 1.09, litchi intercrop 1.04, uncultivated LU 1.02 and least recorded in rice-wheat 0.94. Among various soil depths recorded highest SQI 1.16 in the upper soil layer 0-15 cm and thereafter decreased with increasing depth.

5.9 Tree biomass carbon

- Total tree biomass carbon mango solo LUS observed to sequestered more in mango solo LUS 51.59 q tree^{-1} which was about 216% higher than litchi solo LUS 16.32 q tree^{-1}.
- The CO_2 mitigation by the mango LUS was observed to be 189.34 q tree^{-1} followed by litchi solo 59.89 q tree^{-1} and litchi intercrop mitigated least 58.07 q tree^{-1}.

CONCLUSION

Based on the results obtained from research conclusion derived are as below

- The prevailing LUS's of ACZ-I significantly affected various physical chemical and biological properties of soil and on an average superior soil properties were observed in sequence mango solo > litchi solo > litchi intercrop > uncultivated.> rice-wheat LUS's.
- Soil C-stock in 0-60 cm was observed highest 71.34 Mg C ha^{-1} in mango solo LUS while least 54.19 Mg C ha^{-1} was observed in rice-wheat LUS. Horticulture tree biomass carbon stock was observed highest in mango solo LUS 51.59 q tree^{-1} and while litchi solo LUS 16.32 q tree^{-1}.
- Soil quality index was observed highest in mango solo 1.15 followed by litchi solo LUS 1.09 while least 0.94 was observed in most disturbed rice-wheat LUS.
- Soil carbon stock, metabolic quotient, soil respiration, clay% and sand% are observed the most sensitive indicator in assessing SQI. In future studies these sensitive parameters may be used for SQI development.
- Land use change in ACZ-I has been observed highest under current fallow land category that may be addressed by cost effective incorporation of tree components which would enhance soil quality and sustainability.

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ANNEXURE

ANNEXURE

ANNEXURE-I

Selected LUS's and their GPS location

Land use	Place and District	Latitude	Longitude
Litchi solo	Mushahari, Muzaffarpur	26°05'59.0"N	85°26'37.8"E
	Birauli, Samastipur	25°56'44.5" N	85°41'08.2" E
	Gauspur Sitamadhi	26°17'27.5" N	85°25'37.7" E
	Katarmala Vaishali	25°54'01.9" N	85°17'39.0" E
	Mehsi, E.Champaran	26°22'04.7" N	85°05'35.2" E
Litchi intercrop	Mushahari, Muzaffarpur	26°06'05.1" N	85°26'38.7" E
	Birauli, Samastipur	25°56'43.9" N	85°41'06.2" E
	Mehsi, E.Champaran	26°21'20.9" N	85°06'28.7" E
	Mehsi, E.Champaran	26°22'00.8" N	85°06'00.4" E
	Katarmala Vaishali	25°53'55.0" N	85°17'45.8" E
Mango solo	Birauli, Samastipur	25°56'43.4" N	85°40'58.4" E
	Gauspur Sitamadhi	26°17'17.6" N	85°25'37.0" E
	Mahnar, Vaishali	25°37'36.6" N	85°28'55.2" E
	Mehsi, E.Champaran	26°20'58.8" N	85°06'15.1" E
	Patory, Samastipur	25°40'40.9" N	85°35'09.0" E
Rice wheat	Mahnar,Vaishali	25°40'11.4" N	85°31'05.2" E
	Patory, Samastipur	25°39'44.4" N	85°35'13.7" E
	Chakiai, E.Champaran	26°28'04.3" N	85°02'33.9" E
	Mushahari, Muzaffarpur	26°06'38.4" N	85°26'30.4" E
	Dholi Muzaffarpur	25°59'11.2" N	85°35'38.5" E
Uncultivated	Birauli, Samastipur	25°56'30.7" N	85°41'15.7" E
	Panchrukhi, E Champaran	26°16'43.6" N	85°09'00.6" E
	Mushahari, Muzaffarpur	26°05'54.1" N	85°26'12.1" E
	Patory, Samastipur	25°39'51.6" N	85°36'38.7" E
	Mushahari, Muzaffarpur	26°05'47.3" N	85°26'37.9" E

ANNEXURE-II

Soil texture of different LUS's at different location in Agro-Climatic Zone –I of Bihar.

