

**Assessment of Biomass Production, Soil Carbon
Stock and Carbon Sequestration under Various
Land use Systems of Vindhyan Region**

काशी हिन्दू
विश्वविद्यालय



BANARAS HINDU
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THE REQUIREMENTS FOR THE DEGREE OF
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Submitted by
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I have great pleasure in forwarding the thesis entitled “*Assessment of Biomass Production, Soil Carbon Stock and Carbon Sequestration under Various Land Use Systems of Vindhyan Region*” submitted by **Mr. Hitesh Gupta**, I.D No. **20430AGF008** in partial fulfilment of the requirements for the degree of **Master of Science (Agriculture) in Agroforestry**, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi (U.P.) and placing on record that she has completed the requisite requirements as contained in the statutes of the University.

I certify that the entire scheme of investigation reported herein was planned and carried out solely by the candidate under my guidance and supervision. The data presented in the thesis, to the best of my knowledge and belief, are genuine and have not been utilized for the award of other degree or dissertation.

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Yours faithfully,

Forwarded by

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Assessment of Biomass Production, Soil Carbon Stock and Carbon Sequestration under Various Land Use Systems of Vindhyan Region



by

Hitesh Gupta

**Thesis submitted in partial fulfillment of
the requirements for award of
Master of Science (Agriculture)
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SYMBOLS AND ABBREVIATIONS

\$	Dollar
%	Per cent
₹	Rupee
@	At the rate of
AF	Agroforestry
AFs	Agroforestry systems
AH	Agri-horticulture
AHS	Agri-horti-silviculture
Approx.	Approximately
AS	Agri-silviculture
AGB	Aboveground biomass
BD	Bulk density
BGB	Belowground biomass
C	Carbon
CAFRI	Central Agroforestry Research Institute
C/ha	Carbon per hectare
C/ha/yr	Carbon per hectare per year
CD	Critical difference
CH ₄	Methane
cm	Centimetre
CO ₂	Carbon dioxide
CSP	Carbon sequestration potential
CV	Coefficient of variance
DBH	Diameter at breast height
<i>et al.</i>	co-workers
Fe	Iron
FCCC	Framework Convention on Climate Change
FSI	Forest Survey of India
FYM	Farm yard manure

g	Gram
g/kg	Gram per kilogram
g/cm	Gram per centimetre cube
g/cc	Gram per centimetre cube
GHG	Green House gas
GHGs	Greenhouse gasses
Gt	Giga tonne
ha	Hectare (10,000 m ²)
HP	Horti-pastoral
i.e.	That is
IPCC	Intergovernmental Panel on Climate Change
ISFR	India State of Forest Report
ICAR	Indian Council of Agricultural Research
K	Potassium
Kg/cm	Kilogram per square centimetre
kg CO ₂ ha/day	Kilogram carbon dioxide per hectare per day
kg ha/day	Kilogram per hectare per day
kg ha/yr	Kilogram per hectare per year
Kg/m ²	Kilogram per square meter
km	Kilometre
LULUCF	Land Use, Land Use Change and Forestry
m	Metre
m ha	Million hectare
MAP	Mean annual precipitation
MAT	Mean annual temperature
Mg C/ha	Mega gram carbon per hectare
Mg C/ha	Mega gram carbon dioxide per hectare
Mg C/ha/yr	Mega gram carbon per hectare per year
Mg/ha	Mega gram per hectare
Mg/m ³	Mega gram per metre cube
Mt	Million tons

NATCOM	National Communication
NE	North East
NRCS	National Resource Conservation Services
NFP	National Forest Policy
OC	Organic carbon
P	Phosphorus
PA	Pure agriculture
Pg	Petagram
PG	Pure grassland
Pg C	Peta gram carbon
PPM	Parts Per Million
₹/ha/yr	Rupees per hectare per year
RDF	Recommended dose of fertilizer
SC	Soil carbon
SOC	Soil organic carbon
SOM	Soil organic matter
SP	Silvi-pastoral
SEm	Standard error of the mean
t C/ha	Tonne Carbon per hectare
t C/ha/yr	Tonne Carbon per hectare per year
UNCED	United Nations Conference on Environment and Development
UNFCCC	United Nations Framework Convention on Climate Change
US\$	United States' dollar
USA	United States of America
USDA	United State Department of Agriculture
°C	Degree Celsius

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INTRODUCTION

Climate change ascribed directly or indirectly to human activities that are changing the state of the global atmosphere and observed that these changes caused variability to the natural climate over the comparable time periods because it impacts every country on the planet. Moreover, climate change is a worldwide concern. “A change in the condition of the climate (temperature, rainfall, humidity etc.) that can be determined (e.g. via statistical tests) by shifts in the average and/or variability of its attributes, and that endures for a longer duration, often decades or longer” is termed climate change as defined by UNFCCC, 2011.

By the end of the United Nations Framework Convention on Climate Change (UNFCCC), Conference of the Parties (COP 21) in Paris in December 2015, countries from all around the world have pledged to construct a new International Climate Pact (Paris Agreement, UNFCCC, 2015). India has committed to produce an increased carbon sink of 2.5 to 3.0 billion tonnes CO₂ equivalent by increased in forest and tree cover by 2030 (FSI Technical Information Series, 2019).

The Paris Agreement, authorised in 2015, committed petitioners to keeping increased global temperature well below 2°C and pursuing measures to keep them below 1.5°C. The annual reduction in agriculture emissions that may help to attain the 2°C target was estimated to be between 14 and 33 percent (Wollenberg *et al.*, 2016; IPCC, 2019; Henderson *et al.*, 2021). The Land Use, Land Use Change and Forestry (LULUCF) division is sure to perform a larger role as these temperature stabilization goals are not likely to get without the removal of carbon dioxide from the atmosphere (Smith, 2016; Wollenberg *et al.* 2016). Carbon emissions from land use change were estimated to be 0.9 Pg C/yr from 2005 to 2014 (Le Quere *et al.*, 2016). The Paris Agreement (2015) also stressed lowering worldwide temperature increases to 2°C by 2,100 and pursuing attempts to generate more carbon via agricultural materials

through both traditional mitigation efforts and other channels (Gupta and Kumar, 2020; Kumar and Gupta, 2020), so as to minimize the earth's temperature increase to 1.5°C.

In the UNFCCC, the Parties have accepted various policy actions, measures and functions to put forward the problems of climate change reduction and acclimation. India is also an important member to the convention and therefore, it is important for the country to submit greenhouse gas (GHG) inventory periodically from almost all the sectors which encompasses Land Use, Land-Use Change and Forestry (LULUCF) as National Communication (NATCOM). As much concentration has been paid to forest carbon sequestration as a central element of global reduction efforts, there is a wide opportunity for LULUCF and agriculture to give through carbon sequestration in the soils of agriculture. Few countries of the world have merged soil carbon targets into their policy of national climate mitigation and where they reside, policy incentives that target net soil carbon sequestration have not proved yet had wide-ranging impact (Henderson, Frezal and Flynn, 2020).

Rapid changes in land use alone account for roughly 10% of worldwide CO₂ into the atmosphere (IPCC, 2007; Le Quere *et al.*, 2016). Betts *et al.* (2016) found an increase in atmospheric CO₂ concentration to > 400 ppm in tropical zones in 2015, and this accumulation is expected to approach 500 ppm by 2050 (Cai *et al.*, 2014). Besides that, rapid increases in CO₂ levels will raise the average temperature of the earth, resulting in additional negative consequences (e.g., flooding, sea level rise and increased ecological and human health risks) (IPCC, 2007; IPCC, 2014; Kumar *et al.*, 2021). Carbon dioxide is the most common greenhouse gas (GHG) in the atmosphere and a large cause of global warming (>50%). Most of the goals of anthropogenic climate change research have shifted since the mid 1900s, with the target of decreasing terrestrial carbon sources and increasing sinks as a way to fight climate change effects under carbon dioxide (CO₂) enrichment (Kumar *et al.*, 2017).

Agroforestry has a wide heritage in the Indian subcontinent and it is a very good option to mitigate and prevent climate change. Trees are fully integrated into

region's crop and animal production systems. The alternative aim of agroforestry is to maximize the positive interactions between various components in view to get a more sustainable, fruitful and variegated output from the land. Although natural vegetation is vanished for agriculture, trees are incorporated into productive landscapes – the exercise known as agro-forestry (Garrity *et al.*, 2006). Data presented by remote sensing in 2010 showed that, 43% of the total agricultural land globally had a minimum of 10% tree cover and this aimed to be increased by 2% over the last 10 years (Zomer *et al.*, 2016). Chavan (2015) reported the agro-forestry area based on data taken from CAFRI, Jhansi and Bhuvan LISS III, was 13.75 m ha. FSI evaluated the identical as 11.54 m ha, which is 3.39% of the total geographical area of India (FSI, 2013). Although agroforestry has been identified as having the highest potential for C sequestration (Fig. 1) of all of the other land uses studied in the IPCC's Land-Use, Land-Use Change, and Forestry report (2000), our knowledge of carbon storage in specific agroforestry practices from around the world is at effectively simple, primitive and basic.

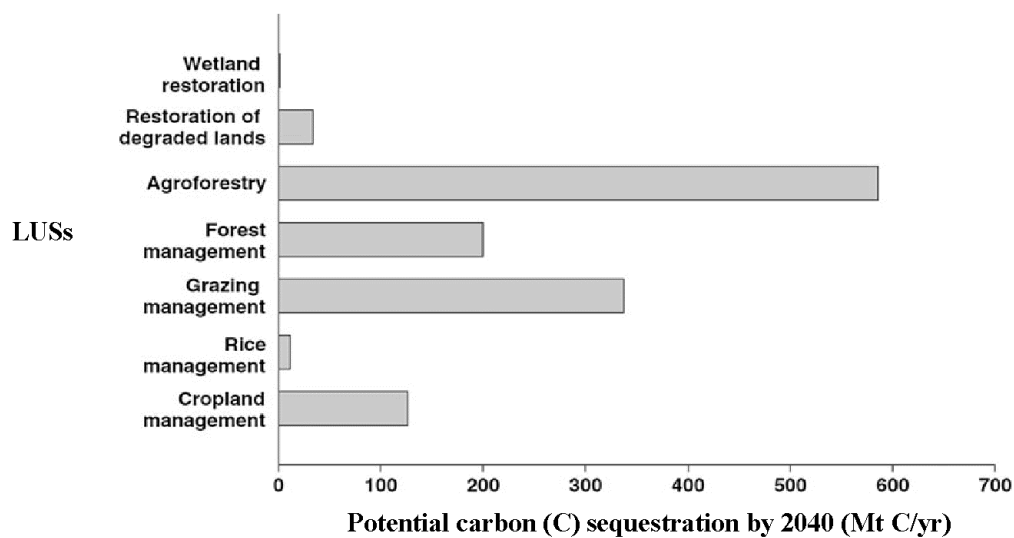


Fig 1.1: Potential carbon sequestration of various LUSs by 2040 (IPCC, 2000).

According to IPCC (2000), carbon sequestration capacity or potential of various land use systems. Due to the obvious vast amount of land (63,09,106 ha) available for agroforestry adoption, agroforestry has the greatest potential of carbon sequestration.

Continuously increasing trend has been noticed in the carbon stock of the India's forest, over the last 5 biennial assessments. There has been an increase in carbon stock from 6,663 million tonnes (Mt) in year 2011 assessment to 7,204.0 Mt has been assessed in the present, which showing an increase of 541 million tonnes within the period 2011 to 2021 (India State of Forest Report, 2021).

Hombegowda *et al.* (2016) suggested that agroforestry systems (AFS) have larger debris inputs and can incorporate carbon deep into the soil with their root systems, resulting in higher CO₂ sequestration rates than traditional agriculture systems. Agroforestry has been recognized by the International Panel on Climate Change as having a maximum potential for carbon sequestration as element of climate change reduction strategies (Watson *et al.*, 2000). It can maximize and stabilize agricultural yields and minimize soil erosion (Prinsley, 1990). While the atmospheric carbon is increasing, we are having another problem that soil organic carbon (SOC) is decreasing (Gupta *et al.*, 2009) due to inappropriate land management practices such as maximum tillage operations and excessive use of fertilizers (Bhattacharyya *et al.*, 2015), SOC is one of the essential factors which improves the soil fertility status and increases productivity by improving the physical, chemical and biological properties of soil (Sahoo *et al.*, 2019).

The United Nations Framework Convention on Climate Change (UNFCCC) claimed to estimate above and below ground carbon stocks from tree biomass and soil as one of the most important CO₂ sinks in the terrestrial environment (Green *et al.*, 2007). The removal of atmospheric carbon and its storage in the terrestrial biosphere by fast-growing species is a viable option for reducing greenhouse gas emissions (Chauhan *et al.*, 2016). Several authors observed that the total existing biomass of various trees such as, *Albizia lebbeck* (67.70 t/ha), *Delonix regia* (38.110 t/ha) (Chavan and Rasal, 2012); *Dalbergia sissoo* (94.8 t/ha), *Populus deltoids* (63.0 t/ha) (Kanime *et al.*, 2013); *Mangifera indica* (104.41 t/ha) (Chavan and Rasal, 2012).

There is a lot of proof that agroforestry systems aid in raising carbon stocks in soil and mitigating climate change through carbon sequestration. Agroforestry systems have a carbon sequestration potential of between 12 and 228 Mg/ha. Carbon (C) sequestration potential is estimated to be 95 Mg/ha on average. As per the Earth's surface area, 1.1-2.2 Pg C might be stored in terrestrial ecosystems within the next 50 years (Albrecht and Kandji, 2003).

Carbon sequestration rate, carbon price and carbon credit played a great role in the agroforestry systems (AFSs) productivity. The amount of carbon captured from the atmosphere and stored as biomass was used to compute the carbon credits in US dollars (Meena *et al.* 2022). Agricultural greenhouse gas (GHG) emissions (particularly CO₂) are quite modest when compared to industrial emissions. As a matter of fact, carbon credit systems in agriculture have received a lot of attention around the world (Shockley and Snell, 2021) as away to achieve climate neutrality by allowing agricultural farmers to sell their excess offsets to producers who emit more GHGs. Amidst the COVID-19 pandemic and the resulting economic crises, the World Bank (2021) reports that carbon credit markets have grown significantly in the last year. The numbers of projects submitted and the quantity of credits issued have both increased by 11% and 10%, respectively. This increase takes the total quantity of carbon dioxide equivalents (t CO₂e) certificates issued since 2002 to about 4.3 billion tonnes (World Bank, 2021). Most of the analysts pointed that if an estimated carbon price of \$80 to \$120 is reached by 2030, global climate change or global warming will be limited to 2°C (IPCC 2014).

According to the World Agroforestry Centre, the carbon market could approach US\$1 trillion by 2025, implying that agroforestry could earn large funds (Goswami *et al.*, 2014). Agroforestry is currently seen as a promising economic possibility to prevent global climate change, trade, and offer different goods by sequencing carbon. With these considerations in mind, the current study, titled **"Assessment of Biomass Production, Soil Carbon Stock and Carbon Sequestration under Various Land Use Systems of Vindhyan Region,"** was

carried out at Rajiv Gandhi South Campus, Banaras Hindu University, Barkachha, Mirzapur, Uttar Pradesh, India, with the following research goals:

1. To find out the impact of diverse land-use regimes on soil physico-chemical attributes at different depths.
2. To analyze the value of biomass accumulation or biological yield, biomass carbon stock and biomass carbon sequestration potential of different land use systems.
3. To investigate the total carbon stock, total carbon sequestration and carbon credit under different land use systems.



REVIEW OF LITERATURE

Agroforestry systems are made up of various models that are used in various parts of the world to counter the adverse effects of climate change by increasing tree-crop diversification, which results in a greater carbon sequestration than solely cultivating agricultural crops. With the exception of agriculture, the farmers have adopted a variety of land use systems, the most attractive of which is agroforestry, because agroforestry products are alternatives for similar products derived from forest areas and provide a variety of miscellaneous benefits, including carbon sequestration or storage. Many investigations have been undertaken on the effectiveness of agroforestry systems as storage of carbon (C), soil improvement, environment safety and financial feasibility *modus operandi*. Further improvements must be fostered to promote this multidimensional activity among the masses, for which earlier studies must be taken into account. As a result, in this chapter, an effort has been made to review prior investigations on soil improvement, biomass potential, carbon stock, carbon sequestration and carbon credit and the available literature relevant to the current study has been examined under the following sub sections:

- 2.1 Different methods for quantification of carbon sequestration in various LUSs
 - 2.1.1 In Abroad
 - 2.1.2 In India
- 2.2 Effect of different land-use system on soil physicochemical properties
 - 2.2.1 Bulk density (BD)
 - 2.2.1.1 In Abroad
 - 2.2.1.2 In India
 - 2.2.2 Soil Organic Carbon (SOC) and Soil Organic Carbon Stock
 - 2.2.2.1 In Abroad
 - 2.2.2.2 In India

- 2.3 Effect of different land-use system on biomass accumulation
 - 2.3.1 Aboveground biomass accumulation
 - 2.3.1.1 In Abroad
 - 2.3.1.2 In India
 - 2.3.2 Belowground biomass accumulation
 - 2.3.2.1 In Abroad
 - 2.3.2.2 In India
 - 2.3.3 Total and rate of biomass accumulation
- 2.4 Biomass carbon stock estimation of different land use system
 - 2.4.1 Above and below ground biomass carbon stock
 - 2.4.1.1 In Abroad
 - 2.4.1.2 In India
 - 2.4.2 Crop carbon stock
 - 2.4.2.1 In Abroad
 - 2.4.2.2 In India
 - 2.4.3 Total and rate of biomass carbon stock
 - 2.4.3.1 In Abroad
 - 2.4.3.2 In India
- 2.5 Biomass carbon sequestration potential of different land use system
 - 2.5.1 In Abroad
 - 2.5.2 In India
- 2.6 Leaf litter and leaf litter carbon accumulation in different land use system
- 2.7 Total carbon stock estimation
 - 2.7.1 In Abroad
 - 2.7.2 In India
- 2.8 Total carbon sequestration estimation

2.9 Carbon credit

2.9.1 In Abroad

2.9.2 In India

2.1 Different methods for quantification of carbon (C) sequestration in various LUSs

2.1.1 In Abroad

Issa *et al.* (2020) carried out a study to review different methods of terrestrial carbon assessment by using Geo-spatial technologies with special reference to Arid lands. Two methods were generally used for biomass and carbon estimation viz. traditional methods and Geo-spatial methods. Allometric approach comes under traditional methods. Geo-spatial methods encompass RS-Based Methods, Biophysical Predictors, Remote Sensing Variables and RS-GIS Integrated Models. The review paper concluded that for aboveground biomass evaluation, monitoring, modelling, and management of carbon sequestration, geospatial technologies are realistic, feasible and provide acceptable validation.

Sun and Liu (2020) conducted a study in China to investigate various methods for forest carbon storage estimation. According to them, estimation of vital forest C sequestration methods were divided into three crucial types and fifteen subtypes emphasis on estimation of C storage by vegetation, C storage estimation by soil, and C storage by litter. They mainly used soil type method, inventory based methods and biomass model for forest estimation in China. The results showed that vegetation C density through average biomass method was maximum (57.07 Mg/ha) as compared to other 9 types of vegetation C sequestration approximation methods practiced during 1989 to 1993.

Gao *et al.* (2015) carried out research work in China for evaluation of four methods for calculating carbon stocks of Korean Pine. The results of the investigation reported that compatible biomass and carbon models with tree diameter (D) performed well, so that this method was the best method for estimating the carbon stocks of tree components and total carbon stock.

