

**Biomass, carbon sequestration and nutrient status of
prominent agroforestry systems of district Anantnag of
Jammu and Kashmir**

Ishrat Saleem
(2017-722-D)



Faculty of Forestry
**Sher-e-Kashmir University of Agricultural Sciences &
Technology of Kashmir**

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“Parents”

*Someone who hold us in arms as we enter this world
Someone who always encourage us with their loving words of praise
Someone who constantly support us
Someone who listens patiently to all our worries and stresses
Someone who's eyes shine with pride and happiness at our every little
Achievement*

DEDICATE MY THESIS

To the most beautiful creatures of God

“MY BELOVED PARENTS”

For their constant care, encouragement, unconditional love and sacrifices.

*(Rabbir - hamhuma - Kama - rabbayani - saghira)
“Ameen”*

Sher-e-Kashmir
University of Agricultural Sciences and Technology of Kashmir
Faculty of Forestry, Benhama, Ganderbal

Certificate – I

This is to certify that the thesis entitled, “**Biomass, carbon sequestration and nutrient status of prominent agroforestry systems of district Anantnag of Jammu and Kashmir**” submitted in partial fulfilment of the requirements for the award of the degree of **Doctor of Philosophy in Forestry** to the **Faculty of Forestry, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir** is a record of bonafide research work carried out by **Ms. Ishrat Saleem (Regd. No. 2017-722-D)** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

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

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Certificate – III

This is to certify that the thesis entitled, “**Biomass, carbon sequestration and nutrient status of prominent agroforestry systems of district Anantnag of Jammu and Kashmir**” submitted by **Ms. Ishrat Saleem (Regd. No. 2017-722-D)** to the **Faculty of Forestry, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir** in partial fulfilment of the requirements for the award of the degree of **Doctor of Philosophy in Forestry** was examined and approved by the Advisory Committee and External Examiner on

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ABSTRACT

The present investigation entitled “**Biomass, carbon sequestration and nutrient status of prominent agroforestry systems of district Anantnag of Jammu and Kashmir**” was carried out, during the year 2018 and 2019. The experimental site is located between 33°.73' N latitude and 75.15' E longitude at an altitude of 1601 m above mean sea level (msl) at a distance of 53 kms from Srinagar. The main aim was to assess the prevalent agroforestry systems, their carbon sequestration and nutrient status. Six agroforestry systems *viz.*, Horti-agriculture, agri-silviculture (boundary plantation), agri-horti-silviculture (homegarden) Horti-silvi-pasture, horti-pasture and silvipasture were found prevalent in the area by stratified random sampling procedure. The district was dominated by 70.83% (170) marginal followed by 20.41% (49) small, 7.08% (17) medium and 1.67% (4) large farmers. Most prominent agroforestry systems were selected for further evaluation for biomass, carbon sequestration and nutrient status. Horti-agricultural system emerged as dominant agroforestry system of district Anantnag. Horti-silvi-pasture recorded maximum total biomass production (66.55 t ha⁻¹), carbon stock (28.46 t ha⁻¹) and carbon sequestration potential (104.4t ha⁻¹), followed by agri-horti-silviculture (homegardens) having biomass (50.18 t ha⁻¹), carbon stock (22.56 t ha⁻¹), and carbon sequestration (82.86 t ha⁻¹).

Maximum soil reaction (pH) was recorded in boundary plantation (7.05). Maximum electrical conductivity (0.32 dSm^{-1}), organic carbon 1.55% , available nitrogen (313.6 kg ha^{-1}), available phosphorus (39.6 kg ha^{-1}) and available potassium ($292.15 \text{ kg ha}^{-1}$) in soil was recorded under horti-silvi-pasture. In horti-agriculture system, maximum nitrogen, phosphorus and potassium uptake among crops was recorded in maize as 167.4 kg ha^{-1} , 35.1 kg ha^{-1} and $166.05 \text{ kg ha}^{-1}$ respectively. In case of tree leaves, maximum nitrogen, phosphorus and potassium uptake was recorded as 70.71 kg ha^{-1} , 8.67 kg ha^{-1} and 27.32 kg ha^{-1} , respectively in walnut. Maximum retranslocation of 58.60% nitrogen and 37.88% potassium in apple and 63.61% phosphorus in walnut and maximum return of 55.01% nitrogen and 63.91% potassium in walnut, and 62.06% phosphorus in apple. In boundary plantation, maximum nitrogen and potassium uptake among crops was recorded in paddy as $124.74 \text{ kg ha}^{-1}$ and $135.63 \text{ kg ha}^{-1}$ respectively and maximum phosphorus uptake was recorded as 14.97 kg ha^{-1} in mustard. In case of tree leaves, maximum uptake of nitrogen as 56.35% , phosphorus as 16.42% and potassium as 28.65% was recorded in poplar. Maximum retranslocation of 68.75% nitrogen in salix, 71.64% phosphorus and 66.67% potassium in poplar and maximum return of 41.18% nitrogen in poplar, 37.31% phosphorus and 46.65% potassium in Salix. In homegardens, maximum nitrogen, phosphorus and potassium uptake was recorded in kale as 52.73 kg ha^{-1} , 15.14 kg ha^{-1} and 45.44 kg ha^{-1} respectively. In case of tree leaves, maximum nitrogen, phosphorus and potassium uptake was recorded in poplar as 35.54 kg ha^{-1} , 11.99 kg ha^{-1} and 20.19 kg ha^{-1} , respectively. Maximum retranslocation of 62.52% nitrogen in apple, 58.52% phosphorus and 54.13% potassium in poplar and maximum return of 50.05% nitrogen in poplar, 46.76% phosphorus in apple and 58.82% potassium in salix. In horti-silvi-pasture, nitrogen, phosphorus and potassium uptake was 86.01 kg ha^{-1} , 3.78 kg ha^{-1} , and 6.49 kg ha^{-1} respectively in case of perennial grasses. In case of tree leaves, maximum uptake of nitrogen as 68.51% , phosphorus as 22.83% and potassium as 44.18% was recorded in poplar. Maximum retranslocation of 59.08% nitrogen in salix, 53.85% phosphorus and 51.79% potassium in poplar and maximum return of 52.15% nitrogen in poplar, 68.55% phosphorus and 66.70% potassium in apple trees.