Land Use	**Texture and Location**				
Litchi solo	Mushahari, Muzaffarpur	Birauli, Samastipur	Gauspur Sitamadhi	Katarmala Vaishali	Mehsi, E.Champaran
Texture	Silty loam	Clay Loam	Silty loam	Silty loam	Silty loam
Litchi Intercrop	Mushahari, Muzaffarpur	Birauli, Samastipur	Mehsi, E.Champaran	Mehsi, E.Champaran	Katarmala Vaishali
Texture	Silty loam	Clay Loam	Silty loam	Silty loam	Silty loam
Mango solo	Birauli, Samastipur	Gauspur Sitamadhi	Mahnar, Vaishali	Mehsi, E.Champaran	Patory, Samastipur
Texture	Clay Loam	Silty loam	Clay Loam	Silty loam	Clay Loam
Rice Wheat	Mahnar,Vaishali	Patory, Samastipur	Chakiai, E.Champaran	Mushahari, Muzaffarpur	Dholi Muzaffarpur
Texture	Clay Loam	Clay Loam	Silty loam	Silty loam	Sandy Loam
Uncultivated	Birauli, Samastipur	Panchrukhi, E Champaran	Mushahari, Muzaffarpur	Patory, Samastipur	Mushahari, Muzaffarpur
Texture	Clay Loam	Silty loam	Silty loam	Clay Loam	Silty loam

ANNEXURE-III

Horticulture tree height and girth of selected LUS's

Land use systems	Height (m)	Girth (m)
Litchi solo	8.749	1.25
Litchi intercrop	8.668	1.24
Mango solo	11.184	1.76
SEm±	0.077	0.02
C.D.(P=0.05)	0.219	0.04

ANNEXURE-IV

Scoring of the observed variables for SQI determination

Score	PC-1	PC-1	PC-2	PC-3	PC-4
	C-stock	META. Q	Soil Respiration	Sand%	Clay%
L1R1D1	0.819	0.695	0.716	0.725	0.525
L1R1D2	0.710	0.665	0.537	0.742	0.544
L1R1D3	0.547	0.616	0.305	0.815	0.560
L1R1D4	0.506	0.523	0.189	0.896	0.599
L1R2D1	0.849	0.656	0.835	0.486	0.802
L1R2D2	0.732	0.667	0.596	0.504	0.860
L1R2D3	0.667	0.715	0.337	0.538	0.882
L1R2D4	0.764	0.790	0.211	0.581	0.890
L1R3D1	0.874	0.551	0.989	0.780	0.522
L1R3D2	0.775	0.593	0.747	0.861	0.541
L1R3D3	0.605	0.551	0.442	0.888	0.580
L1R3D4	0.725	0.930	0.253	0.938	0.591
L1R4D1	0.807	0.693	0.755	0.783	0.516
L1R4D2	0.712	0.736	0.463	0.835	0.533
L1R4D3	0.603	0.660	0.295	0.861	0.549
L1R4D4	0.420	0.463	0.179	0.930	0.566
L1R5D1	0.821	0.597	0.895	0.717	0.527
L1R5D2	0.679	0.538	0.726	0.759	0.552
L1R5D3	0.640	0.633	0.389	0.798	0.569
L1R5D4	0.576	0.665	0.242	0.896	0.591
L2R1D1	0.769	0.518	0.789	0.697	0.538
L2R1D2	0.624	0.511	0.568	0.725	0.555
L2R1D3	0.545	0.541	0.339	0.770	0.577
L2R1D4	0.525	0.593	0.200	0.857	0.588
L2R2D1	0.766	0.583	0.653	0.505	0.871
L2R2D2	0.567	0.482	0.516	0.514	0.885
L2R2D3	0.474	0.467	0.306	0.545	0.907
L2R2D4	0.704	0.720	0.189	0.574	0.918