2.1.2 In India

Das *et al.* (2021) carried out an experiment at **Arunachal Pradesh** to estimate the carbon pool, above ground biomass and C sequestration potential of different land use systems (LUSs) and planned future tendency of carbon stock by using spatial modelling. The Land use/cover map of the study area has been generated using Landsat OLI satellite data (2016). The results revealed that the CO₂FIX model was chosen in this study to determine the carbon stock and sequestration because of the model's simplicity, which encompasses numerous modules that work in a systematic manner, and modules such as bioenergy, products and finances are vital for the future prediction. Although there was some mistake in terms of surface reflectance owing to terrain, sun, and sensor position, the Landsat OLI generated vegetation indices are highly effective in predicting AGB.

Pandey *et al.* (2013) at **Gujarat** assessed the carbon storage by using allometric or non-destructive approach of twenty-five species. An allometric equation was evolved for the calculation of tree biomass i.e., Tree biomass volume = 0.4 * (D) * H, where H = height, D = diameter and tree species to factor 0.4.

Yadava (2011) at **Tarai region of Central Himalayas** estimated the C sequestration potential of different agroforestry systems for climate change mitigation. The results showed that the C sequestration of different agroforestry systems is assessed by multiplying the factor of 3.66 with carbon stock values.

2.2 Effect of different land-use systems on soil physico-chemical properties

2.2.1 Bulk density (BD)

2.2.1.1 In Abroad

Gebeheyu and Soromessa (2018) carried out a comparative study at Mecha, **Northwest Ethiopia** to study the status of total nitrogen and soil organic carbon between various farming systems in Koga watershed area. The results showed that a negative relation exists between soil organic carbon and bulk density. The relation showed that if bulk density increases then soil organic carbon decreases.

Ouyang *et al.* (2017) undertook a research in **Southern China** to study the changes in floristic composition during forest succession and its influence on soil carbon, phosphorus, nitrogen and stoichiometry along successional stages. Soil samples were collected at the depth of 0-10, 10-20 and 20-30 cm from three forests at early, middle and late stages of succession. The results revealed adversarial relationship between bulk density and organic matter. Soil bulk density, litter, stand density, pH and elevation affected total nitrogen, soil organic carbon and total phosphorus.

Yiheneu and Getachew (2013) carried out an experiment at Achefer, **Northwestern Ethiopia** to study the influence of various land use systems on physico-chemical properties of soil for better land management practices in rural villages of Aferfida Georgis and Abechikeli Mariam. Four land use systems studied were cultivated land, grassland, natural forest and plantation forest. Soil samples were collected at the depth of 0-15 cm and 15-30 cm. The results revealed that the highest bulk density (1.31 g/cc) was recorded in cultivated land, followed by Eucalyptus plantations at the depth of 15-30 cm. The lowest bulk density (1.13 g/cc) was observed under natural forest. The research also revealed that in the uncultivated land due to the accumulation of higher organic matter, the soil becomes loose and porous which lead to decrease in the bulk density of the soil.

2.2.1.2 In India

Bhuyan *et al.* (2021) carried out an experiment at Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, **Himachal Pradesh** to study the effect of the application of different organic fertilizer applications on the physicochemical properties of the soil in the Morus-based agro-silviculture system. Different organic matter combinations had been taken. The minimum soil density was estimated in T₁₀ (100% Poultry manure (25.08 q/ha) + FYM) and T₉ (75% Poultry manure (18.81 q/ha) + 25% RDF + FYM) i.e. 1.24 g/cm³. Bulk density ranged between 1.24-1.26 g/cm³. T₁₀ has maximum SOC. This revealed that the SOC and BD has inverse relation.

Kaur et al. (2021) carried out an experiment using five LUSs to study nutrient status in the lower Sutlej basin of the foothills of Shiwalik in the Himalayas of **Punjab**. One hundred and twenty samples were collected at four soil depths, namely 0-15, 15-30, 30-45, and 45-60 cm to evaluate soil physicochemical properties. The result of experiment showed that the soil BD ranged between 1.30 to 1.59 g/cm³.

Ram et al. (2021) undertook a study at Pantnagar, **Uttarakhand** to evaluate the effect of various LUSs on physical properties of Mollisol at Norman E. Borlaug Crop Research Centre, G. B. Pant University of Agriculture and Technology. Nine LUSs were selected viz., (Rice-potato-okra), (Rice-wheat-green gram), (Rice-pea vegetable-maize), (Rice-berseem + mustard-maize + oat + cowpea), (Poplar + turmeric), (Guava + lemon), (Fallow uncultivated land). Soil samples were collected from four depths viz. D₁ (0-15) cm, D₂ (15-30) cm, D₃ (30-45) cm, and D₄ (45-60) cm. The highest bulk density was founded in D₄ (1.4 g/cm³) depth. This revealed that the bulk density increases with increase in depth and it's vice versa. LUSs also affected the soil BD and the study exhibited that the maximum soil BD was found in the fallow uncultivated LUS 1.65 g/cm³. BD ranged between 1.25-1.65 g/cm³ in different LUSs and between 1.39-1.47 g/cm³ under various depths.

Singh et al. (2020) at Rajiv Gandhi South Campus, Banaras Hindu University, Barakachha, Mirzapur, **Uttar Pradesh** conducted an experiment with four land use systems (degraded forest, natural forest, bioenergy and agroecosystem) to study the changes in soil physicochemical properties due to land-use transformation from natural forest to other type of land-use. The results revealed that the soil bulk density ranged from 1.13-1.46 g/cm³. The lowest bulk density was seen in natural forest (1.13 g/cm³) at the depth of 0-10 cm. However, the highest bulk density was observed in agro ecosystem (1.46 g/cm³) at the depth of 20-40 cm.

Ekka et al. (2017) conducted an experiment at Rajiv Gandhi South Campus, Banaras Hindu University, Barakachha, Mirzapur, **Uttar Pradesh** to estimate the various changes in soil physicochemical properties by the effect of four agri-horticulture systems. The bulk density ranged between 0.01 to 2.68 Mg/m³. The maximum bulk density (BD) was recorded in custard apple orchard. They proposed

that bulk density also vary with depth, the highest between 15-30 cm (1.37 Mg/m³) and the lowest between 0-15 cm (1.33 Mg/m³).

Maqbool *et al.* (2017) studied seven land-use systems at district Ganderbal, **Jammu and Kashmir** to evaluate soil physicochemical properties. The various LUSs were horticulture, forest, wastelands, pastures, irrigated agriculture, agri-horticulture, and non-irrigated agriculture. The BD varied from 1.23-1.65 g/cm³ and showed the following trend: non-irrigated agriculture (1.57 g/cm³) > wastelands (1.52 g/cm³) > agri-horticulture (1.44 g/cm³) > horticulture (1.43 g/cm³) > irrigated agriculture (1.42 g/cm³) > pastures (1.31 g/cm³) > forestry (1.28 g/cm³).

2.2.2 Soil organic carbon (SOC) and soil organic carbon stock

2.2.2.1 In Abroad

Bato and Bekele (2020) conducted an experiment in the central highlands of **Ethiopia** to evaluate the chemical properties dynamics of soil under various land use systems and at various depths. The study indicated that the general mean value of the organic carbon (OC) concentration below the eight various land use systems (grassland, natural forest, grazing land, four exotic tree species plantation and cropland) was ranged between 1.47 to 3.49 %. The maximum organic carbon concentration was observed in the natural forests and minimum in the cropland.

2.2.2.2 In India

Ahirwal *et al.* (2021) carried out a study in the **Indian Himalayan Region (IRR)** to investigate the various carbon stock patterns and the significance of environmental variables in anticipating soils and biomass carbon stock. The results showed that plantation forests had the highest SOC stock (168.8 ± 74.4 Mg C/ha) and forests exhibited the highest biomass carbon stock (138.5 ± 87.3 Mg C/ha).

Bhuyan *et al.* (2021) carried out an experiment at Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, **Himachal Pradesh** to study the effect of the application of different organic fertilizer applications on the physico-chemical properties of the soil in the morus-based agro-silviculture system. Different organic matter combinations had been taken. Maximum soil organic carbon had been

found in treatment ten (T₁₀) (100% Poultry manure (25.08 q/ha) + FYM) i.e 1.86%. SOC ranged from 1.46-1.86% in agrisilviculture system. The results revealed that SOC increased by applying different organic manure combinations.

Manpoong *et al.* (2021) conducted an experiment at **Mizoram** to estimate the soil carbon stock in different land use systems at various soil depths in the hilly topography. Soil samples were taken from ten land use systems viz. oil palm plantation (OPP), rubber plantation (RP), bamboo forest (BF), 5 years fallow (5YF), teak plantation (TP), horticulture garden (HORT), *Tephrosia candida* plantation, homegarden (HG), natural forest (NF), and 10 years fallow (10YF). The results revealed that soil carbon concentration was significantly highest in the natural forests, followed by *Tephrosia candida* plantation, five years fallow, oil palm plantation, ten years fallow, rubber plantation, bamboo forest, homegarden, horticulture garden and teak plantation. The soil organic carbon stock decreased with increasing depth in RP, OPP and HG whereas the maximum soil organic carbon stock was found at the depth of 10-20 cm in BF, 5YF, 10YF, TCP. The maximum soil carbon stock was found in OPP, RP and HG at upper depth and proposed that the carbon sequestration from the atmosphere was more active in the surface soil after the land use change. The study concluded that soil organic carbon decreased and bulk density increased with depth.

Sahoo *et al.* (2021) carried out an experiment in the **North Eastern India** to investigate the carbon storage potential and total biomass of various land use systems using a model for biomass estimation evolved for this region. Seven land use systems were preferred viz., 1) bamboo forest; 2) forest: temperate, subtropical, tropical; 3) shifting cultivation fallows: 11-20 years, 5-10 years, < 5 years; 4) plantations: temperate, subtropical, and tropical; 5) agroforestry 6) agriculture; and 7) grasslands. The results revealed that the mean soil organic carbon stock was recorded maximum in tropical forests (72.54 ± 2.02 Mg C/ha), followed by temperate (63.4 ± 6.94 Mg C/ha) and subtropical forests (42.58 ± 3.32 Mg C/ha). SOC values in tropical forests varied between 10.13-119.65 Mg C/ha and in temperate forests ranged from 22.32-114.59 Mg C/ha. The average SOC stock of bamboo forests was 29.83 ± 0.97 Mg C/ha and varied between 25.28-34.67 Mg C/ha. The SOC stock of plantations showed

the following trend: tropical > subtropical > temperate zones. The average SOC stock of agriculture land was 40.13 ± 1.77 Mg C/ha. Total carbon stock (TCS) was highest in tropical forests (185.5 ± 15.55 Mg C/ha) and lowest in grassland (40.55 ± 7.77 Mg C/ha).

Uthappa and Devakumar (2021) carried out an investigation at University of Agricultural Sciences, GKVK, Bengaluru, **Karnataka** to estimate the carbon sequestration potential of different land use systems. The results revealed that the highest 37.69, 19.37, 19.70 and 25.59 t/ha soil organic carbon was noted in natural forest and the lowest 13.25, 10.29, 8.24 and 10.59 t/ha in horticulture system at the depth of 0-20 cm, 20-40cm, 40-60 cm and mean, respectively. At the depth of 0-20 cm, 20-40 cm, 40-60 cm and mean value the SOC stock ranged between 13.25-37.69 t/ha, 10.29-19.37 t/ha, 8.24-19.70 t/ha and 10.59-25.59 t/ha, respectively.

Maini et al. (2020) carried out an experiment in north eastern region of **Punjab** to assess the effects of rainfed land use systems (LUSs) on soil biochemical properties and soil organic carbon. Study was conducted in six land use systems comprising of horticulture, agri-horticulture, agroforestry, agriculture, forestry and barren lands. The results revealed that higher soil organic carbon was recorded in agri-horticulture system whereas lower was recorded in barren land use system due to intensive cultivation. The soil organic carbon of the remaining land use systems followed the trend: Agroforestry > Horticulture > Agriculture. The soil organic carbon ranged from 0.20- 0.63 %.

Mishra et al. (2020) carried out an experiment at **Meghalaya** to determine the effects of different land use systems on total soil organic carbon content. Soil samples were amassed from the rubber plantation, forest, and cultivated fields from the depth of 30 cm. Total soil organic carbon (SOC) was notably higher in forest soils (1.81%). More soil organic carbon was recorded in forest soils because of regular and more accumulation of organic matter into the soil in the various forms of above and below ground plant parts. Less soil organic carbon was found in cultivated land due to intensive cropping system and more tillage practices which disturb the rate of decomposition of organic matter.

Singh et al. (2020) carried out an experiment at Sambalpur, **Orissa** to evaluate the total carbon sequestration potential of 20 year old teak plantation forest. Soil samples were collected at the depth of 0-10, 10-20 and 20-30cm. The results revealed that the soil organic carbon values ranged from 0.30-1.26%, 0.48-1.48% and 0.14-1.02% at the depth of 0-10, 10-20 and 20-30cm, respectively. The soil organic carbon stock ranged from 3.39-15.30 t/ha, 5.41-17.74 t/ha and 1.62-12.24 t/ha and 1.62-17.74 t/ha at the depth of 0-10, 10-20, 20-30 and 0-30cm, respectively.

Singh et al. (2020) conducted an experiment at Rajiv Gandhi South Campus, Banaras Hindu University, Barakachha, Mirzapur, **Uttar Pradesh** to study the changes in soil physicochemical properties due to land-use transformation from natural forest to other type of land-use. Four land use systems were selected for the study viz. degraded forest, natural forest, bio-energy and agro-ecosystem. The results revealed the SOC varied from 0.16%-0.85%. There was a decrease in soil organic carbon stock with soil depths. This happened due to increased root activity and the production of a bed of leaf litter and other parts of plant at the upper soil horizon.

Sahoo et al. (2019) undertook a study at **Mizoram** to determine different soil organic carbon contents (very liable, less liable, liable and non-liable) and their relative ratios in total organic carbon in diverse land use patterns. Seven land use patterns were selected for the study viz. agroforestry, plantation, forest, wet rice cultivation, jhum fallow, current jhum and grassland. Soils samples were taken from the depth of 0-15, 15-30 and 30-45 cm. The results revealed that the total organic carbon was recorded maximum (2.75%) in natural forest and minimum (1.31%) in grassland. The study also reported that amount and quality of litter in various LUSs regulate the quality of organic carbon produced which in turn determines the physico-chemical properties of soil.

Sharma et al. (2019) carried out a study at Pushkar valley of **Rajasthan** to determine the influence of various land use changes on soil carbon stock. Soil organic carbon stock was recorded at the depth of 30 cm. The results showed that dry deciduous forest recorded the highest and agricultural land recorded the lowest soil organic carbon stock. The reason for more SOC stock in the forest soil was mainly

due to the litter deposition and less disturbance in forest soil. Whereas, wheat based agriculture LUS observed less SOC stock due to intensive farming practices which results in soil disturbance at large extent.

Mandal *et al.* (2018) directed an experiment in the south-western plains of **Punjab** to investigate the effect of three agricultural land uses (horticultural land, cropland and uncultivated land) on status of soil fertility. The results revealed that the horticulture land use system had the maximum soil organic carbon storage both in subsurface (5.15 g/kg soil) and surface (8.91 g/kg soil).

Das *et al.* (2017) at Indian Council of Agriculture and Research (ICAR) complex for Eastern region, Ranchi, **Jharkhand** performed an experiment to assess the productivity, behaviour of various crops, soil fertility status and carbon sequestration of 20 agri-horticultural systems. The results revealed that the growth of mango and filler plants with paddy as intercrop was improved. The highest organic carbon content was observed in mango + gamhar + french bean soil due to more litter fall in the intercropping method used in the mango orchard.

Singh *et al.* (2017) carried out an investigation at **Himachal Pradesh** to study the effect of various land use systems on soil physico-chemical properties in sub-montane and low hill sub-tropical zone. Eight land use systems were selected viz. horticulture (T₂), forest (T₇), agri-horti-silviculture (T₆), agri-horticulture (T₅), silvo-pastoral (T₄), grassland (T₈), agriculture (T₁) and agri-silviculture (T₃). The results revealed that the highest soil organic carbon was recorded in forest land use system and the lowest was recorded in agriculture land use system. Soil organic carbon of remaining land use systems followed the trend: T₄ > T₂ > T₅ > T₃ > T₆ > T₈. The soil organic carbon values ranged from 0.34-0.73%.

2.3 Effect of different land-use system on Biomass estimation

2.3.1 Aboveground biomass accumulation

2.3.1.1 In Abroad

Pietrzykowski *et al.* (2021) carried out an experiment in **Southern Poland** to estimate the carbon sequestration potential and allocation in below and above ground

biomass of willow coppice (12-yr-old). The calculations revealed that the AGB of willow coppice was found to be 69.0 Mg/ha and the annual rate was 23.0 Mg/ha/a.

Hammad *et al.* (2020) conducted a study in the arid zone of **Pakistan** to compare the carbon sequestration potential of different land use systems encompassing agroforests, orchard, forest lands, and croplands. Soils were taken from 0-20, 20-40, 40-60, and 60-80 cm depths. The calculations revealed that at the soil depth of 0-20 cm, the belowground biomass (BGB) was reported maximum in forest land (14.09 Mg/ha). However, belowground biomass was reported ranged between 10.92-14.09 Mg/ha.

2.3.1.2 In India

Das *et al.* (2021) carried out an experiment at **Arunachal Pradesh** to estimate the carbon pool, above ground biomass and sequestration potential of different LUSs. The results showed the following trend of above ground biomass in various LUSs: Dense Forest (332.28 t/ha) > Moderately Dense Forest (246.63 t/ha) > Plantations (179.31 t/ha) > Jhum more than 5 years (149.63 t/ha) > Open Forest (145.36 t/ha) > Jhum less than 5 years (55.40 t/ha) > Current Jhum (16.84 t/ha). Maximum above ground biomass noted in dense forests.

Das *et al.* (2021) conducted a study in district Karimganj, **Assam** within the foothills of Himalayas and Barkak river basin for evaluating the carbon storage and biomass storage in areca palm plantations and developing biomass assessment modals in *Areca catechu*. The results revealed that the aboveground biomass of individual plants varied between 4-56 Kg/plant and model three i.e. $\ln(Y) = \ln(\alpha) + \beta \ln(D^2H)$ was more appropriate in the calculation of biomass stock which considered the usage of both height and diameter in this model.

Chisanga *et al.* (2018) conducted an experiment at Kinnur, **Himachal Pradesh** to estimate the difference in carbon stocks and biomass in various land use systems and recommended the appropriate eco-friendly land use for the region. The total biomass production in various land use systems showed the following trend: silviculture > agri-horti-silviculture > agro + horticulture > horticulture > agriculture > barren land. The highest mean aboveground biomass (84.65 t/ha), belowground

biomass (84.65 t/ha) and total biomass (104.10 t/ha) were recorded in silviculture land use system.

Singh and Sahoo (2018) performed an experiment at **Mizoram** to compare the CO₂ potential of two major LUSs viz. home gardens and shifting agriculture. The results revealed that the biomass in home gardens was recorded between 116.8 and 278.5 Mg/ha and between 60.0 and 95.2 Mg/ha in alternating fallow crops. In contrast, biomass carbon in shifting agriculture and home gardens varied from 31.6 to 49.1 Mg C/ha and 59.0 to 140.0 Mg C/ha, respectively.