L2R3D1	0.731	0.485	0.863	0.725	0.555
L2R3D2	0.535	0.454	0.611	0.747	0.574
L2R3D3	0.528	0.520	0.362	0.798	0.591
L2R3D4	0.381	0.414	0.222	0.896	0.613
L2R4D1	0.740	0.484	0.905	0.786	0.536
L2R4D2	0.652	0.523	0.674	0.825	0.555
L2R4D3	0.575	0.547	0.373	0.880	0.574
L2R4D4	0.498	0.568	0.221	0.930	0.591
L2R5D1	0.779	0.527	0.737	0.835	0.536
L2R5D2	0.774	0.640	0.537	0.892	0.555
L2R5D3	0.523	0.492	0.326	0.943	0.577
L2R5D4	0.532	0.557	0.198	1.000	0.593
L3R1D1	0.975	0.839	0.768	0.481	0.835
L3R1D2	0.748	0.673	0.579	0.504	0.871
L3R1D3	0.603	0.682	0.327	0.542	0.929
L3R1D4	0.572	0.695	0.187	0.613	1.000
L3R2D1	1.000	0.862	0.779	0.753	0.511
L3R2D2	0.919	0.778	0.611	0.776	0.525
L3R2D3	0.729	0.792	0.341	0.832	0.547
L3R2D4	0.840	1.000	0.189	0.930	0.574
L3R3D1	0.956	0.736	0.853	0.712	0.769
L3R3D2	0.892	0.891	0.547	0.759	0.794
L3R3D3	0.734	0.824	0.354	0.792	0.810
L3R3D4	0.699	0.876	0.194	0.857	0.863
L3R4D1	1.000	0.734	1.000	0.776	0.522
L3R4D2	0.849	0.707	0.716	0.835	0.541
L3R4D3	0.806	0.897	0.391	0.884	0.577
L3R4D4	0.698	0.901	0.202	0.952	0.596
L3R5D1	0.909	0.682	0.958	0.733	0.838
L3R5D2	0.808	0.712	0.674	0.773	0.865
L3R5D3	0.685	0.799	0.363	0.825	0.890
L3R5D4	0.668	0.866	0.200	0.888	0.909
L4R1D1	0.639	0.518	0.569	0.756	0.799
L4R1D2	0.434	0.445	0.401	0.767	0.824
L4R1D3	0.385	0.493	0.198	0.843	0.843
L4R1D4	0.374	0.561	0.135	0.896	0.857
L4R2D1	0.638	0.561	0.598	0.783	0.857
L4R2D2	0.527	0.552	0.451	0.822	0.816
L4R2D3	0.493	0.642	0.238	0.880	0.797
L4R2D4	0.466	0.678	0.158	0.938	0.786
L4R3D1	0.646	0.519	0.579	0.773	0.527
L4R3D2	0.504	0.506	0.421	0.828	0.549
L4R3D3	0.389	0.481	0.203	0.886	0.582
L4R3D4	0.392	0.583	0.137	0.934	0.591
L4R4D1	0.646	0.537	0.589	0.780	0.552
L4R4D2	0.519	0.539	0.432	0.839	0.577

L4R4D3	0.443	0.559	0.211	0.900	0.596
L4R4D4	0.428	0.629	0.147	0.930	0.618
L4R5D1	0.663	0.576	0.612	0.307	0.404
L4R5D2	0.538	0.554	0.472	0.314	0.415
L4R5D3	0.498	0.623	0.246	0.316	0.423
L4R5D4	0.456	0.657	0.162	0.318	0.429
L5R1D1	0.759	0.508	0.800	0.528	0.830
L5R1D2	0.603	0.512	0.575	0.559	0.849
L5R1D3	0.513	0.537	0.316	0.617	0.868
L5R1D4	0.601	0.796	0.177	0.676	0.904
L5R2D1	0.783	0.487	0.863	0.697	0.527
L5R2D2	0.664	0.542	0.601	0.731	0.566
L5R2D3	0.557	0.556	0.338	0.776	0.577
L5R2D4	0.610	0.792	0.178	0.839	0.599
L5R3D1	0.687	0.551	0.600	0.792	0.560
L5R3D2	0.546	0.482	0.505	0.818	0.577
L5R3D3	0.451	0.446	0.265	0.868	0.599
L5R3D4	0.347	0.421	0.171	0.938	0.632
L5R4D1	0.769	0.548	0.726	0.818	0.780
L5R4D2	0.593	0.512	0.537	0.861	0.816
L5R4D3	0.557	0.570	0.296	0.884	0.865
L5R4D4	0.482	0.615	0.175	0.930	0.912
L5R5D1	0.761	0.580	0.642	0.702	0.549
L5R5D2	0.619	0.522	0.516	0.733	0.566
L5R5D3	0.477	0.443	0.280	0.773	0.591
L5R5D4	0.422	0.505	0.173	0.853	0.621

ANNEXURE-V

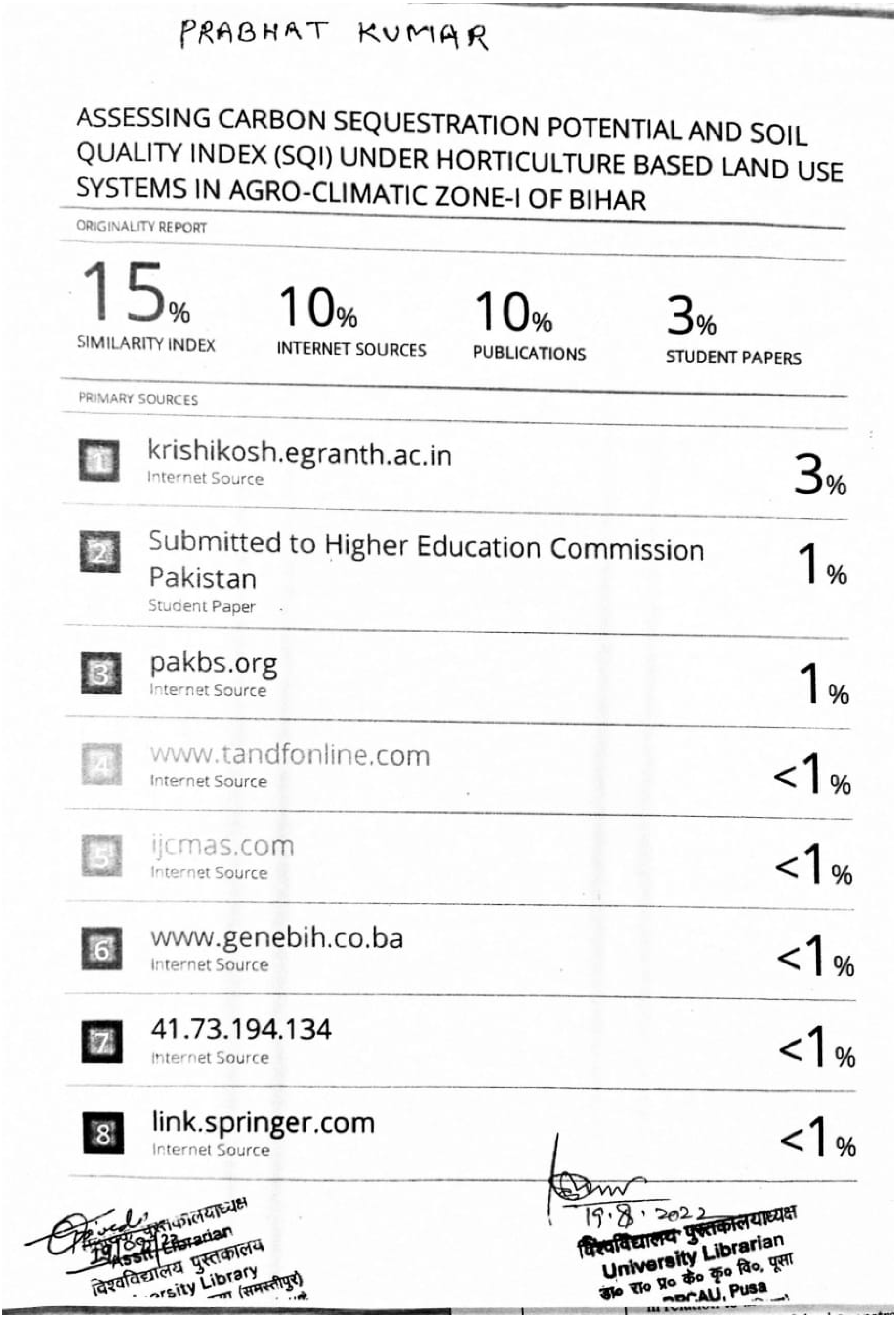
Value of weight multiplied with score of the observed variables for SQI determination