Rahangdale et al. (2016) carried out a study in the agricultural field of Muskura village, Jabalpur, **Madhya Pradesh** under the project of Department of Forestry, JNKVV, Jabalpur on nine LUSs viz., mustard-soybean conventional cropping, Eucalyptus + wheat-paddy agri-silviculture system, mustard-soybean conventional cropping, wheat-mungbean conventional cropping, sole Eucalyptus cropping, pigeon pea cropping, Eucalyptus + wheat-mungbean agri-silviculture, Eucalyptus + mustard-soybean agri-silviculture and pigeon pea + Eucalyptus agri-silviculture in Randomised Block Design (RBD) design with four replications. The results revealed that the AGB was ranged from 8.54-17.37 (t/ha/yr) and annual BGB was ranged from 0.85-3.89 (t/ha/yr). Maximum AGB and BGB were found in pigeon pea + Eucalyptus agri-silviculture system.

Salunkhe et al. (2016) carried out an experiment in seven districts of **Madhya Pradesh** to estimate the biomass of tree by using non-destructive method in tropical mixed deciduous forest (MDF) and tropical dry deciduous forest (DDF). The results revealed that the average value of aboveground biomass of both tropical mixed deciduous forest (MDF) and tropical dry deciduous forest (DDF) was recorded 20.7 t/ha and 31.8 t/ha, respectively. Moreover, the total biomass of MDF and DDF was observed 44.5 t/ha and 54.9 t/ha, respectively.

Mishra et al. (2013) carried out a research at Mirzapur, **Uttar Pradesh** to calculate the C sequestration of various tree species in natural ecosystem without any management practices of tree to improve the carbon neutral and good environment to support better life in Rajiv Gandhi South Campus, Banaras Hindu University,

Barakachha. The results showed that the AGB ranged from 0.08 to 49.5 tons. The maximum AGB was found in *Madhuca longifolia* (49.57 tons). The BGB ranged from 0.01 to 7.44 tons. The minimum BGB was found in *Acacia catechu* (0.01 tons).

2.3.2 Belowground biomass accumulation

2.3.2.1 In Abroad

Bilgili et al. (2021) carried out an experiment at Erzurum province of **Eastern Turkey** to evaluate the relationship between root biomass and root nutrients on land managed under various management practices (rangeland, forest and plantation). The results reported that the total root biomass was 8.02 Mg/ha in the rangelands, 6.94 Mg/ha in the plantation areas and 5.95 Mg/ha in the forest areas.

2.3.2.2 In India

Chavan et al. (2022) carried out a study at Jhansi, **Uttar Pradesh** to estimate the biomass and carbon sequestration potential of eight years old poplar based agroforestry systems. The results concluded that the aboveground biomass and belowground biomass of poplar varied from 69.90-207.98 t/ha and 13.46-36.69 t/ha, respectively.

Harishma et al. (2020) conducted a study in the mangroves of **Kerala** to estimate the ecosystem carbon stock and its dimensional or geographical variations. They reported that the value of AGB found under mangrove vegetation was 80.22 ± 0.80 t/ha where as the value of BGB was 36.89 ± 0.23 t/ha.

Pragasan and Karthick (2013) at Bharathiar University, Coimbatore, **Tamil Nadu** carried out an experiment to determine the carbon sequestration potential (CSP) of different plantation types i.e., mixed and eucalyptus plantation. The results revealed that eucalyptus plantation recorded the highest 34.47 t/ha whereas mixed plantation recorded the lowest 5.17 t/ha belowground biomass.

2.3.3 Total and rate of biomass accumulation

Roy et al. (2022) conducted an experiment at Rajiv Gandhi South Campus (BHU), Mirzapur, **Uttar Pradesh** to estimate the carbon stock, nutrient status of soil,

carbon credit and sequestration potential of different LUSs in Vindhyan region. Six treatments were taken in the study viz. guava (*Psidium guajava*) + linseed (*Linum usitatissimum*) based LUS (GLBLUS), bael (*Aegle marmelos*) + mustard (*Brassica juncea*) based LUS (BMBLUS), custard apple (*Annona reticulata*) + barley (*Hordeum vulgare*) based LUS (CABBLUS), legumes cereal wheat (*Triticum aestivum*) based LUS (LCBLUS), vegetable - cabbage (*Brassica oleracea*) based LUS (VBLUS) and teak (*Tectona grandis*) based forest LUS (TBFLUS). The results revealed that TBFLUS recorded maximum 60.18, 15.65, 75.82 t/ha, and 0.76 t/ha/yr and LBCLUS recorded minimum 7.45, 1.94, 9.39 and 0.78 t/ha/yr aboveground, belowground, total, and rate of biomass accumulation, respectively. The total biomass accumulation ranged from 9.39–75.82 t/ha.

Dabi et al. (2021) emphasized the CO₂ potential and biomass of different plantations in the East Siang division of **Arunachal Pradesh**. The study was conducted in three plantations (*Citrus sinensis* plantation, *Areca catechu* plantation, and *Hevea brasiliensis* plantations). The results revealed that the highest total biomass (AGB = 60.74 t/ha) was observed in *Hevea brasiliensis* (73.26 t/ha) plantations, followed by *Areca catechu* (51.42 t/ha) and *Citrus sinensis* (18.84 t/ha) plantation.

Das et al. (2021) conducted a study at Karimganj, **Assam** within the foothills of Himalayas and Barkak river basin for evaluating the carbon storage and biomass storage in areca palm plantations and developing biomass assessment modals in *Areca catechu*. The results revealed that the total biomass ranged from 5 to 75 Kg/plant. 80%-20% of total biomass was available in aboveground and belowground biomass. The calculated total biomass stocks varied between 7.8Mg/ha in the ten years old plantation to 43.6 Mg/ha in thirty five years old plantation. Therefore, monoculture plantation (*Areca* plantation) contributes less to the biomass carbon storage and played a less role in climate change and sustainable land use system.

Raj et al. (2021) conducted a study at **Chhattisgarh** to evaluate vegetational statistics accompanying carbon storage, flux and budget in tropical deciduous forests of Sal. The experiment was conducted in four different location qualities of soil or site

qualities (SQ). The results showed that the total biomass ranged from 182.27 to 375.84 t/ha in different site qualities.

Sahoo *et al.* (2021) carried out an experiment in north eastern parts of **India** to investigate the carbon storage potential and total biomass of various land use systems using a model for biomass estimation evolved for this region. The results revealed that the values of biomass differ remarkably between various land use systems and values were ranged from 2.53 ± 0.51 Mg/ha (grassland) to 259.77 ± 15.43 Mg/ha (temperate forest) and showed the following trend: agriculture < bamboo forest < agroforestry < fallows of older shifting cultivation (5-10 and 11-20 years) < plantations < natural forests. The biomass values of tropical, subtropical and bamboo forests were 224.11 ± 8.26 , 225.55 ± 24.66 and 46.77 ± 2.35 Mg/ha, respectively. Biomass of tropical, subtropical and temperate plantations were 198.58 ± 16.55 , 245.64 ± 45.10 and 106.60 ± 14.29 Mg/ha, respectively. Biomass of agroforestry systems, agriculture and grassland were 92.58 ± 28.73 , 6.48 ± 1.26 and 2.53 ± 0.81 Mg/ha, respectively.

Harishma *et al.* (2020) conducted a study in the mangroves of **Kerala** to estimate the ecosystem carbon stock and its dimensional or geographical variations. They reported that mean biomass estimated in the mangroves of Kerala was 117.11 ± 1.02 t/ha. The highest biomass was reported in *Avicennia marina* (162.18 t/ha) and lowest was found in *Sonneratia alba* (0.61 t/ha).

Rajput *et al.* (2017) carried out an experiment at Kullu, **Himachal Pradesh** to determine the affects of five different altitudes and agro-ecosystems on carbon sequestration and biomass accumulation. The investigated area had five land use systems viz. horticulture, agri-horticulture, agriculture, forest and silvi-pasture. The results revealed that maximum total biomass was recorded in forest land use, followed by silvi-pasture, agri-horticulture, horticulture and minimum was found in agriculture land use. The tropical dry deciduous forest (T₁) LUS observed higher biomass accumulation due to more tree age, high tree density (190-650 trees/ha), low biotic interference, more tree height, more diameter at breast height and better soil quality in comparison to other land use systems.

Rahangdale et al (2016) reported that the total biomass accumulation (21.26 t/ha/yr) was recorded maximum in pigeon pea + Eucalyptus agri-silviculture system.

Mishra et al. (2013) carried out a research at Rajiv Gandhi South Campus (Banaras Hindu University) Barakachha, Mirzapur, **Uttar Pradesh** showed that the total biomass ranged from 0.09-57.01 t/ha. The maximum total biomass accumulation was recorded in *Madhuca longifolia*.

2.4 Biomass carbon stock estimation of different land use system

2.4.1 Above and below ground biomass carbon stock

2.4.1.1 In Abroad

Karuru et al. (2021) had carried out a study in **Indonesia** to calculate the various LUSs. The four LUSs were secondary forest, oil palm plantation, agroforestry and rice fields. The results revealed that the highest carbon stock was estimated in the secondary forest (265.86 t/ha), followed by agroforestry (131.31 t/ha), followed by oil palm plantation (100.89 t/ha) and the lowest was recorded in paddy fields (70.50 t/ha).

Menzes et al. (2021) in **North East Brazil** investigated the effects of various LUSs and cover changes on total carbon stocks of ecosystem. This study aimed to estimate the values of carbon losses after the transformation of native forest, which is known as Caatinga. Four LUSs used were Open Caatinga, Dense Caatinga, Pasture and crop fields. On an average, areas under Dense Caatinga stored the maximum carbon, nearly 125 M g/ha. This carbon was stored on the soil organic matter (72.1%), followed by AGB (15.9%), BGB (7.3%), deadwood (2.9%), litter (1.3%) and the lowest in herbaceous biomass (0.5%). The results revealed that the Dense Caatinga forest store more carbon and by its transformation to crop fields and plant pastures causes losses of carbon stocks (>50%) that reached almost 65 Mg/ha of carbon.

Hammad et al. (2020) conducted a study in the arid zone of **Pakistan** to compare the carbon sequestration potential of different land use systems encompassing agroforests, orchards, forest lands, and croplands. The results revealed that the total carbon content of the systems was arranged in the following trend: Forest land > Mango orchards > Agroforests > Citrus orchards > Croplands. The

maximum total carbon content was estimated in forestland (6.84 Mg/ha). Without reference to soil depth, total carbon and ground biomass followed the trend : Forestland > Mango orchards > Citrus orchard > Agroforests > Croplands.

2.4.1.2 In India

Dabi et al. (2021) emphasized the CO₂ potential and biomass of different plantations in the East Siang division of **Arunachal Pradesh**. The study was conducted in three plantations (*Citrus sinensis* plantation, *Areca catechu* plantation and *Hevea brasiliensis* plantation). The results revealed that the total biomass carbon stock was ranged from 0.07-35.58 t/ha. The highest total biomass carbon stock was noted in *Hevea brasiliensis* (43.10 t/ha) plantation. Whereas the highest total carbon was stored by *Areca catechu* (67.82 t/ha) plantation.

Raj et al. (2021) carried out a study at **Chhattisgarh** to evaluate vegetational statistics accompanying carbon storage, flux and budget in tropical deciduous forests of Sal. The results showed that the above ground carbon quantity varied from 72.32-143.36 t/ha and below ground carbon quantity varied from 7.54-20.27 t/ha.

Sahoo et al. (2021) reported that the maximum mean of aboveground biomass carbon (AGBC) stock was observed in temperate forest (100.51 ± 11.33 Mg C/ha) and minimum in grassland (0.96 ± 0.31 Mg C/ha). The average vegetation carbon stock (AGB + BGB) was maximum in temperate forest (122.09 ± 13.59 Mg C/ha), after that subtropical (106.01 ± 11.59 Mg C/ha) and tropical forests (105.33 ± 3.88 Mg C/ha). The total biomass carbon and aboveground biomass carbon in bamboo forests were recorded 21.98 ± 1.80 Mg C/ha and 17.79 ± 1.46 Mg C/ha, respectively. The biomass carbon stock in plantations was higher in subtropical (115.45 ± 21.20 Mg C/ha, range 57.15 ± 266.5 Mg C/ha) in comparison to tropical (93.00 ± 7.80 Mg C/ha, range $7.23-341.92$ Mg C/ha) and temperate (50.10 ± 6.72 Mg C/ha, range $18.75-75.05$ Mg C/ha) zones. The mean biomass carbon stock of agricultural land was 2.71 ± 0.36 Mg C/ha.

Thakur et al. (2021) carried out an experiment at Achanakmaar Amarkantak Biosphere Reserve at **Chhattisgarh** to study the biomass, plant diversity, carbon

sequestration potential and net productivity of four types of vegetation viz., Open mixed forest (OMF), Teak plantation (TP), Dense mixed forest (DMF) and Sal mixed forest (SMF). The results revealed that the total standing biomass ranged between 83.77-111.21 t/ha. DMF recorded the highest biomass followed by TP, SMF and lowest was found in OMF. Rate of biomass production varied from 7.61-9.94 t/ha/yr.

Gandhi and Sundarapandian (2017) directed a study at Sathanur reserve forest of Eastern Ghats, **Tamil Nadu** to estimate the carbon stock in woody vegetation on a wide scale in the tropical dry deciduous forests of the area. The results revealed that total biomass carbon stock ranged from 37.86 to 322.16 t/ha.

Mishra *et al.* (2012) recorded that the above ground carbon ranged between 0.04-22.31 t/tree. Maximum AGB was observed in *Madhuca longifolia* (22.31 t/tree). However, below ground carbon was ranged between 0.01-3.34 t/tree.

Yadava (2011) in **Tarai region of Central Himalayas** estimated the carbon sequestration potential of different agroforestry systems for climate change mitigation. The results concluded that the carbon sequestration of different agroforestry systems was assessed by multiplying the factor of 3.66 with carbon stock values.

Pande (2005) at Satpura plateau, **Madhya Pradesh** conducted an experiment to estimate the biomass and productivity of some tropical dry deciduous teak forest in three different sites. The study reported that the biomass of tropical dry deciduous teak forest ranged from 28.1-85.3 t/ha.

2.4.2 Crop carbon stock

2.4.2.1 In Abroad

Sonto-Pinto *et al.* (2010) carried out a study at **Chiapas, Mexico** to evaluate the content of carbon in biomass of vegetation, soil at the depth of 0-10, 10-20, 20-30 cm, non-living organic matter between the agroforestry and non-agroforestry prototypes. The results revealed that the baseline (AG carbon in pastures with no presence of trees) in the agroclimatic zone was 3.36 Mg C/ha, while the baseline (AG

carbon in classic maize) in the above and middle tropical agroclimatic zones was 11.1 Mg C/ha.

2.4.2.2 In India

Kajal *et al.* (2021) conducted a study at the experimental area of Chaudhary Charan Singh Agricultural University, **Haryana**, Regional Research Station, Bawal to investigate the C sequestration and biomass under various plant configurations, that is, 10×5 , 10×20 , 10×6.5 and 10×10 m² of agro-forestry system of Mahaneem and sole cropping. The results revealed that the highest C sequestration (16.5 t/ha/yr) was observed in Mahaneem + wheat agroforestry system under 10×5 m² plant configuration. The biomass carbon under various configurations in Mahaneem under agroforestry i.e. with crops was ranged between 3.66-14.31 t/ha and in sole plantation i.e. without crops was 3.64-13.91 t/ha.

Mandal *et al.* (2006) carried out an experiment at Gayeshpur and Barrackpur in **West Bengal**, Cuttack in **Orissa** and Mohanpur in **Uttar Pradesh** to study the effects of various cropping systems on soil organic carbon and soil carbon sequestration. The results revealed that the higher C sequestration rate was recorded in rice-mustard-seasame (1.91 Mg C/ha/yr) accompanied by rice-wheat-fallow (0.27 Mg C/ha/yr) and rice-fallow-rice (0.28 Mg C/ha/yr).

2.4.3 Total and rate of biomass carbon stock

2.4.3.1 In Abroad

Zhuang *et al.* (2015) in the northern part of **Fujian, China** analyzed stands of Moso bamboo in the forests of Jian-ou city and evaluated that the total carbon biomass was 14 Kg/culm. Total carbon storage in biomass was estimated to be 54.6 Mg/ha on average, with soil carbon storage of 90.6 Mg/ha down to the soil depth of 60 cm. The estimated total carbon storage was 145.3 Mg C/ha. The withdrawal of the annual yield by harvesting was estimated at around 3.97 Mg/ha, that is 7.3% of the total carbon of the bamboo biomass, measured.

Navar *et al.* (2011) carried out a study in tropical forests of **Mexico** to determine and contrast aboveground biomass carbon stock of tropical forests by using

three methods of biomass estimation. The results revealed that the aboveground biomass carbon stock of tropical dry deciduous forests of the world ranged from 14-123 t/ha.

2.4.3.2 In India

Uthappa and Devakumar (2021) carried out an investigation at University of Agricultural Sciences, GKVK, Bengalore, **Karnataka** to estimate the carbon sequestration potential of different land use systems. The research found that the highest biomass carbon stock was recorded in *Artocarpus hirsutus* (868.70 Mg/ha), followed by *Terminalia bellirica* (414.87 Mg/ha), *Swietenia macrophylla* (323.57 Mg/ha) and *Tectona grandis* (213.43 Mg/ha) plantations. The natural forest had recorded 81.43 Mg/ha total biomass carbon stock. The lowest biomass carbon stock was observed in the horticulture system (34.85 Mg/ha) followed by agroforestry (53.64 Mg/ha).

Gogoi et al. (2020) conducted an experiment at Jorhat, **Assam** to evaluate carbon storage and biomass stock of planted forest in comparison to natural forest. The results revealed that natural forest recorded the highest (358.30 t/ha) and planted forest recorded the lowest (299.86 t/ha) total biomass stock.

Harishma et al. (2020) reported that the mean carbon stock in mangroves of **Kerala** was recorded 139.82 t/ha which is the highest of all LUSs. The aboveground carbon stock and belowground carbon stock stored in the ecosystem was 58.56 t C/ha and 81.26 t C/ha, respectively.

Thong et al. (2020) attempted an experiment at **Manipur** to determine the various patterns of forest recovery after shifting cultivation by assessing diversity, tree species composition and abundance in relation to various topographical factors. The results showed that biodiversity and land area recovered relatively over time and north facing fallow land at lower elevations showed higher biodiversity and trunk density than those at higher elevations. The total carbon storage of living woody biomass ranged from 0.98 Mg/ha in five years fallow to 142.58 Mg/ha in twenty years fallow.

Joshi and Dhyani (2018) conducted a study in the tropical dry deciduous forests of district Singrauli, **Madhya Pradesh**. The objective of study was to determine the relationship between basal area, carbon stocks, density and diversity of trees in tropical dry deciduous forests. The results showed that total biomass carbon (aboveground + belowground) was ranged from 48.97-214.98 Mg C/ha.

Subba et al. (2018) conducted a study in northern parts of **West Bengal** to investigate the variability of carbon stock in the home gardens spreading to Jalpaiguri districts, part of Siliguri and Cooch Behar division of Darjeeling. The results revealed that the small sized gardens recorded highest SOC 47.85 Mg/ha, while the extensive gardens recorded highest plant biomass C 60.38 Mg/ha.

2.5 Biomass Carbon sequestration potential of different land use system

2.5.1 In Abroad

Hammad et al. (2020) in the arid zone of **Pakistan** revealed that the maximum carbon sequestration potential (64.54 Mg/ha) was recorded in the above ground biomass (AGB) of the forests whereas minimum (33.50 Mg/ha) was recorded in cropland. The forests sequestered more carbon in comparison to other LUSs because of more tree density, better soil quality, higher tree biomass, better microclimatic conditions and less anthropogenic activities.