W*S	PC-1	PC-1	PC-2	PC-3	PC-4
	C-stock	**META.Q**	**Soil Respi**	**Sand%**	**Clay%**
L1R1D1	0.184	0.156	0.304	0.508	0.028
L1R1D2	0.160	0.150	0.228	0.519	0.029
L1R1D3	0.123	0.139	0.130	0.570	0.030
L1R1D4	0.114	0.118	0.081	0.627	0.032
L1R2D1	0.191	0.148	0.355	0.341	0.043
L1R2D2	0.165	0.150	0.253	0.353	0.046
L1R2D3	0.150	0.161	0.143	0.377	0.048
L1R2D4	0.172	0.178	0.089	0.406	0.048
L1R3D1	0.197	0.124	0.421	0.546	0.028
L1R3D2	0.174	0.133	0.318	0.603	0.029
L1R3D3	0.136	0.124	0.188	0.622	0.031
L1R3D4	0.163	0.209	0.107	0.657	0.032
L1R4D1	0.182	0.156	0.321	0.548	0.028
L1R4D2	0.160	0.166	0.197	0.585	0.029
L1R4D3	0.136	0.149	0.125	0.603	0.030
L1R4D4	0.095	0.104	0.076	0.651	0.031
L1R5D1	0.185	0.134	0.380	0.502	0.028
L1R5D2	0.153	0.121	0.309	0.531	0.030
L1R5D3	0.144	0.142	0.166	0.559	0.031
L1R5D4	0.129	0.150	0.103	0.627	0.032
L2R1D1	0.173	0.117	0.336	0.488	0.029
L2R1D2	0.140	0.115	0.242	0.508	0.030
L2R1D3	0.123	0.122	0.144	0.539	0.031
L2R1D4	0.118	0.133	0.085	0.600	0.032
L2R2D1	0.172	0.131	0.277	0.354	0.047
L2R2D2	0.128	0.109	0.219	0.360	0.048
L2R2D3	0.107	0.105	0.130	0.382	0.049
L2R2D4	0.158	0.162	0.081	0.402	0.050
L2R3D1	0.165	0.109	0.367	0.508	0.030
L2R3D2	0.120	0.102	0.259	0.523	0.031
L2R3D3	0.119	0.117	0.154	0.559	0.032
L2R3D4	0.086	0.093	0.094	0.627	0.033
L2R4D1	0.166	0.109	0.385	0.550	0.029
L2R4D2	0.147	0.118	0.286	0.578	0.030
L2R4D3	0.129	0.123	0.158	0.616	0.031
L2R4D4	0.112	0.128	0.094	0.651	0.032
L2R5D1	0.175	0.118	0.313	0.585	0.029
L2R5D2	0.174	0.144	0.228	0.624	0.030
L2R5D3	0.118	0.111	0.139	0.660	0.031