Pietrzykowski et al. (2020) in **Southern Poland** reported that the carbon accumulation rate was 32.3 Mg/ha in the above ground biomass and in the below ground in two forms i.e. fine roots (1.2 Mg/ha) and coarse roots (18.3 Mg/ha). The total annual sequestration of carbon was found at 13.5 Mg/ha/a for above ground and belowground biomass.

2.5.2 In India

Meena et al. (2022) carried out a study at Rajiv Gandhi South Campus (Banaras Hindu University), Mirzapur, **Uttar Pradesh** to estimate physico-chemical properties of soil and carbon sequestration potential of different agro-ecosystems. Seven land use systems were preferred for the study viz. Karonda (*Carissa carandas*) cultivation land (KCL), mono-cropping wheat (*Triticum aestivum*) cultivated land

(MCWCL), manual forest land (FL), guava (*Psidium guajava*) + green gram (*Vigna radiata*) cultivation land (GGCL), pasture land (PL), seasonal pond area (SPA) and mono-cropping rice (*Oryza sativa*) cultivation land (MCRCL). The results revealed that the forest land (FL) recorded maximum carbon sequestration (115.06 t/ha) whereas minimum was recorded in SPA (0.87 t/ha). The remaining LUSs followed the trend: KCL (41.11 t/ha) > GGCL (38.93 t/ha) > MCWCL (22.1 t/ha) > MCRCL (17.65 t/ha). Tropical dry deciduous forest (T₁) have the greatest potential for carbon sequestration because of their dense trees, old age, higher biomass accumulation, higher carbon stock in comparison to other LUSs.

Das et al. (2021) at district Karimganj, **Assam** conducted a study within the foothills of Himalayas and Barkak river basin for evaluating the carbon storage and biomass storage in areca palm plantations and developing biomass assessment modals in *Areca catechu*. The results showed that the carbon accumulation rate was recorded maximum in 15 years old plantation (1.22 Mg/ha/yr) and minimum in 35 years old plantation (0.59 Mg/ha/yr). Therefore, monoculture plantation (Areca plantation) contributes less to the biomass carbon storage and played a less role in climate change and sustainable land use system.

Kumar et al. (2021) at Haridwar (Dhanauri range), **Uttarakhand** conducted an experiment to study the carbon sequestration and biomass accumulation in various agroforestry systems. The results revealed that the highest (81.01%) carbon storage was found in the stem of *Toona ciliate*, root of *Anthocephalus cadamba* (16.83%), leaves of *Eucalyptus tereticornis* (2.93%), and branch of *Populus deltoids* (5.73%). The maximum carbon sequestration (45.33 ± 0.60 Mg/ha) and CO₂ mitigation (160.5 ± 2.55 Mg CO₂/ha) were estimated in *Eucalyptus tereticornis*.

Raj et al. (2021) at **Chhattisgarh** reported that the total aboveground carbon sequestration values of tree varied from 5.12-11.68 t C/ha/yr on various site qualities.

Sahoo et al. (2021) in north eastern parts of **India** recorded that the maximum CO₂ sequestration rate was found in forests (2.81-5.51 Mg C/ha/yr), followed by plantations (1.80-5.08 Mg C/ha/yr) and secondary forests (1.35-2.84 Mg C/ha/yr).

Uthappa and Devakumar (2021) at University of Agricultural Sciences, GKVK, Bengalore, **Karnataka** reported that tree spacing was one of the factor due to which there is significant variation in the CO₂ sequestration in different land use systems and highest was found under *Artocarpus hirsutus* (3182.03 Mg/ha), followed by *Terminalia bellirica* (1519.66 Mg/ha), *Swietenia macrophylla* (1185.24 Mg/ha), *Tectona grandis* (781.80) and natural forest (298.26 Mg/ha). The minimum CO₂ sequestration was found under horticulture system (127.65 Mg/ha) followed by agroforestry (196.47 Mg/ha).

Dhyani et al. (2016) at ICAR-CAFRI, Jhansi, **Uttar Pradesh** presented an overview of literature that related to the potential of agroforestry systems in CO₂ sequestration in India. The results revealed that in India, CO₂ potential was varied between 0.25-19.14 Mg C/ha/yr of tree component and 0.01 to 0.60 Mg C/ha/yr of crop component. CO₂ potential of soils in agroforestry systems was estimated between 0.003 to 3.98 Mg C/ha/yr. The review indicated that agroforestry systems with reference to accumulation and sequestration of carbon provided a best possibility to raise the tree cover to an extent of 33% of the total geographical area of the country as required by the NFP (National Forest Policy).

Mishra et al. (2013) at Mirzapur, **Uttar Pradesh** reported that CO₂ sequestration ranged from 0.16-94.13 t/tree. Maximum CO₂ sequestration was found in *Madhuca longifolia* (94.13 t C/yr).

2.6 Leaf litter and leaf litter carbon accumulation in different land use system

Uthappa and Devakumar (2021) at University of Agricultural Sciences, GKVK, Bengalore, **Karnataka** revealed that the leaf litter carbon (Mg/ha/yr) showed the following trend: *Artocarpus hirsutus* (3.87 Mg/ha/yr) > *Swietenia macrophylla* (2.98 Mg/ha/yr) > *Terminalia bellirica* (2.38 Mg/ha/yr) > Natural forest (2.28 Mg/ha/yr) > *Tectona grandis* (1.16 Mg/ha/yr).

Rao and Rao (2015) conducted an experiment at **Andhra Pradesh** to access the biomass and carbon sequestration of tropical deciduous forests of Nallamalais. The results showed that the carbon stock and biomass of investigated area were

estimated at 26.34 Mt and 56.047 Mt, respectively. Litter biomass density was ranged from 0.02-1.34 t/ha.

2.7 Total carbon stock estimation

2.7.1 In Abroad

Montagnini and Nair (2004) at **Costa Rica** carried out a study to find out the role of agroforestry in carbon sequestration. The study concluded that the mean storage or total carbon stock by different agroforestry practices in semiarid, subhumid, humid and temperate regions had been approximated as 9, 12, 50 and 63 Mg C/ha, respectively.

2.7.2 In India

Nasam et al. (2022) carried out an investigation in the **Central Telangana** of the Deccan plateau to estimate the soil organic carbon and carbon stocks of primary and secondary forests in the Medak forests. The results revealed that total carbon stock in primary forests and secondary forests was ranged from 18.1-22.5 t/ha and 9.4-19.1 t/ha, respectively.

Dabi et al. (2021) at **Arunachal Pradesh** reported that the total carbon stock was ranged from 28.50- 67.82 t/ha. Maximum total carbon stock was recorded in *Areca catechu* plantation (67.82 t/ha) and minimum was observed in *Citrus sinensis* plantation (28.50 t/ha).

Raj et al. (2021) at **Chhattisgarh** showed that the total carbon stock ranged between 79.86 to 163.63 t/ha in tropical deciduous forests.

Uthappa and Devakumar (2021) reported that the highest total carbon stock was found in *Artocarpus hirsutus* plantation, followed by *Terminalia bellirica* plantation, *Swietenia macrophylla* plantation, *Tectona grandis* plantation, natural forest, agroforestry system however lowest was recorded in horticulture land use system.

2.8 Total carbon sequestration estimation

Sahoo *et al.* (2021) in **Northeast India** showed that the average carbon sequestration varied between 1.80 t/ha (tropical plantations) and 5.51 t/ha (temperate forests). The carbon sequestration rate was found highest in forests and lowest in agriculture LUS.

Uthappa and Devakumar (2021) at University of Agricultural Sciences, GKVK, Bangalore, **Karnataka** reported that tree spacing is one of the factor due to which there is significant variation in the CO₂ sequestration in different land use systems and highest was found under *Artocarpus hirsutus* (3321.46 t/ha), followed by *Terminalia bellirica* (1680.80 t/ha), *Swietenia macrophylla* (1387.84 t/ha), *Tectona grandis* (955.80 t/ha) and natural forest (587.26 t/ha). The minimum CO₂ sequestration was found under horticulture system (244.03 t/ha) followed by agroforestry (367.58 t/ha).

Rajput *et al.* (2017) at Kullu, Himachal Pradesh, **India** reported that the carbon density ranged between (10.01-202.2 Mg C/ha/yr). The maximum mean carbon density of both soil and plant was recorded in forest based land use system. Carbon density of remaining LUSs followed the trend: Silviculture > Agro-horticulture > Horticulture > Agriculture. The maximum carbon sequestration potential or rate of carbon sequestration was found in agri-horticulture system (2.08 Mg C/ha/yr). It ranged between (0.50-2.08 Mg C/ha/yr).

Reddy *et al.* (2014) at **Karnataka** conducted a study to evaluate carbon sequestration of teak in three agro-climatic zones (northern dry zone, northern transition zone and hilly zone) and three age gradations (10, 15 and 20 years). The results revealed that the 20-year teak plantations observed the higher (247.47 t/ha) total carbon sequestration in comparison to 15-year (157.60 t/ha) and 10-year (70.27 t/ha) teak plantations.

Saha and Jha (2012) in the **North-Eastern Hill Regions of India** reported that the carbon sequestration potential was estimated to be within the range of 12-228 Mg/ha with a median value of 95 Mg/ha.

2.9 Carbon credit

2.9.1 In Abroad

Walden *et al.* (2020) at **Ethiopia** evaluated the financial impact of carbon income on the economics of multistrata smallholder agroforestry systems (AFSs), as well as its influence in comparison to Ethiopia's dominating monocultures. By closely resembling monitored examples in Ethiopia's Central Rift Valley in Sire, 8 stylised AFSs were constructed using the average values of the collected empirical data if available. Research was based on an economic model that included soil C calculations from AFSs in the area, crop yields and prices were applied to compare AFSs profits with and without income of carbon as compared to monocultures. The results revealed that the overall revenue of the AFSs ranged from \$600 to \$1385 when the C revenue was included to the conventional agricultural income of the AFSs plots (0.2 ha). After accumulating the carbon income, the overall revenue of the AFSs plots increased by 0.5-15 percent at a \$8.40 carbon price, 1-40 percent at a \$20.30 carbon price, and 3-73 percent at a highest modelled carbon cost of \$40.20, based on the sequestration rate of 0.6/9.2/17.2 Mg C/ ha/year.

Derwisch *et al.* (2009) carried out a study at Chiriqui province, **Western Panama** to calculate the C storage potential of one, two and ten years-old teak plantations and to evaluate the cash value of aboveground carbon storage if sold as CER (certified emission reduction) carbon credits. The results showed that short-term CER carbon credits were about 460 US\$ for short-term CER and 560 US\$ for everlasting CER, which contributing to 1% of the total revenue at the plantations of teak (20 years old).

2.9.2 In India

Zagade *et al.* (2022) at Dr Balasaheb Sawant Konkan Agriculture University, Dapoli, Ratnagiri, **Maharashtra** experimented on assimilation of carbon, carbon credit and carbon stock of teak plantation during 2020-21. The results revealed that the one carbon credit, or CER (certified emission reduction), is worth around \$17.7 in U S dollars. As a result, the mean value of 57.25 carbon credits in US dollars was

around \$1,013.33 (77, 175.21 in rupees). It ranged between 126.06-2,151.74 US\$ (Rs 9600.73-1, 63, 876.52) of different girth classes of teak plantation of 6 years old.

Rahangdale *et al.* (2016) at Jabalpur, **Madhya Pradesh** reported that the highest value of carbon credit was found under Eucalyptus + pigeon pea agricultural system (Rs 27,763/ha/yr. Values ranged between (Rs 15,009-27,763/ha/yr).



MATERIAL AND METHODS

The present investigation entitled "**Assessment of Biomass Production, Soil Carbon Stock and Carbon Sequestration under Various Land Use Systems of Vindhyan Region**" was executed at Rajiv Gandhi South Campus, Banaras Hindu University, Barkachha, Mirzapur, the district of Northeastern Uttar Pradesh, India. The specifics of various materials used, techniques and methods followed during the research work had been briefly described in this section.

3.1 Geographical description of the study area

The study area lies on the Vindhyan plateau at Rajiv Gandhi South Campus, of the Banaras Hindu University, India. The campus is spreading over an area of more than 1000 ha (approximate 2763 acres) and it is established in Vindhyan region of district Mirzapur, India (25.0579°N latitude, 82.5997°E longitudes and 80 meters elevation and an average altitude of 145 m above mean sea level). The university is bordered on the north-east by Varanasi district, on the south by Sonbhadri district and on the north-west by Allahabad district. The Ganges River divides the tehsil of Chunar from the Varanasi district. The Chunar fields, considered one of India's most important fertile land tracts, are located in Gangetic flood plains of the district.

3.2 Land use

The rainfed farming system is typically carried out in this region. The topography of agricultural land is undulating where different types of crops are grown, such as field crops, horticultural, medicinal and aromatic. This region appeared under agro-climatic zone III A (semi-arid eastern plain zone) where rainfall is very less and invariably poor fertility status of the soils. Red laterite soil is found in this region. Land use and other features are depicted in table 3.1.

Table 3.1: Land use and other agricultural parameters of the investigation area – Rajiv Gandhi South Campus (2021-2022)

S. No.	Agricultural parameters	Area (ha)
1	Geographical area (GA)	2763 acre
2	Forest area	500 acre
3	Land not available for cultivation – non-agricultural Uses	1880 acre
4	a) Current fallows	900 acre
	b) Other fallows	450 acre
5	Pasture land	200 acre
6	Net cropped area (NCA)	375 acre
7	Area sown more than once	78 acre
8	Total cropped area	450 acre
9	Intensity of cropping	120%
10	Cultivable waste land	300 acre
11	Cultivated area	450 acre
12	Barren land	1888 acre
13	Land under miscellaneous tree crops and groves	515 acre
14	Net irrigated area	100 acre
15	Gross irrigated area	175 acre
16	Rainfed area	275 acre

3.3 Forest type

The forest site represented tropical dry deciduous type with minimum human disturbance. There is a wide variation in the rainfall i.e. 1200-3720 mm in July-August. Locally dominated species of the area are *Boswellia serrata*, *Butea monosperma*, *Diospyros melanoxylon*, *Acacia catechu*, *Lagerstroemia parviflora*, *Azadirachta indica*, *Acacia nilotica*, *Terminalia tomentosa*, *Madhuca latifolia*, *Abrus precatorious*, *Zizyphus glaberrima*, *Nyctanthes arbortristis*, *Sida cordifolia*, *Cassia sophera*, *Cannavis sativa* etc.

3.4 Common cultivated crops

Major cultivated crops are wheat (*Triticum durum*), rice (*Oryza sativa*) under irrigated conditions and wheat (*Triticum aestivum*), gram (*Cicer arietinum*), bagra (*Pennisetum typhoides*), arhar (*Cajanus cajan*), mustard (*Brassica juncea*), linseed (*Linum usitatissimum*), barley (*Hordeum vulgare*), rice under rainfed conditions. Horticultural crops, i.e., mango (*Mangifera indica*), guava (*Psidium guajava*), custard apple (*Annona reticulate*), bael (*Aegle marmelos*), citrus (*Citrus sp.*), custard apple (*Annona squamosa*) and vegetables include pea (*Pisum sativum*), okra (*Abelmoschus esculentus*), cabbage (*Brassica oleracea*), common bean (*Phaseolus vulgaris*), potato (*Solanum tuberosum*), black-eyed pea (*Vigna unguiculata*) cauliflower (*Brassica oleracea*) are cultivated in this region.

3.5 Different types of land use systems at Rajiv Gandhi Campus

The different types of Land use systems were found at RGSC campus to reduce the pressure on forest land and to get different and more returns from the same unit of land.

Table 3.2: Different types of land use systems at Rajiv Gandhi South Campus

S. No.	Land use systems (LUSs)
1.	Forest
2.	Agriculture (sole-cropping)
3.	Plantation
4.	Horticulture
5.	Agri-horticulture



Fig. 3.1: Location of Banaras Hindu University - South Campus, Mirzapur

3.6 Climate

The climate of Mirzapur is semi-arid, i.e., moderate humidity and low rainfall. Three seasons are mainly seen in this area -winter (November-February), summer (April-mid June) and rainy (late June to October) seasons. The summer months are hot and dry, whereas the winter months are cool. The coldest and hottest months are January and May, respectively. The temperature begins to rise from February and

reaches its maximum in May. The maximum temperature was 40.5°C seen in May, and the minimum temperature was 10.8 °C seen in January. 85% of the annual precipitation happens during the rainy season (late June to October) due to the southwest monsoon. In between December to mid-February, winter showers are often experienced.

3.7 Weather during the experiment

The meteorological data obtained from Krishi Vigyan Kendra, Banaras Hindu University-South Campus, Mirzapur are presented in table 3.2.

Table 3.3: The 13 years mean weather data of the area is presented in the table (2009-2021)

Months	Rainfall (mm)	Temperature (°C)		Relative Humidity (%)	Sunshine (Hours)	Evaporation (mm)
		Max Temp	Min Temp			
January	15.0	22.8	10.2	68	8.7	3.0
February	19.3	26.3	13.4	60	9.4	3.6
March	10.7	33.9	18.0	41	10.9	4.8
April	6.5	38.9	22.1	27	12.4	6.9
May	9.1	41.2	26.1	35	12.7	10.5
June	137.9	37.8	28.4	51	10.6	8.5
July	301.4	32.1	26.9	76	8.2	4.3
August	256.8	31.8	25.2	80	8.8	3.9
September	176.7	32.3	25.0	87	8.3	3.0
October	43.6	31.7	22.1	68	10.4	3.5
November	5.4	28.5	15.1	62	9.6	2.7
December	6.1	23.8	11.6	61	9.3	1.9

Source: Krishi Vigyan Kendra, Banaras Hindu University-South Campus, Mirzapur

3.7.1 Rainfall (mm)

The maximum rainfall of 301.4 mm was recorded in July 2021, and the minimum rainfall of 5.8 mm was recorded in December 2021.

3.7.2 Temperature

During the experiment period, the monthly mean maximum temperature ranges from 20.8 °C to 48.4 °C, and minimum temperature ranges from 7.0 °C to 26.7 °C. The maximum temperature of 43.7 °C was recorded in May, whereas the minimum temperature of 11.8 °C was observed in January.

3.7.5 Relative humidity (%)

During the period of experimentation, relative humidity ranges from 26-88 %.

3.7.4 Sunshine (Hours)

The sunshine (hours) was ranged from 8.0 to 12.2 during the period of experimentation.

3.7.5 Evaporation (mm)

The monthly mean evaporation (mm) is ranged from 1.7 to 10.6 during the period of experimentation.

3.8 Experimental Design and Details of Experiment

The experiment was conducted for the estimation of the physico-chemical properties of soil (bulk density, soil organic carbon and soil organic carbon stock), biomass accumulation (above, below, total and rate), biomass carbon stock (above, below, total and rate), leaf litter accumulation, biomass carbon sequestration, total carbon stock, total carbon sequestration and carbon credit. The experiment was conducted in a Randomized Complete Block Design (RBD) with 7 treatments and three replications. The details of treatments are as follows-

Table 3.4: Details of treatments in various land use systems

S.No.	Land Use Systems	Treatment Details	Symbol
1	Forest based land use system	Tropical dry deciduous forests	T ₁
2	Agriculture based land use system	Wheat	T ₂
3	Teak Plantations	Teak	T ₃
	Horticulture system	Karonda	T ₄
5	Agri-horticulture system	Bael + lentil (Hul-57)	T ₅
		Guava + mustard (Giriraj)	T ₆
		Custard apple + mustard (Pitambri)	T ₇

Table 3.5: Details of experimental layout plan

Experimental design	Randomized complete block design
No. of treatment	7
No. of replication	3
Soil Depth	D1 (0-20) cm D2 (20-40) cm
Total no of plots	21
Sample plot size	10 × 10 m ²
Area of agri-horticulture system	
1. Custard apple	50 × 10 m ²
2. Bael	50 × 10 m ²
3. Guava	50 × 10 m ²

Planting Distance

1. Custard apple	$5 \times 5 \text{ m}^2$
2. Bael	$7 \times 7 \text{ m}^2$
3. Guava	$5 \times 5 \text{ m}^2$
4. Karonda	$5 \times 4.5 \text{ m}^2$
5. Mustard (Pitambri)	Line sowing (row to row distance = 15 cm)
6. Lentil (Hul-57)	Spacing = $30 \times 2 \text{ cm}$
7. Mustard (Giriraj)	Line sowing (row to row distance = 20cm)
8. Tropical dry deciduous forest	Zigzag manner
9. Wheat	Line sowing (row to row distance = 15cm)
10. Teak Plantation	$3 \times 3 \text{ m}^2$