L2R5D4	0.120	0.125	0.084	0.700	0.032
L3R1D1	0.219	0.189	0.327	0.336	0.045
L3R1D2	0.168	0.151	0.246	0.353	0.047
L3R1D3	0.136	0.153	0.139	0.380	0.050
L3R1D4	0.129	0.156	0.080	0.429	0.054
L3R2D1	0.225	0.194	0.331	0.527	0.028
L3R2D2	0.207	0.175	0.259	0.544	0.028
L3R2D3	0.164	0.178	0.145	0.582	0.030
L3R2D4	0.189	0.225	0.081	0.651	0.031
L3R3D1	0.215	0.166	0.362	0.499	0.042
L3R3D2	0.201	0.200	0.233	0.531	0.043
L3R3D3	0.165	0.185	0.150	0.554	0.044
L3R3D4	0.157	0.197	0.082	0.600	0.047
L3R4D1	0.225	0.165	0.425	0.544	0.028
L3R4D2	0.191	0.159	0.304	0.585	0.029
L3R4D3	0.181	0.202	0.166	0.619	0.031
L3R4D4	0.157	0.203	0.086	0.666	0.032
L3R5D1	0.204	0.153	0.407	0.513	0.045
L3R5D2	0.182	0.160	0.286	0.541	0.047
L3R5D3	0.154	0.180	0.154	0.578	0.048
L3R5D4	0.150	0.195	0.085	0.622	0.049
L4R1D1	0.144	0.117	0.242	0.529	0.043
L4R1D2	0.098	0.100	0.170	0.537	0.045
L4R1D3	0.087	0.111	0.084	0.590	0.046
L4R1D4	0.084	0.126	0.057	0.627	0.046
L4R2D1	0.143	0.126	0.254	0.548	0.046
L4R2D2	0.119	0.124	0.191	0.575	0.044
L4R2D3	0.111	0.144	0.101	0.616	0.043
L4R2D4	0.105	0.152	0.067	0.657	0.042
L4R3D1	0.145	0.117	0.246	0.541	0.028
L4R3D2	0.113	0.114	0.179	0.580	0.030
L4R3D3	0.088	0.108	0.086	0.620	0.031
L4R3D4	0.088	0.131	0.058	0.654	0.032
L4R4D1	0.145	0.121	0.251	0.546	0.030
L4R4D2	0.117	0.121	0.183	0.587	0.031
L4R4D3	0.100	0.126	0.089	0.630	0.032
L4R4D4	0.096	0.142	0.063	0.651	0.033
L4R5D1	0.149	0.130	0.260	0.215	0.022
L4R5D2	0.121	0.125	0.200	0.220	0.022
L4R5D3	0.112	0.140	0.105	0.221	0.023
L4R5D4	0.103	0.148	0.069	0.223	0.023
L5R1D1	0.171	0.114	0.340	0.370	0.045
L5R1D2	0.136	0.115	0.244	0.392	0.046
L5R1D3	0.115	0.121	0.134	0.432	0.047
L5R1D4	0.135	0.179	0.075	0.473	0.049
L5R2D1	0.176	0.110	0.367	0.488	0.028

L5R2D2	0.149	0.122	0.255	0.511	0.031
L5R2D3	0.125	0.125	0.144	0.544	0.031
L5R2D4	0.137	0.178	0.076	0.587	0.032
L5R3D1	0.155	0.124	0.255	0.554	0.030
L5R3D2	0.123	0.108	0.215	0.573	0.031
L5R3D3	0.102	0.100	0.113	0.608	0.032
L5R3D4	0.078	0.095	0.072	0.657	0.034
L5R4D1	0.173	0.123	0.309	0.573	0.042
L5R4D2	0.134	0.115	0.228	0.603	0.044
L5R4D3	0.125	0.128	0.126	0.619	0.047
L5R4D4	0.108	0.138	0.074	0.651	0.049
L5R5D1	0.171	0.131	0.273	0.491	0.030
L5R5D2	0.139	0.117	0.219	0.513	0.031
L5R5D3	0.107	0.100	0.119	0.541	0.032
L5R5D4	0.095	0.114	0.073	0.597	0.034

* * * * *



PRABHAT KUMAR

ASSESSING CARBON SEQUESTRATION POTENTIAL AND SOIL QUALITY INDEX (SQI) UNDER HORTICULTURE BASED LAND USE SYSTEMS IN AGRO-CLIMATIC ZONE-I OF BIHAR

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