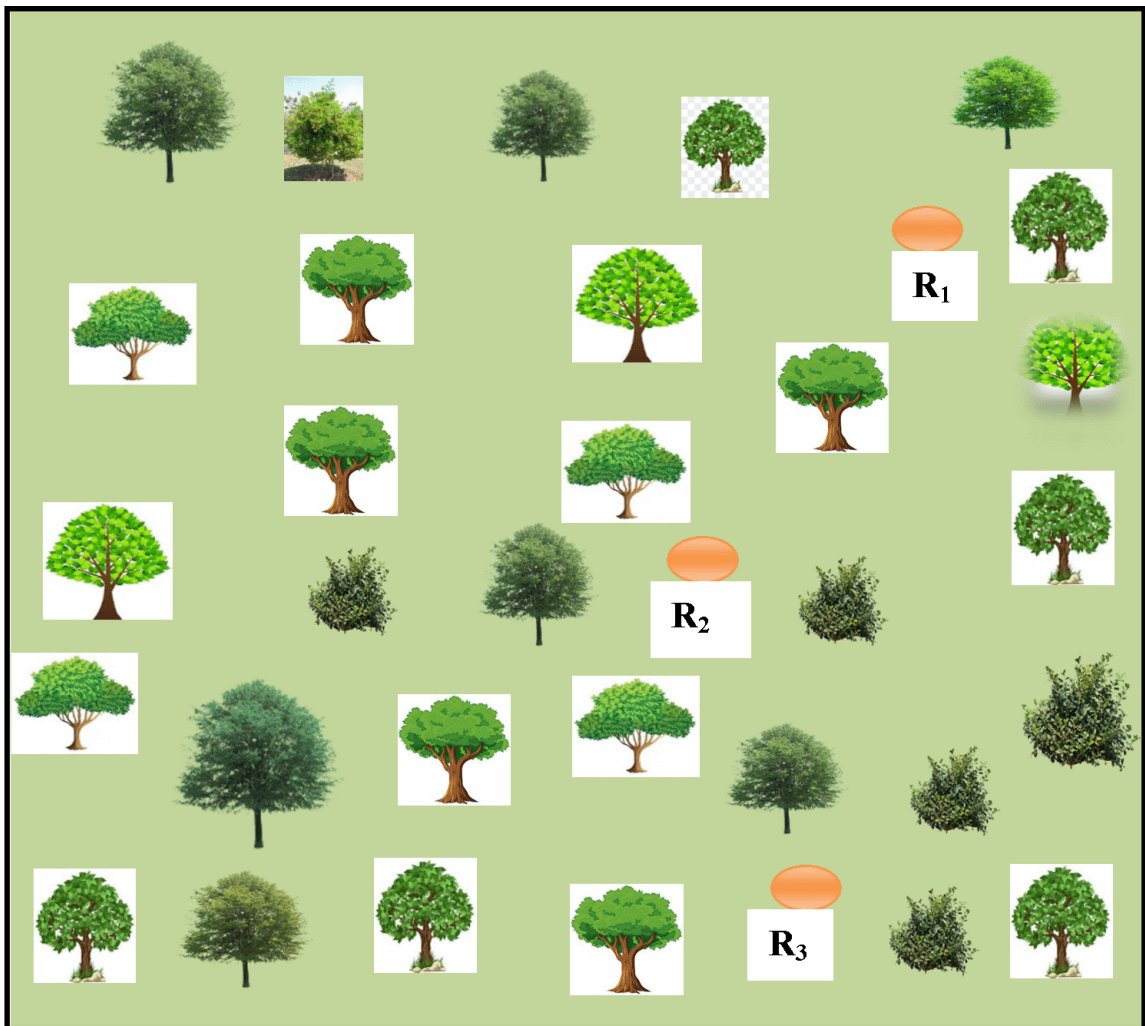


Fig. 3.2: Layout of tropical dry deciduous forests LUS



Fig. 3.3 : Picture of tropical dry deciduous forest based LUS

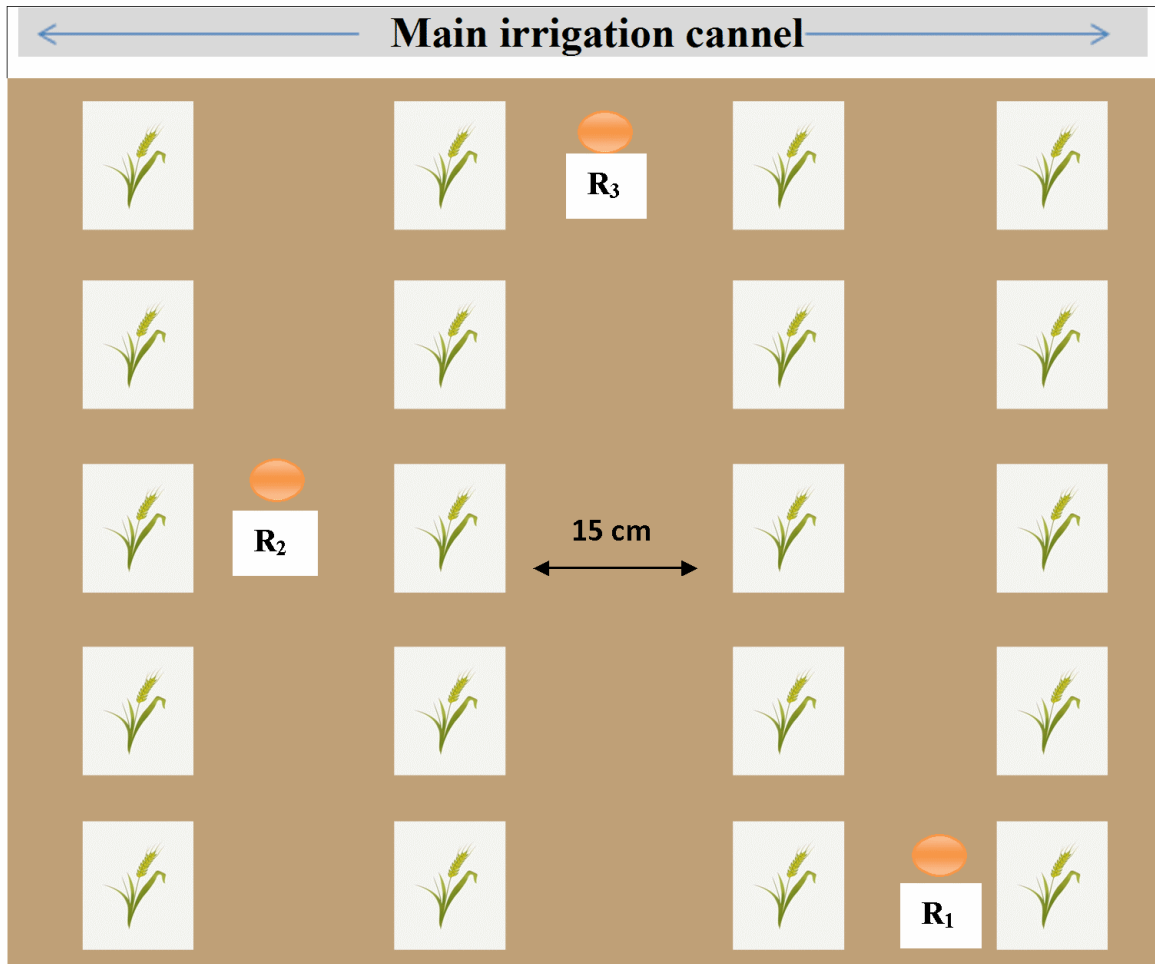


Fig. 3.4: Layout of wheat based agriculture LUS



Fig. 3.5: Picture of wheat based agriculture LUS

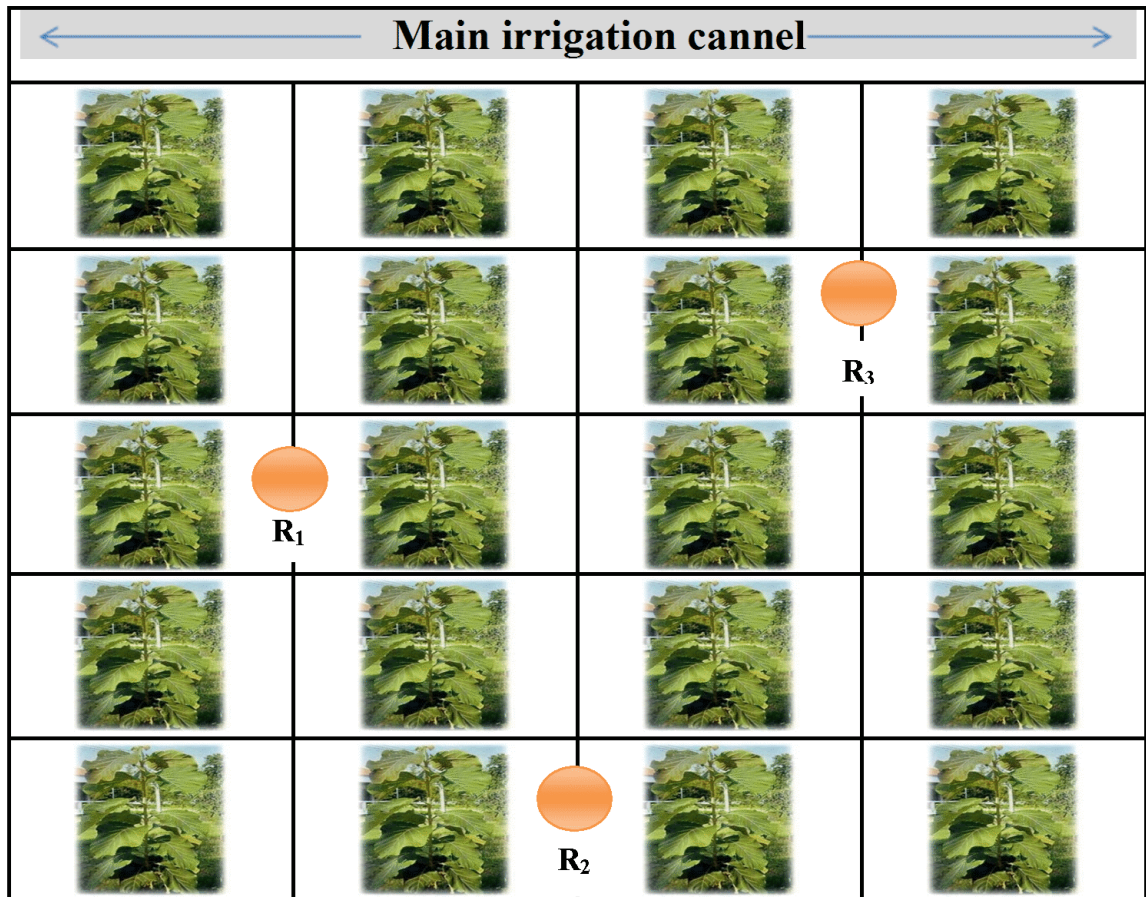


Fig. 3.6: Layout of Teak based plantation LUS



Fig. 3.7: Picture of teak based plantation LUS

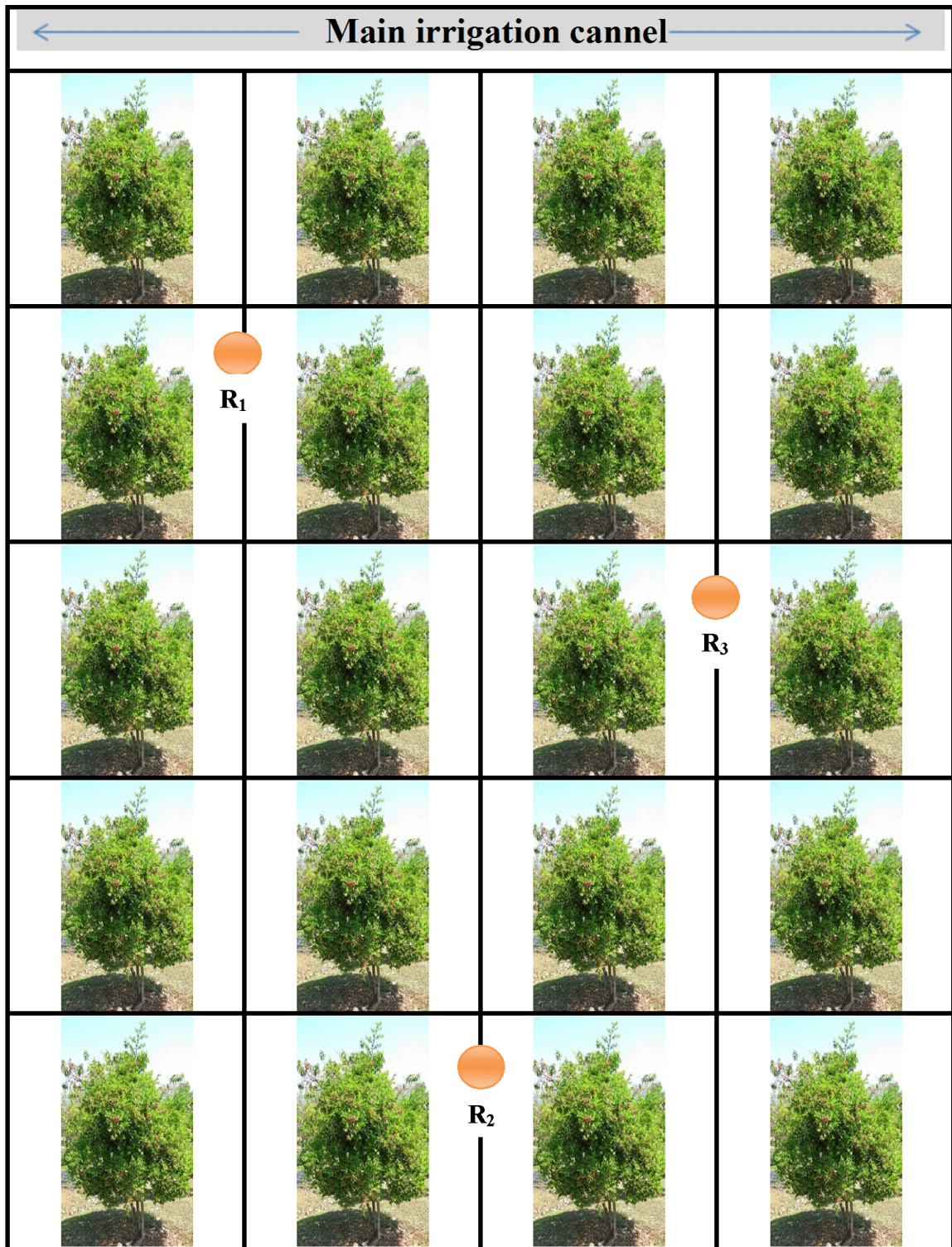


Fig. 3.8: Layout of karonda based horticulture LUS

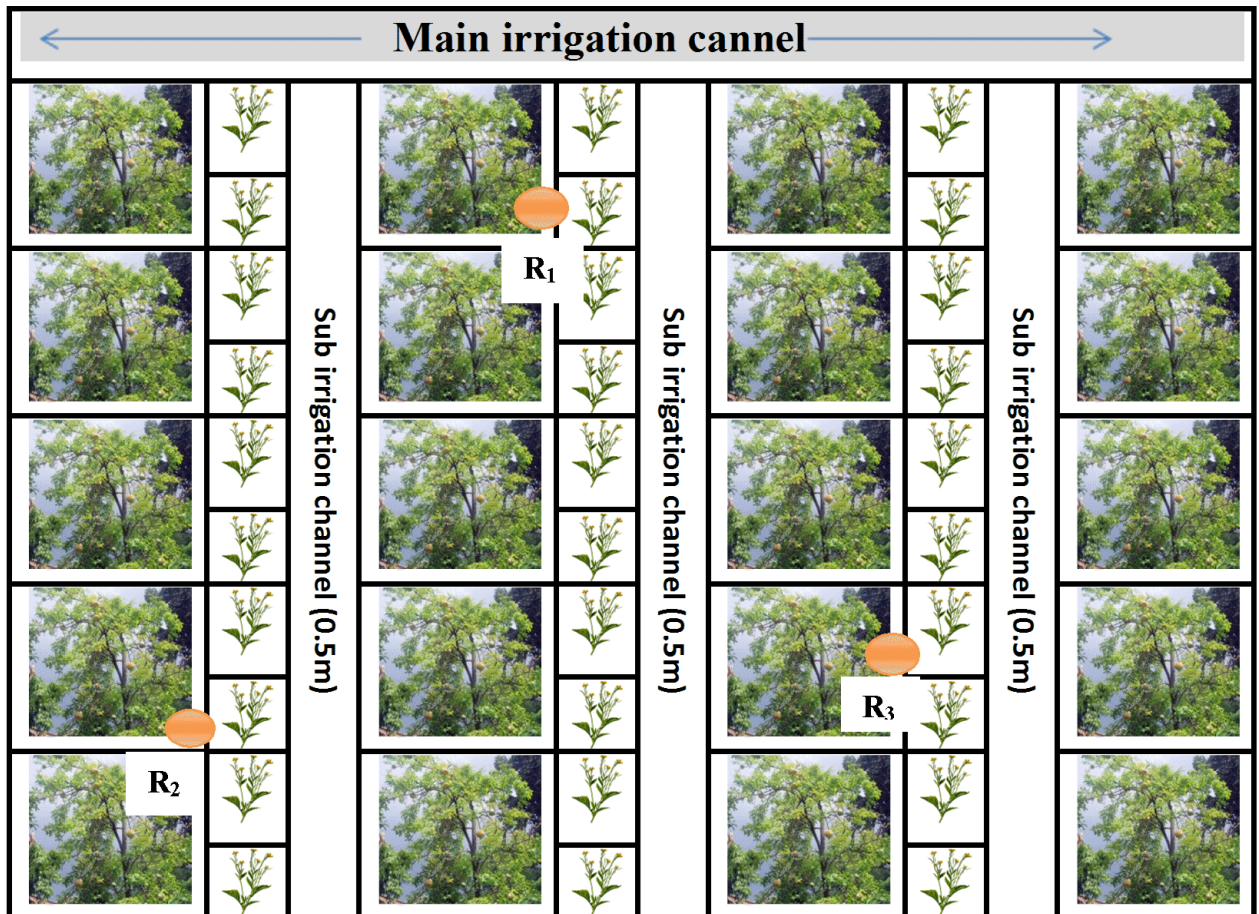


Fig. 3.9: Layout of bael + lentil (Hul-57) based agri-horticulture system



Fig. 3.10: Picture of bael + lentil (Hul-57) based agri-horticulture LUS

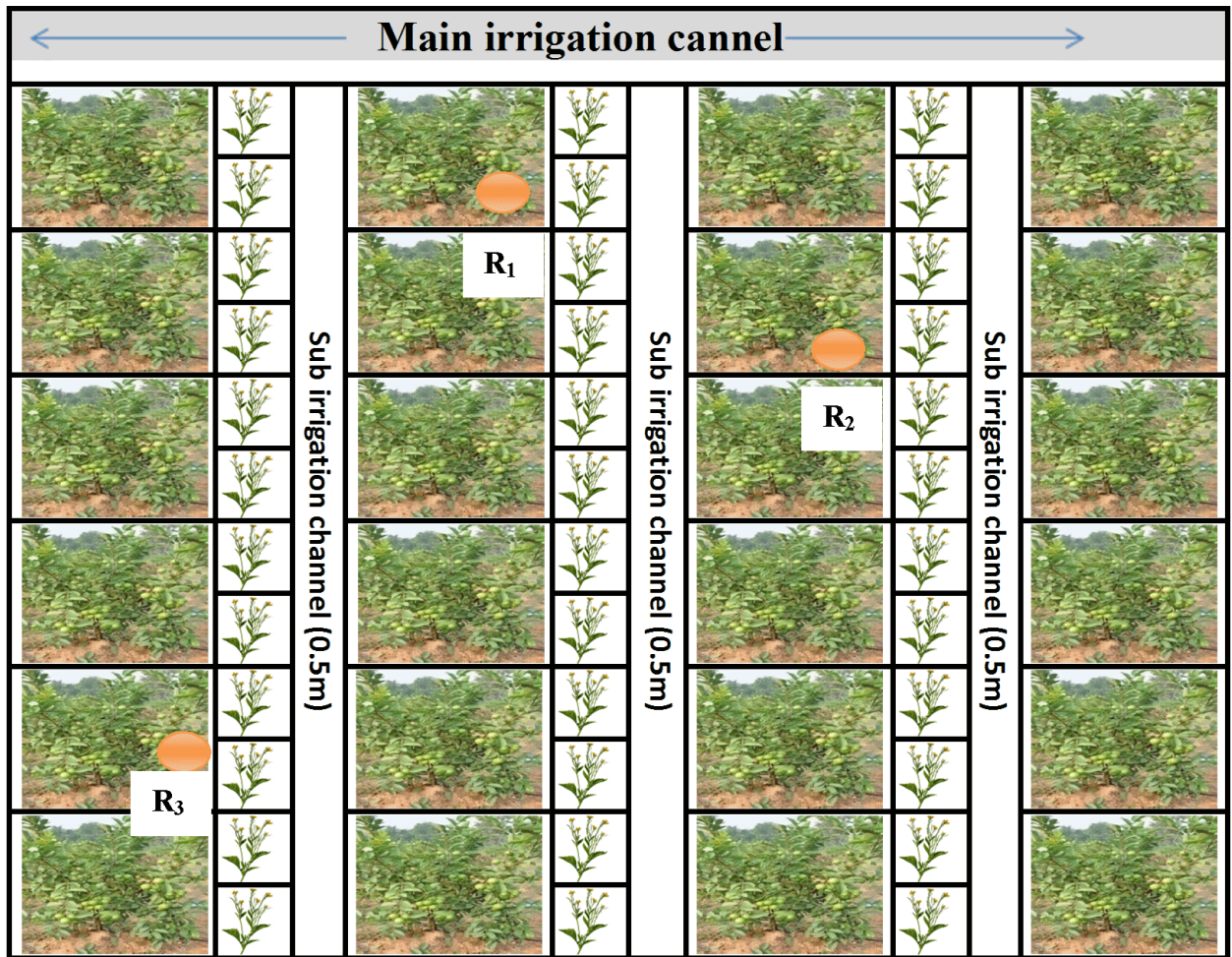


Fig. 3.11: Layout of guava + mustard (Giriraj) based agri-horticulture system



Fig. 3.12: Picture of guava + mustard (Giriraj) based agri-horticulture LUS

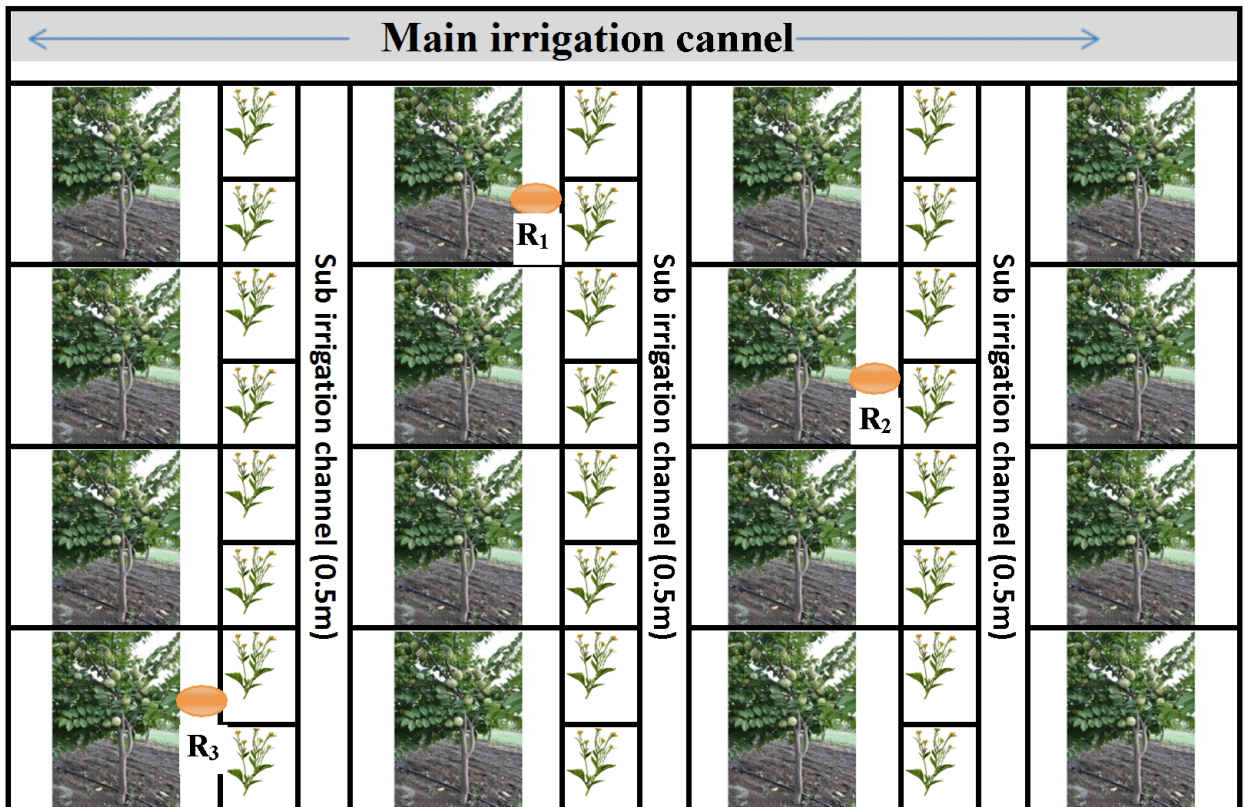


Fig. 3.13: Layout of custard apple + mustard (Pitambri) based agri-horticulture system



Fig. 3.14: Picture of custard apple + mustard (Pitambri) based agri-horticulture LUS

3.9 Soil samples collection and preparation

3.9.1 Site of soil samples collection

The present field investigation was carried out at Rajiv Gandhi South Campus, of the Banaras Hindu University, India to estimate the types of biomass by using allometric equations and carbon sequestration in various land use systems. Various land use pattern are featured in this region. Five land-use system types selected for the study during winter (*rabi*) season 2021 were: agri-horticulture, horticulture, forest, agriculture and teak plantation land-use systems. For the investigation, eighteen soil samples were collected from three agri-horticulture (custard apple + mustard, bael + linseed, guava + mustard) based LUSs of RGSC campus, six soil samples from the forest LUS of Marihan range, about 8-9 km from Barakachha, six soil samples from the horticulture LUS of RGSC campus, six soil samples from the agriculture LUS from the farmer's field at Barkachha and six soil samples from the teak plantations of RGSC campus.

3.9.2 Method of soil collection and samples preparation

Soil samples were taken at all seven sites randomly from three experimental plots marked within 10m × 10m sampling plots. The soil samples were collected with the help of soil sampler. All the twigs, debris, and stones were removed from the sampling site using a shovel. Following that, soil samples were obtained from the research area to depths of 0-20 cm and 20-40 cm using a core sampler to evaluate bulk density and chemical analysis; soil samples were gathered from a given depth using an auger or core sampler. Further, soil samples were brought to the laboratory and dried in the shade for 48 hours by scattering on a clean sheet of paper. After air-drying, the soil sample clods were broken with a wooden hammer and to eliminate stone bits and big root particles, soil samples of the research locations and stratum were carefully mixed, air dried, and put through a 2mm mesh screen. After the sieving is finished, the samples were gathered in clearly labelled polythene bags that were sealed tightly to avoid air exchange and store it.



Fig. 3.15 : Soil sample collection



Fig. 3.16 : Soil samples of different LUSs

3.10 Analysis of physico-chemical properties of soil

Bulk density, Soil organic carbon and soil carbon stock of the sampled soils were analysed by various methods described in the next section.

3.10.1 Soil bulk density (g/cm^3)

The dry weight of a unit volume of soil is called bulk density. It is measured in g/cm^3 . Bulk density is a measure or indicator of soil compaction and soil health. The bulk density (BD) was determined by core sampler method by placing a cylindrical core sampler of known volume into the soil at two depths: 0-20cm and 20-40 cm. To acquire the oven-dry weight of the soil, the soil remained in the sampler was moved to a previously weighted moisture box and dried at 105°C for 18-24 hours. BD was computed as the ratio of the oven-dry weight of the soil to its volume (Blake, 1965).

$$\text{BD } (\text{g}/\text{cm}^3) = \text{weight of oven dry soil (g)}/\text{volume of the soil } (\text{cm}^3)$$

$$\text{Volume of the cylinder} = \pi r^2 h$$

3.10.2 Soil organic carbon (SOC %)

The Walkley and Black (1934) method was used to calculate soil organic carbon. In a 500 ml conical flask, measure 1gm soil sample after passing it through a 0.2 mm screen and adding approximately 10 ml of 1N potassium dichromate ($\text{K}_2\text{Cr}_2\text{O}_7$) solution. Add 20ml of concentrated sulphuric acid to the flask and stir gently for 1 minute to achieve complete interaction of the reagent with the soil, but be careful not to throw up soil along the flask's sides. Allow 30 minutes for the mixture to rest. In the same way, a standardization blank (without soil) is run. After half an hour add around 200 mL distilled water, 30 drops of diphenylamine indicator, and 0.2 gram (g) of sodium fluoride in blank as well as sample. Using ferrous ammonium sulphate (FAS), back titrate the solution. With chromos ion, the colour is dull green at first, then turns to a muddy blue as the titration progresses. This colour abruptly changes to vibrant green at the end. If more than 8 mL of chromic acid is used during the titration, the test is repeated with a tiny amount of soil or by adding a double or

triple amount of potassium dichromate ($K_2Cr_2O_7$) and sulphuric acid (H_2SO_4) to the solution.

$$\text{Organic 'C' in soil (\%)} = 0.5 (B-T) \times 0.003 \times 100/\text{wt. of soil.}$$

Where,

B = Volume of 0.5 N ferrous ammonium sulphate (FAS) solution used for blank titration.

T= Volume of 0.5 N ferrous ammonium sulphate solution (FAS) used for sample titration.

0.003g is the basic determinant for oxidising 0.003 g of carbon from organic materials with 1 ml of $K_2Cr_2O_7$.

Nutrient	Low	Medium	High
Organic carbon (%)	<0.5	0.5-0.75	>0.75

3.10.3 Soil carbon stock

The soil organic (t/ha) carbon was calculated as per formula suggested by Pearson *et al.* (2007).

$$\text{SOC (t/ha)} = (p \times d \times \%C) \times 100$$

Where,

SOC = Soil organic carbon stock per unit area (t/ha),

p = Soil bulk density (g/cm)

%C = Carbon concentration (%)

3.11 Tree Biomass Estimation

In a forest ecosystem or other LUSs, there are five carbon pools; the complete expression for carbon pool calculations is $C = AGB +BGB +DW+ LT +SC$, where C

is total carbon, AGB is above-ground biomass, BGB is below-ground biomass, DW is deadwood, LT is litter, and SC is soil organic carbon (Ravindranath and Ostwald, 2007). To quantify the quantity of carbon and biomass stock in a forest or other LUSs, only four elements out of five are evaluated using specific methodologies outlined in the following sections. Despite the fact that this study focuses on above-ground biomass, below-ground biomass and carbon, other pools are briefly detailed for consistency. These pools may be measured using their own model and methodologies, as described below.

Carbon stock assessments are typically derived by first calculating the total biomass of the population using one of two ways:

- The first step is to quantify the amount of wood for every tree using a volume equation, then transform the volume to mass using an estimation of timber density, and finally to total tree biomass applying biomass expansion factors.
- The second approach is to use a regression equation to translate exterior measurements, such as stem diameter and sometimes height, to total tree biomass. Individual tree biomass estimates generated by either method are added together to give the biomass of the overall population, which is then multiplied by a reference value of carbon concentration to compute the value of carbon stock.

The biomass of a tree is the sum of the biomass of its roots, trunk, branches, leaves and reproductive organs- flowers and fruits. For a precise measure of biomass the tree would have to be cut or felled. To avoid destruction, the standing woody biomass has been assessed by allometric equations based on diameter and height.

3.11.1 Tree components

First to calculate tree components to estimate the biomass by different ways.

3.11.1.1 Tree Height

I. Shadow Method:

To determine the tree height, measure the length of the tree's shadow, the observer's shadow, and his height all at once and estimated by using formula:

Tree's height = (Tree shadow/observer's shadow) x observer's height

II. Instrumental Method:

The height of the tree was estimated falling in the plot (10 ×10 m²) by using Ravi altimeter.

3.11.1.2 Tree diameter at breast height (DBH) in cm

All standing tree individuals greater than 1 cm girth at breast height (GBH) were counted, and their diameter at 1.37 m height was recorded in centimetres with the help of measuring tape and a tree calliper. For multi-stemmed trees, the diameter of every stem was determined and totalled.

3.11.1.3 Volume of selected tree species (m³)

The volume was calculated using the local volume equation for individual tree species. Where a volume equation for the species was not provided, the form factor was computed using Pressler (1865) and Bitterlich (1984).

$$f = 2h_1/3h$$

Where,

f = form factor

h₁ = height at which diameter is half of diameter at breast height (dbh)

h = total height

Volume was calculated by Pressler's formula (1865)

$$V = f \times g \times h$$

Where,

V = volume (m³)

f = form factor

h = total height (m)

g = basal area = πr^2 or $\pi (\text{dbh}/2)^2$

Where,

r = radius

dbh = diameter at breast height

3.11.1.4 Wood specific gravity

Specific gravity values were adopted to determine the biomass and stem cores were exposed to find out specific gravity by using maximum moisture method (Smith, 1954).

$$Gf = \frac{1}{\frac{Mn - Mo + 1}{Mo + Gso}}$$

Where,

Gf = Specific gravity based on gross volume

Mn = Weight of saturated volume sample

Mo = Weight of oven-dried sample

Gso = Average density of wood substances equal to 1.53

Thus, the weight of wood was estimated using the formula, i.e., mass per unit volume

Mass = Average specific gravity of stem wood \times volume



Fig. 3.17: Measuring diameter at tree breast height of different LUSs



Fig. 3.18: Measuring tree height in different LUSs

3.11.2 Above ground tree biomass

3.11.2.1 Method 1: Estimating Above Ground Biomass (AGB) by summation of branch biomass, and leaf biomass (Destructive Method).

The average tree was extracted per plot (MacDicken, 1997) in order to calculate the biomass of branches, leaves and roots and the weight (kg) of each component was determined in the field.

3.11.2.1a Branch biomass

The total number of branches, regardless of size, on each of the sample trees were counted and divided into three groups according to the basal diameter, viz., < 6 cm, < 6-10 cm and >10 cm. The green weight of two representative branches from each group was accounted separately. The formula taken to evaluate the dry weight of branches was as suggested by (Chidumaya 1990).

$$Bdwi = Btwi/(1+Mcbdi)$$

Where,

Btwi = Oven dry weight of the branch

Bdwi = Fresh weight of branch

Mcbdi = Moisture content of branch on a dry weight basis

Total branch biomass (Fresh/dry) per sample tree was determined by:

$$Bbt = n1bw1 + n2bw2 + n3bw3 \sum nibwi$$

Where,

BBt = Branch biomass (fresh/dry) per tree

Ni = Number of branches in the ith branch group

Bwi = Average weight of branch of the ith group

i = 1,2,3,... refers to the branch group

3.11.2.1b Leaf biomass

The fallen leaves under each tree were collected and dried separately in the oven at 80 ± 5 °C until the weight was constant (Chidumaya, 1990). The leaf biomass of forest tree species was accounted using the table by Jenkins *et al.* (2003). The leaf biomass of every fruit tree compared to another was estimated during leaf fall (December-January). Leaf biomass was changed to carbon by multiplying by a factor of 0.5.

Now, total aboveground biomass was calculated by the sum of biomass of all tree components.

Above ground biomass = Branch biomass + Leaf biomass + Stem biomass

3.11.2.2 Method 2: Estimation of above ground biomass (AGB) by using bio-volume (Non-Destructive method)

Above ground biomass of trees (AGB)

AGB has been estimated by multiplying biomass volume and wood density (Ravindranath and Ostwald, 2008). The volume was estimated based on diameter and height. The wood density value for the tree species were obtained from the available literature.

$$\text{Bio-volume} = b = 0.4 \times [(GBH)/2] \times H$$

$$\text{Biomass} = \text{Specific gravity of wood} \times b$$

Where,

GBH = girth at breast height 1.3 m, assuming the trunk to be cylindrical.

H = height (m)

As the wood density of some tree species was unavailable; the standard average of 0.6 g/cm³ was taken.

3.11.2.3 Method 3: Estimation of above ground biomass (AGB) by using Volume Regression Equations (FSI, 1996)

Individual tree wood volume was calculated using species-specific volumetric formulae and the trees' DBH (diameter at breast height). To calculate above-ground biomass, the volume was multiplied by the species specific gravity (AGB). FSI published and gathered species-specific volumetric formulae and specific gravity (FSI, 1996). The total biomass for each site was calculated by adding the average biomass of various trees.

3.11.2.4 Method 4: Biomass estimation using allometric equations

To keep away from destruction, the standing biomass of trees has been estimated by using allometric equations based on diameter and height.

10×10 m² plot in three replications was laid in each study site and all the individuals at breast height were enumerated in each plot for the present study. Diameter at breast height (1.37 m) was measured for every sample tree. The aboveground biomass, belowground biomass and total biomass of tree species was estimated using allometric equation method.

Allometric equations for various species are given below:

* For guava (*Psidium guajava*):

$$Y = a/(1 + b \exp(-cX))^{(1/d)} + \varepsilon, \text{ (Richard' s model) (Naik et al., 2021)}$$

Where,

Y = dry weight of tree component (kg/tree)

X = collar diameter of individual trees (cm),

ε = random error term

a, b, c and d represent the model coefficients.

For AGB, a = 28.099, b = 8.483, c = 0.505, d = 0.652, ε = 1.643

For BGB, a = 10.862, b = 1.690, c = 0.319, d = 0.228, ε = 0.378

For TGB, a = 42.868, b = 0.234, c = 0.330, d = 0.044, ε = 1.693

* For custard apple (*Annona squamosa*), bael (*Aegle marmelos*) and karonda (*Carissa carandas*)

$$\text{I. } (\text{AGB})_{\text{est}} = p \times \exp [-0.667 + 1.784 \text{ LN } (D) + 0.207(\text{LN } (D))^2 - 0.0281(\text{LN } (D))^3] \text{ (Chave } et al., 2005)$$

Where,

-0.667, 1.784, 0.207 and -0.028 are constants

D = trunk diameter at breast height (cm)

LN = Natural logarithm

p = oven-dry wood specific gravity/wood density (g/cm).

$$\text{II. } \text{BBD} = \text{Exp} [-1.0587 + 0.8836 \times \text{LN } (\text{ABD})] \text{ (Cairns } et al., 1997)$$

Where,

BBD is below ground biomass density (dry t/ha)

LN = Natural logarithm

ABD = above ground biomass density (dry Mg/ha)

-1.0587, 0.8836 are constants

* For teak (*Tectona grandis*) plantation

I. $AGB = 0.045 (D^2 H)^{0.921}$ (Ounban *et al.*, 2016)

Where,

AGB = above round biomass (t/ha)

D = diameter at breast height (cm)

H = height of the tree (m)

II. $BBD = \text{Exp} [-1.0587 + 0.8836 \times \text{LN} (ABD)]$ (Cairns *et al.*, 1997)

Where,

BBD = below ground biomass density (dry t/ha)

LN = Natural logarithm

ABD = above ground biomass density (dry Mg/ha).

-1.0587, 0.8836 are constants

* For Dry deciduous mixed forests

I. $AGB = 0.18 D^{2.16} \times 1.32$ (Nath *et al.*, 2019)

Where,

D = diameter at breast height

AGB = above ground biomass

II. $BBD = \text{Exp} [-1.0587 + 0.8836 \times \text{LN} (ABD)]$ (Cairns *et al.*, 1997)

Where,

BBD = below ground biomass density (dry t/ha)

LN = Natural logarithm

ABD = above ground biomass density (dry Mg/ha)

-1.0587, 0.8836 are constants

3.11.3 Below ground biomass of trees (BGB)

The BGB of roots of the tree was determined by multiplying the below-ground biomass by a factor 0.26 (Cairns *et al.*, 1997).

$$\text{BGB of trees} = \text{AGB of trees} \times 0.26.$$

3.11.4 Total tree biomass

Total tree biomass = total above-ground biomass + below-ground biomass of trees.

3.11.5 Total carbon in trees

By multiplying the factor of 0.5 to the calculated tree biomass, we get the total carbon in trees (IPCC, 2006).

$$\text{Total carbon in trees} = \text{Total biomass} \times 0.5$$

3.12 Fruit tree biomass estimation

Fruit tree biomass was estimated by using equations which were developed on the basis of Diameter-dry biomass. Trees were selected according to their numbers fallen in the $10 \times 10 \text{ m}^2$. Number of fruit trees also depend on the spacing between them. Every representative tree was then divided into the main stem and secondary branches. The green weight of each branch and the diameter of the basal portion were estimated in the field with the help of balance and tree calliper respectively. The dry weight of branches was evaluated using the equation given as under (Chidumaya, 1990).

$$\text{Bdwi} = \text{Bdwi}/(1+\text{Mcbdi})$$

Where,

$$\text{Btwi} = \text{Oven dry weight of the branch (g)}$$

$$\text{Bdwi} = (\text{Fresh weight of branches})/(\text{green weight of branches})$$

$$\text{Mcbdi} = \text{Moisture content of branch on a dry weight basis}$$

After approximating the dry biomass of every secondary branch, a non-linear regression equation between the diameter and dry biomass of the branches was evolved. This regression equation was applied to evaluate the dry weight of secondary branches of the selected trees from the sample plot (Chidumaya, 1990).

Dry weight of sample tree = biomass of the main stem log + accumulative weight of all the secondary branches.

Biomass of the main stem log was determined as below:

The volume of the main stem was calculated by using Smalian's formula (Khanna and Chaturvedi 1986) given as under:

$$\text{The volume of the main stem} = (S_1 + S_2) / 2 \times l$$

Where,

S_1 = Basal area of the lower portion

S_2 = Basal area of the upper portion

l = Length of the main stem

Biomass of the main stem of the sample tree = volume of the main stem \times specific gravity.

Biomass of the sample tree = biomass of the main stem + sum biomass of all the secondary branches.

3.13 Estimation of biomass for agricultural crops

3.13.1 Above-ground biomass for agricultural crop

For evaluation of biomass of agricultural crop, plotted five quadrants of 1×1 m². All the stems of the crops within the area of the quadrants were cut at the ground level, and took the fresh weight of the collected samples and kept in oven at 65 ± 5 °C

to get oven dry weight till value became constant. The biomass of crop was converted into carbon by multiplying it with a factor of 0.5 (IPCC, 2006).

3.13.2 Below-ground biomass for agricultural crop

Below ground biomass of agricultural crops was estimated by multiplying above-ground biomass with a factor of 0.26 (Cairns *et al.*, 1997).

Below-ground biomass of crops = Above-ground biomass of crops x 0.26.

3.13.3 Surface litter

Litter trap measurements were used to determine how much litter felled. On each land use system, ten litter traps measuring 1m x 1m with nylon netting were placed 50 cm above ground. Surface litters under the each system were collected from the five quadrates of 1 × 1 m². The litter specimens were taken to the lab and divided into two categories: leaf litter and twig litter. The litter weight was measured after being oven dried to a consistent dry weight at 80°C.

3.14 Estimation of Biomass Carbon Stock and Carbon Sequestration of (Tree and agricultural crop)

3.14.1 Biomass C stock or storage (Tree and agricultural crop)

The formula used for calculation of carbon stock was mentioned by IPCC (2006).

$$\text{C stock} = \text{Biomass} \times 0.5$$

3.14.2 Biomass Carbon sequestration estimation in the tree

CO₂ molecule is made of one molecule of Carbon and 2 molecules of Oxygen. The proportion of CO₂ to C is estimated by using following calculations:

The atomic weight of C is 12.001115.

The atomic weight of O is 15.9994.

The weight of CO₂ is C+2*O=43.999915.

The proportion of CO₂ to C is 43.999915/12.001115=3.6663.

Therefore, to estimate the weight of CO₂ sequestered in the tree, the weight of tree carbon is multiplied by 3.6663.

Formula for the estimation of carbon sequestration was given by Pearson *et al.* (2007)

$$\text{Carbon (CO}_2\text{) sequestered (t/ha)} = \text{Biomass carbon stock (t/ha)} \times 3.67$$

3.15 Total carbon stock

In a forest ecosystem or other LUSs, there are five carbon pools; the complete expression for carbon pool or total carbon stock calculations is $C = \text{AGB} + \text{BGB} + \text{DW} + \text{LT} + \text{SC}$, where C is total carbon, AGB is above-ground biomass, BGB is below-ground biomass, DW is deadwood, LT is leaf litter, and SC is soil organic carbon (Ravindranath and Ostwald, 2007). The total carbon stock was calculated by addition of carbon stock densities of the different carbon pools by using the Pearson *et al.* (2005) formula. Carbon stock density of the study area:

$$C \text{ density} = C_{\text{AGB}} + C_{\text{BGB}} + C_{\text{LT}} + \text{SOC}$$

Where,

C density = Carbon stock density for all pools (t/ha)

C_{AGTB} = Carbon in aboveground tree biomass (t/ha)

C_{BGB} = Carbon in belowground biomass (t/ha)

C_{Lit} = Carbon in dead litter (t/ha)

SOC = Soil organic carbon (t/ha)

3.16 Total carbon sequestration

The total carbon stock was then converted to tons of CO₂ equivalent or carbon sequestration by multiplying it by 44/12, or 3.67 (Pearson et al., 2007).

$$\text{Total carbon sequestration (t/ha)} = \text{total carbon stock (t/ha)} \times 3.67$$

3.17 Carbon credits

One carbon credit is equivalent to one tonne of net sequestered or reduced CO₂ in the form of plant biomass (IPCC, 2007). As a result, total carbon credit in a land-use system was determined using CO₂-equivalent values of retained biomass in that system. The acceptable carbon credits were computed solely on the basis of net sequestered or reduced CO₂ in tree or agricultural biomass.

Carbon credit was approximated as per the formula given by (Mukherjee and Ghosh, 2014):

$$\text{Carbon credit (t/ha/yr)} = \text{Rate (t/ha/yr)} \times \text{US \$} \times \text{Indian rupees}$$

$$\text{Rate} \times 50 \text{ US\$} \times 77.95 \text{ Indian rupees (Dated: 18/06/2022)}$$

(<https://www.edf.org>)

$$\text{Carbon credit (US\$/ha)} = \text{Total carbon sequestration} \times 50 \text{ US\$/ha}$$

$$\text{One ton CO}_2 \text{ sequestered per year} = \text{One carbon credit}$$

3.18 Statistical analysis

To draw meaningful results, data on biomass and carbon of the trial crop and tree were recorded and statistically evaluated using the conventional analysis of variance. The 'F' test of significance was used to assess for treatment differences based on the null hypothesis. Where the 'F' test was relevant, critical differences were calculated at a 5% level of probability. If the variance ratio (F test) was determined to be significant at a 5% level of significance, the standard error of the mean (SEm) and

critical differences (C.D.) were calculated for any further comparison using the procedure below. Duncan Multiple Range Test (DMRT) (Gomez and Gomez, 1984) was used for comparing treatment means using SPSS software.

CD at 5% = $S.Em_{\pm} \times \sqrt{2} \times t$ value at 5 % of error degree of freedom.

$S.Em_{\pm} = \sqrt{(\text{Error sum of square}/n)}$

$CV(\%) = \sqrt{(\text{EMS})/\text{GM}} \times 100$

Where,

CD = Critical difference,

$S.Em_{\pm}$ = Standard error of mean,

EMS = Error mean square,

CV (%) = Coefficient of variance.



DISCUSSION

The present research entitled "**Assessment of Biomass Production, Soil Carbon Stock and Carbon Sequestration under Various Land Use Systems of Vindhyan Region**" conducted at Rajiv Gandhi South Campus, Banaras Hindu University, Barkachha, Mirzapur, Uttar Pradesh during the year of 2021-2022. The current investigation is an attempt to estimate the various parameters such as soil physico-chemical properties (bulk density, soil organic carbon and soil organic carbon stock), biomass accumulation, biomass carbon stock, biomass carbon sequestration, leaf litter accumulation (fresh weight, dry weight and leaf litter carbon) of 13-year old horticulture trees, agricultural crops of the year 2021 and long aged forest trees, total carbon stock, total carbon sequestration and carbon credit under various land use systems. This unit of work has been directed to examining the findings of the study, which are accompanied by logical arguments, scientific studies, and evidence from the literature. The findings of this study have been proved by showing cause and effect relationships among each other to achieve an effective relationship under the following sections.

5.1 Effect of different land use systems on soil physico-chemical properties

The physical and chemical attributes of soil changes vary substantially mainly because of quality of surface litter, decomposition and tree spacing.

5.1.1 Bulk density (g/cm^3)

The data presented in table 4.1 revealed that bulk density of the soil varied significantly under various land use systems and at various depths. The lowest bulk density was recorded in tropical dry deciduous forest (1.31 g/cm^3) land use system. However, the highest bulk density was observed in wheat based agriculture system (1.52 g/cm^3) at mean value. The remaining land use systems followed the trend: T₃

(1.33 g/cm³) < T₄ (1.40 g/cm³) < T₅ (1.44 g/cm³) < T₆ (1.45 g/cm³) < T₇ (1.48 g/cm³) at mean value. Due to high soil organic carbon content and organic matter in soil make the soil porous and loose which leads to decrease in the bulk density of the soil in tropical dry deciduous forest. These findings were also reported by Maqbool *et al.* (2017) and Yihenew and Getachew (2013).

The bulk density was varied with different depths in different LUSs. The bulk density was more in sub-surface soil than in surface soil. The lowest bulk density was recorded at the depth of 0-20 cm in tropical dry deciduous forest (1.28 g/cm³). However, the highest bulk density was found at the depth of 20-40 cm in wheat based agriculture system (1.55 g/cm³). The findings were in agreement with Maqbool *et al.* (2017) and Kaur *et al.* (2021). The bulk density is a characteristic that controls the amount of organic carbon that stored in the soil. The present investigation showed that the bulk density increases with increase in depth and it's vice versa. This might be due to increase in compaction of the soil. There is also an inverse relation between the soil bulk density and soil organic carbon (Bhuyan *et al.*, 2021). Among the agriculture systems, the lower bulk density was found in Bael + lentil (Hul-57) (T₅) at both depths. This result was in close agreement with the finding of Ekka *et al.* (2017).

The bulk density varied between 1.28-1.49 g/cm³, 1.34-1.55 g/cm³ and 1.31-1.52 g/cm³ at the depth of 0-20, 20-40 cm and mean value, respectively. The range values were corroborated with Kaur *et al.* (2021) and Ram *et al.* (2021).

5.1.2 Soil organic carbon (%)

A critical analysis of data in table 4.2 showed that different LUSs had a substantial impact on soil organic carbon. Tropical dry deciduous forest based LUS recorded significantly the highest (0.72, 0.66 and 0.69%) whereas wheat based agriculture LUS observed the lowest (0.39, 0.35 and 0.37%) soil organic carbon at the depth of 0-20, 20-40 cm and mean value, respectively. The remaining land use systems followed the trend: Teak plantation (T₃) > Karonda (T₄) > Bael + lentil (Hul-57) (T₅) > Guava + mustard (Giriraj) (T₆) > Custard apple + mustard (Pitambri) (T₇)

at the depth of 0-20, 20-40 cm and mean value. Similar findings were observed by Maini *et al.*, 2020 and Singh *et al.*, 2017.

Sahoo *et al.* (2019) reported that amount and quality of litter in various LUSs regulate the quality of organic carbon produced which in turn determines the physico-chemical properties of soil. The highest soil organic carbon was found in the tropical dry deciduous forest because of regular and more accumulation of organic matter into the soil in the various forms of above and below ground plant parts and its less decomposition or oxidation through disturbances and better carbon nutrient release to the soils through decomposition. Whereas, low soil organic carbon under cultivated land may be due to the intensive cropping system and more tillage practices which disturb the rate of decomposition of organic matter. Similar findings were also reported by Mishra *et al.*, 2020. During their experiment, Bato and Bekele (2020) discovered that the natural forest had the highest concentration of organic carbon, whereas agriculture had the lowest concentration.

The soil organic carbon also varied with soil depth. It is evident from the data that the soil organic carbon was ranged from 0.39-0.72%, 0.35-0.66% and 0.37-0.69% at the depth of 0-20, 20-40 cm and mean value, respectively. The maximum (0.72%) and minimum (0.35%) soil organic carbon were recorded under the depth of 0-20 cm in tropical dry deciduous forest LUS and at the depth of 20-40 cm in wheat based agriculture LUS, respectively. The range values were corroborated with Singh *et al.*, 2020, Singh *et al.*, 2020 and Mani *et al.*, 2020. But there was slightly increase in the values of soil organic carbon in the current study as observed by Singh *et al.*, 2020 because of increased in the depth of soil taken from the field. Among the agri-horticulture and horticulture systems, karonda was found to be higher soil organic carbon followed by bael + lentil (Hul-57) based agri-horticulture, guava + mustard (Giriraj) based agri-horticulture, custard apple + mustard (Pitambri) based agri-horticulture at both depths. A similar finding was observed by Ekka *et al.* (2017), Mandal *et al.* (2018) and Das *et al.* (2017). There was an inverse relation between bulk density and soil organic carbon. Due to this soil organic carbon decreased with soil depth. The finding was found to be similar with Manpoong *et al.*, 2021.

5.1.3 Soil organic carbon stock (t/ha)

It is perusal from the data presented in table 4.3 that the mean soil organic carbon stock varied significantly (11.24-18.09 t/ha) amongst different LUSs. Tropical dry deciduous forest (T₁) recorded the highest (18.43, 17.76 and 18.09 t/ha) where as wheat based agriculture (T₂) LUS observed the lowest (11.69, 10.78 and 11.24 t/ha) soil organic carbon stock at the depth of 0-20, 20-40 cm and mean value, respectively. The reason for more SOC stock in the forest soil may be due to the more litter deposition, less disturbance in forest soil and soil organic carbon decomposes at a slower rate which results in higher agglomeration while wheat based agriculture LUS observed less SOC stock due to intensive farming practices which results in soil disturbance at large extent and the rate of SOC decomposition increases. The results were in harmony with findings of Manpoong *et al.* (2021), Sahoo *et al.* (2021) and Sharma *et al.* (2019).

The agri-horticulture LUSs (T₅, T₆ and T₇) observed higher soil organic carbon stock in comparison to horticulture (T₄) and agriculture (T₂) LUSs. The reason behind this may be more accumulation of leaf litter of crop and tree under the agri-horticulture systems.

Soil organic carbon stock varied at different soil depths. It is apparent from the data that the soil organic carbon stock was ranged from 11.69-18.43 t/ha, 10.78-17.76 t/ha and 11.24-18.09 t/ha at the depth of 0-20, 20-40 cm and mean value, respectively. The maximum (18.43 t/ha) and minimum (10.78 t/ha) soil organic carbon stock were recorded under the depth of 0-20 cm in tropical dry deciduous forest and at the depth of 20-40 cm in wheat based agriculture LUSs, respectively. The range values were corroborated with Uthappa and Devkumar (2021) and Singh *et al.* (2020). There was decrease in soil organic carbon stock with soil depths. This might be due to increased root activity and the production of a bed of leaf litter and other parts of plant at the upper soil horizon. As compared to the lower layer of the soil in our study, greater levels of soil microbial biomass was found in the upper layers of the soil which helped in the conversion of litter into soil organics, resulting in an increase soil

organic carbon and enriched the upper soil layer. The results were in agreement with the findings of Singh *et al.* (2020).

5.2 Effect of different land use systems on biomass accumulation (AGB, BGB and total biomass) (t/ha) and rate of biomass accumulation (t/ha/yr)

Data related to AGB, BGB, total biomass and rate of biomass accumulation in table 4.4 revealed that the different land use systems had a significant influence on micro-climate of plant and soil, which affects the various developmental stages of crop and ultimately, yield. The AGB, BGB and total biomass of tree species mainly depends on age of the tree, soil quality, diameter at breast height, tree height, wood density, volume of tree and growth habit of tree species. Amongst the various LUSs, the AGB, BGB, total and rate of biomass accumulation were recorded maximum 70.23 t/ha, 18.26 t/ha, 88.49 t/ha and 6.81 t/ha/yr in tropical dry deciduous forest (T₁) and minimum 7.73 t/ha, 2.03 t/ha, 9.76 t/ha and 0.75 t/ha/yr in wheat based agriculture (T₂) LUS, respectively. The results were in close agreement with the findings of Thakur *et al.* (2021), Salunkhe *et al.* (2016), Pande (2005), Hammad *et al.* (2020) and Roy *et al.* (2022).

The tropical dry deciduous forest (T₁) LUS observed higher biomass accumulation due to more tree age, high tree density (667 trees/ha), low biotic interference, more tree height, more diameter at breast height and better soil quality in comparison to other land use systems. A similar finding was observed by Rajput *et al.* (2017).

Amongst the agri-horticulture systems, bael + lentil (Hul-57) (T₅) recorded higher AGB biomass in comparison to guava + mustard (Giriraj) (T₆) and custard apple + mustard (Pitambri). This could be mainly due to better growth habit, good management practices, more height, higher wood density of bael trees in comparison to guava and custard apple trees. The results were in close agreement with Roy *et al.* (2022). The BGB, in general follows the same trend as that of AGB. The rate of biomass accumulation was recorded more in tropical dry deciduous forest (T₁) LUS in

comparison to other LUSs. With the increase in the age of trees, there is a decrease in the rate of biomass accumulation.

5.3 Effect of different land use systems on biomass carbon stock (above ground, belowground and total) (t/ha) and rate of biomass carbon stock (t/ha/yr)

It is evident from the data in table 4.5 that the different LUSs had a substantial impact on biomass carbon stock. Tropical dry deciduous forest (T₁) recorded maximum 35.12 t/ha, 9.13 t/ha, 44.25 t/ha and 3.40 t/ha/yr where as wheat based agriculture (T₂) LUS observed minimum 3.87 t/ha, 1.02 t/ha, 4.88 t/ha and 0.38 t/ha/yr aboveground biomass carbon stock, belowground biomass carbon stock, total biomass carbon stock and rate of biomass carbon stock, respectively. The results were in close agreement with the findings of Hammad *et al.* (2020), Joshi and Dhyani (2018) and Navar (2011).

The reason for more aboveground, belowground and total biomass carbon stock in tropical dry deciduous forest (T₁) might be due to more biomass accumulation, continuous accumulation of carbon, more diameter at breast height, higher number of old aged trees, higher diversity. The biomass carbon stock increases with the age of the trees. This could be due to more accumulation or concentration of biomass and old-aged plantations stored the most carbon to achieve a balance between photosynthetic activity and respiration (Wang *et al.*, 2013). Similar findings were recorded by Roy *et al.* (2022) and Gandhi *et al.* (2017).

Amongst the agri-horticulture systems, bael + lentil (Hul-57) (T₅) recorded higher biomass carbon stock (AGB, BGB, total and rate) in comparison to guava + mustard (Giriraj) (T₆) and custard apple + mustard (Pitambri). This could be attributed mainly due to better growth habit, good management practices, more biomass accumulation, higher wood density of bael trees in comparison to guava and custard apple trees. Statistically analysed data showed that the trend of biomass carbon stock of horticulture and agri-horticulture LUSs was found similar to biomass accumulation of horticulture and agri-horticulture LUSs.

5.4 Effect of different land use systems on biomass carbon sequestration (above ground, belowground and total) (t/ha) and rate of biomass carbon sequestration (t/ha/yr)

It is apparent from the data in table 4.6 that different LUSs had a significant effect on aboveground biomass carbon sequestration, belowground biomass carbon sequestration, total biomass carbon sequestration and rate of carbon sequestration. Aboveground, belowground, total and rate of biomass carbon sequestration were recorded maximum 128.87 t/ha, 33.51 t/ha, 162.39 t/ha and 12.49 t/ha/yr in tropical dry deciduous forest (T₁) LUS and minimum 14.18 t/ha, 3.73 t/ha, 17.91 t/ha and 1.38 t/ha/yr in wheat based agriculture (T₂) LUS, respectively. The results were in close agreement with the findings of Roy *et al.* (2022), Uthappa and Devkumar (2021) and Hammad *et al.* (2020)

The tropical dry deciduous forest (T₁) observed higher potential for carbon sequestration due to dense tree density, medium to old age trees, higher biomass accumulation, higher carbon stock in comparison to other LUSs. A similar finding was reported by Meena *et al.* (2022). Kanime *et al.* (2013) reported that biomass carbon sequestration of agroforestry systems is mainly dependent on the tree age, structure, density and carbon concentration of various components.

Teak based plantation (T₃) observed higher aboveground, belowground, total and rate of biomass carbon sequestration in comparison to bael + lentil (Hul-57) (T₅), guava + mustard (Giriraj) (T₆), custard apple + mustard (Pitambri) (T₇) and karonda (T₄) based LUSs.

As biomass carbon sequestration was the product of biomass carbon stock and factor 3.67, a similar trend of biomass carbon sequestration was observed as in biomass carbon stock of various LUSs presented in table 4.5.

5.5 Effect of different land use systems on surface leaf litter accumulation and leaf litter carbon (t/ha)

A critical examination of the data presented in table 4.7 showed that different LUSs had a significant influence on fresh weight of leaf litter, dry weight of leaf litter and leaf litter carbon. Tropical dry deciduous forest (T₁) recorded the highest 4.72 t/ha, 4.63 t/ha and 2.32 t/ha whereas wheat (T₂) based agriculture LUS observed the lowest 1.22 t/ha, 0.91 t/ha and 0.46 t/ha fresh weight of leaf litter, dry weight of leaf litter and leaf litter carbon, respectively. Similar results have been reported by Uthappa and Devkumar (2021) and Rao and Rao (2015).

The highest leaf litter accumulation was recorded in tropical dry deciduous forest (T₁). This could be due to higher tree density, less anthropogenic disturbances on the forest floor and uneven-aged trees as a result of which some trees shed their leaves in winters and some in summers and forest floor never remain leafless.

5.6 Effect of different land use systems on total carbon stock (t/ha) and rate of carbon stock (t/ha/yr)

The data presented in table 4.8 revealed that different LUSs had a substantial impact on total carbon stock and rate of carbon stock. Tropical dry deciduous forest (T₁) recorded the highest 64.65 t/ha and 4.97 t/ha/yr whereas wheat (T₂) based agriculture LUS observed the lowest 16.57 t/ha and 1.27 t/ha/yr total carbon stock and rate of carbon stock, respectively. The similar findings were recorded by Dabi *et al.* (2021) and Nasam *et al.* (2022).

Total carbon stock was the sum of aboveground biomass carbon, belowground biomass carbon, leaf litter carbon and soil organic carbon. The reason for higher total carbon stock in tropical dry deciduous forest (T₁) might be due to more aboveground and belowground biomass carbon stock, more leaf litter carbon and soil organic carbon stock.

5.7 Effect of different land use systems on total carbon sequestration (t/ha) and rate of carbon sequestration (t/ha/yr)

A critical appraisal of the data depicted in table 4.9 revealed that the total carbon sequestration and rate of carbon sequestration from the three major carbon pools (tree biomass, litter and soil) of various LUSs recorded variations. Amongst the various LUSs, the total carbon sequestration and rate of carbon sequestration were recorded maximum 237.28 t/ha and 18.25 t/ha/yr in tropical dry deciduous forest (T₁) and minimum 60.82 t/ha and 4.68 t/ha/yr in wheat based agriculture (T₂) LUS, respectively. Similar findings were observed by Uthappa and Devkumar (2021), Saha and Jha (2012), Sahoo *et al.* (2021). The rate of total carbon sequestration ranged between 4.68-18.25 t/ha/yr. The range value was corroborated with Rajput *et al.* (2016).

Bael + lentil (Hul-57) (T₅) and guava + mustard (Giriraj) (T₆) agri-horticulture LUSs sequestered more carbon in comparison to koranda based horticulture (T₄) and wheat based agriculture (T₂) LUSs due to intensive management practices were applied in agriculture LUS resulted in higher biomass production but produced was removed annually leading to lower sequestration potential. Whereas, in agri-horticulture systems only fruits and pruned branches were removed resulting into higher carbon sequestration. The similar findings were recorded by Rajput *et al.* (2016).

5.8 Carbon credit estimation under various land use systems (t/ha/yr, US\$/ha)

It is perusal from the data depicted in table 4.10 that different LUSs had a significant influence on carbon credit or certified emission reduction (CER). The maximum (71137.69 t/ha/yr or 11863.89 US\$/ha) carbon credit was recorded in tropical dry deciduous forest (T₁) and minimum (18233.23 t/ha/yr or 3040.82 US\$/ha) in wheat (T₂) based agriculture LUS. The finding was consistent with Zagade *et al.* (2022).

The value of one carbon credit is equal to one ton of carbon sequestrated per year (IPCC, 2006). Tropical dry deciduous forest (T₁) observed higher carbon credit due to more carbon content and more biomass accumulation in comparison to other LUSs. The result was corroborated with Meena *et al.* (2022).

Amongst the horticulture and agri-horticulture LUSs, bael + lentil (Hul-57) (T₅) recorded higher carbon credit as compared to guava + mustard (Giriraj) (T₆), karonda (T₄) and custard apple + mustard (Pitambri) (T₇) LUSs.

As carbon credit is directly proportional to total carbon sequestration and rate of carbon sequestration, a similar trend of carbon credit was observed in the total carbon sequestration and rate of carbon sequestration of various land use systems taken in the recent study.



SUMMARY AND CONCLUSION

The current investigation entitled "**Assessment of Biomass Production, Soil Carbon Stock and Carbon Sequestration under Various Land Use Systems of Vindhyan Region**" was executed in various land use systems at Rajiv Gandhi South Campus, Banaras Hindu University, Barkachha, Mirzapur, the district of Northeastern Uttar Pradesh, India. The different land use systems selected for research work were forest (tropical dry deciduous forests), tree plantation (teak plantation), agri-horticulture [bael + lentil (Hul-57), guava + mustard (Giriraj), custard apple + mustard (Pitambri)], horticulture (karonda) and agriculture (wheat) based LUSs. The experiment was carried out in a Randomised Complete Block Design (RBD) with seven treatments and three replications with the following research goals:

1. To find out the impact of diverse land-use regimes on soil physico-chemical attributes at different depths.
2. To analyze the biomass accumulation or biological yield, biomass carbon stock and biomass carbon sequestration potential of different land use systems.
3. To investigate the total carbon stock, total carbon sequestration and carbon credit under different land use systems.

Soil samples were collected from the depth of 0-20 cm and 20-40 cm by using core sampler for estimation of the soil physicochemical properties (bulk density, soil organic carbon and soil organic carbon stock) of different land use systems. Biomass accumulation (AGB, BGB, total and rate) of trees and crops amongst different LUSs were recorded by using non-destructive approach (allometric equations) and quadrature method, respectively. From this data, biomass carbon stock and biomass carbon sequestration are easily calculated for aboveground, belowground, total and rate. During the research work, total carbon stock, total carbon sequestration and carbon

credit of all LUSs were also calculated by proper procedures and formulae. The experimental findings presented in previous chapter were statistically analyzed to get valid conclusions, which are summarized below:

6.1 Effect of the various land use systems on soil physico-chemical properties at different depths

6.1.1 Effect on bulk density (g/cm^3)

Different LUSs had a substantial impact on soil bulk density. The lower bulk density was recorded in tropical dry deciduous forest (T_1) LUS as compared to teak based plantation (T_3), karonda (T_4), bael + lentil (Hul-57) (T_5), guava + mustard (Giriraj) (T_6), custard apple + mustard (Pitambri) (T_7) and wheat based agriculture (T_2) LUSs at the depth of 0-20 cm, 20-40 cm and mean value. It is suggested that bulk density at the depth of 0-20 cm was found to be significantly minimum in comparison to the depth of 20-40 cm.

6.1.2 Effect on soil organic carbon (%)

Different LUSs had significantly influenced the soil organic carbon at the depth of 0-20 cm, 20-40 cm and mean value. The tropical dry deciduous forest (T_1) LUS recorded the highest soil organic carbon, followed by teak based plantation (T_3), karonda (T_4), bael + lentil (Hul-57) (T_5), guava + mustard (Giriraj) (T_6), custard apple + mustard (Pitambri) (T_7) and wheat based agriculture (T_2) LUSs at the depth of 0-20 cm, 20-40 cm and mean value. However, soil organic carbon at the depth of 0-20 cm was found to be significantly maximum in comparison to the depth of 20-40 cm.

6.1.3 Effect on soil organic carbon stock (t/ha)

The data revealed that the soil organic carbon stock was recorded highest in tropical dry deciduous forest (T_1) LUS whereas lowest in wheat based agriculture (T_2) LUS at the depth of 0-20 cm, 20-40 cm and mean value. Teak based plantation (T_3) observed higher SOC stock as compared to karonda (T_4), bael + lentil (Hul-57) (T_5), guava + mustard (Giriraj) (T_6) and custard apple + mustard (Pitambri) (T_7) based

LUSs at the depth of 0-20 cm, 20-40 cm and mean value. It is investigated that soil organic carbon stock was found more at the depth of 0-20 cm whereas less at the depth of 20-40 cm in all the LUSs.

6.2 Effect of the various land use systems on biomass accumulation, biomass carbon stock and biomass carbon sequestration

6.2.1 Effect on biomass accumulation (aboveground, belowground, total and rate)

Different LUSs had a substantial impact on the aboveground, belowground, total and rate of biomass accumulation. Tropical dry deciduous forest (T₁) and wheat based agriculture (T₂) LUSs recorded maximum and minimum aboveground biomass (AGB), belowground biomass (BGB), total biomass (TB) and rate of biomass accumulation, respectively. The remaining land use systems showed the following trend: Teak plantation (T₃) > Bael + lentil (Hul-57) (T₅) > Guava + mustard (Giriraj) (T₆) > Custard apple + mustard (Pitambri) (T₇) > Karonda (T₄).

6.2.2 Effect on biomass carbon stock

The experimental data revealed the substantial effect of different LUSs on aboveground biomass carbon stock, belowground biomass carbon stock, total biomass carbon stock and rate of biomass carbon stock. Tropical dry deciduous forest (T₁) recorded maximum aboveground biomass carbon stock, belowground biomass carbon stock, total biomass carbon stock and rate of carbon stock, followed by teak plantation (T₃), bael + lentil (Hul-57) (T₅), guava + mustard (Giriraj) (T₆), custard apple + mustard (Pitambri) (T₇), karonda (T₄) and wheat based agriculture (T₂) LUSs.

6.2.3 Effect on biomass carbon sequestration

The presented findings revealed that different LUSs had a significant effect on aboveground biomass carbon sequestration, belowground biomass carbon sequestration, total biomass carbon sequestration and rate of biomass carbon sequestration. Aboveground, belowground, total and rate of biomass carbon

sequestration were recorded maximum under tropical dry deciduous forest (T₁) and minimum under wheat based agriculture (T₂) LUS. Teak based plantation (T₃) observed higher biomass carbon sequestration (aboveground, belowground, total and rate) in comparison to bael + lentil (Hul-57) (T₅), guava + mustard (Giriraj) (T₆), custard apple + mustard (Pitambri) (T₇) and karonda (T₄) based LUSs.

6.3 Effect of various land use systems on surface leaf litter accumulation, total carbon stock, total carbon sequestration and carbon credit

6.3.1 Effect on surface litter accumulation (fresh weight, dry weight and leaf litter carbon)

The fresh weight of surface litter, dry weight of surface litter and leaf litter carbon were recorded highest in tropical dry deciduous forest (T₁) while lowest in wheat based agriculture (T₂) LUS. The fresh weight of surface litter, dry weight of surface litter and leaf litter carbon of the remaining land use systems showed the following trend: Teak plantation (T₃) > Bael + lentil (Hul-57) (T₅) > Guava + mustard (Giriraj) (T₆) > Custard apple + mustard (Pitambri) (T₇) > Karonda (T₄).

6.3.2 Effect on total carbon stock

The total carbon stock was the sum of aboveground biomass carbon, belowground biomass carbon, leaf litter carbon and soil organic carbon. The total carbon stock and rate of carbon stock were highly influenced by different LUSs. Tropical dry deciduous forest (T₁) recorded the highest total and rate of carbon stock, followed by teak plantation (T₃), bael + lentil (Hul-57) (T₅), guava + mustard (Giriraj) (T₆), karonda (T₄), custard apple + mustard (Pitambri) (T₇) and wheat based agriculture (T₂) LUSs.

6.3.3 Effect on total carbon sequestration

The total carbon sequestration was computed by multiplying total carbon stock by factor 3.67. The evaluated data showed that total carbon sequestration and rate of carbon sequestration of 13 years old horticulture trees, agricultural crop of 2021 and

uneven-aged forest trees were substantially influenced by different LUSs. The total carbon sequestration and rate of carbon sequestration were observed the highest in tropical dry deciduous forest (T₁), followed by teak plantation (T₃), bael + lentil (Hul-57) (T₅), guava + mustard (Giriraj) (T₆), karonda (T₄), custard apple + mustard (Pitambri) (T₇) and wheat based agriculture (T₂) LUSs.

6.3.4 Effect on carbon credit

Different LUSs and changing value of one tonne carbon had a significant impact on carbon credit. The carbon credit was recorded the highest in tropical dry deciduous forest (T₁) while lowest in wheat based agriculture (T₂) LUS. The carbon credit of remaining LUSs showed the following trend: Teak plantation (T₃) > Bael + lentil (Hul-57) (T₅) > Guava + mustard (Giriraj) (T₆) > Karonda (T₄) > Custard apple + mustard (Pitambri) (T₇).

CONCLUSION

Based on the present study it can be concluded that-

1. Different LUSs had significantly influenced the soil physico-chemical properties. The tropical dry deciduous forest (T₁) LUS recorded the lower bulk density, higher soil organic carbon and soil organic carbon stock in comparison to teak based plantation (T₃), karonda (T₄), bael + lentil (Hul-57) (T₅), guava + mustard (Giriraj) (T₆), custard apple + mustard (Pitambri) (T₇) and wheat based agriculture (T₂) LUSs at the depth of 0-20 cm, 20-40 cm and mean value. The forest LUS has the highest potential for soil enrichment amongst all land use systems, which significantly enhances the physico-chemical characteristics (bulk density and soil organic carbon) of the soil.
2. The study revealed the substantial effect of different LUSs on biomass accumulation (AGB, BGB, total and rate), biomass carbon stock and biomass carbon sequestration. The tropical dry deciduous forest (T₁) LUS recorded maximum whereas wheat based agriculture (T₂) LUS found minimum biomass accumulation, biomass carbon stock and biomass carbon sequestration. The Teak based plantation (T₃) observed higher biomass accumulation, biomass carbon stock and biomass carbon sequestration in comparison to bael + lentil (Hul-57) (T₅), guava + mustard (Giriraj) (T₆) Custard apple + mustard (Pitambri) (T₇) and karonda (T₄) based LUSs. Agri-horticulture based LUSs are mostly preferred for farmers as compared to other LUSs.
3. The leaf litter accumulation, total carbon stock, total carbon sequestration and carbon credit were highly influenced by different LUSs. The leaf litter accumulation was recorded maximum under tropical dry deciduous forest (T₁) while minimum under wheat based agriculture (T₂) LUS. The total carbon stock, total carbon sequestration and carbon credit were observed the highest in tropical dry deciduous forest (T₁), followed by teak plantation (T₃), bael + lentil (Hul-57) (T₅), guava + mustard (Giriraj) (T₆), custard apple + mustard (Pitambri) (T₇), karonda (T₄) and wheat based agriculture (T₂) LUSs.

The investigation concludes how agri-horticulture based land use systems offer a viable alternate strategy to decrease and mitigate carbon emissions through carbon sequestration under agro-climatic condition of Mirzapur. In terms of securing a better livelihood in the study area, agri-horticulture LUSs offer a number of benefits such as higher yields of staple food crops, fodder, better revenue returns, good soil health, lessened soil erosion and assistance anthropogenic warming reduction through carbon sequestration. Since, the experiment was conducted for only one year, the experiment may be repeated to ascertain the results and drawing valid conclusion.



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