Key words: Agroforestry systems, Horti-agriculture, Agri-silviculture, Agri-horti-silviculture, Horti-silvi-pasture, Biomass, Carbon stock, Carbon sequestration, Nutrient, Uptake, Retranslocation, Return.

Signature of Student
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Signature of Major Advisor
Dated _____

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Chapter-1

INTRODUCTION

Agroforestry, the deliberate integration of trees into crop and livestock operations, has the potential to achieve many of the environmental, economic and social objectives being demanded from working landscapes by landowners and society. By adding structural and functional diversity to the landscape, these tree-based plantings can perform ecological functions that have significance far greater than the relatively small amount of land they occupy (Guo, 2000; Nair 2001). Agroforestry can also contribute to landscape conservation of biodiversity by creating corridors and landscape heterogeneity in multi-functional landscapes (WAC, 2006).

Analysis of land potentiality in India for agroforestry suitability reveals 32.8% as highly suitable (S1), 40.4% moderately suitable (S2), 11.7% marginally suitable (S3) and 9.1% not suitable (NS). About 52% of land of India is under the cropland category. In addition, it revealed that the 46% of these cropland areas fall into high agroforestry suitable category “S1” and provide huge opportunity for harnessing agroforestry practices (Ahmad *et al.*, 2019). Agroforestry has traditionally been practiced in India as a way of life and livelihood since ancient time. Agroforestry meets almost half of the demand of fuelwood, 65 per cent (small timber), 70–80 per cent (wood for plywood), 60 per cent (raw material for paper pulp) and 9–11 per cent (green fodder requirement of livestock), in addition to its environmental benefits. Agroforestry in developing nations draw considerable attention for addressing multiple problems and delivering a range of economic, environmental and socioeconomic benefits especially after the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC, 2007).

Agroforestry plays an important role in the production of fuelwood and energy biomass as woody plants and shrubs constitute main source of fire and

other sources of biomass energy. The biomass for energy purposes, coming from agroforestry systems can provide various environmental and socio-economic benefits. Estimating availability of biomass resources is important to assess bioenergy production potential and so bioenergy contribution to annual energy demand. In the supply of biomass to energy use, the planning of operations is the basis for sustainable development of agroforestry system. Production of biomass for bioenergy will depend on the sustainability of the production resource base: the soil, water, air and the diversity of the ecosystem as a whole.

Agroforestry systems are believed to have a higher potential to sequester carbon and mitigate climate change because of their perceived ability for greater capture and utilization of growth resources (light, nutrients and water) than in single-species crop or pasture systems (Dagar *et al.*, 2014). From the agroforestry point of view, C sequestration primarily involves the uptake of atmospheric CO₂ during photosynthesis and the transfer of fixed C into vegetation, detritus and soil pools for “secure” (i.e. long-term) storage (Nair *et al.*, 2010).

Perennial vegetation is more efficient than annual vegetation as it allocates a higher percentage of C to below-ground and often extends the growing season (Morgan *et al.*, 2010) so enhancing C sequestration potential of agricultural systems even further (Oelbermann *et al.*, 2006). The total C storage in the biomass compartments in an AFS exhibits higher estimates than that in land use without trees (Nair, 2011).

Agroforestry has great potential for eco-restoration of degraded lands and mitigating the accumulation of C as CO₂ in the atmosphere by maintaining and increasing the land-based carbon sinks. Agroforestry systems also store carbon in the soils and these also reduce greenhouse gas emissions from soils. In addition to sequestering C in biomass and soil, these systems can contribute to both carbon conservation (conservation of carbon stocks in forests by alleviating the pressure) and carbon substitution (reducing fossil fuel burning by producing fuel wood).

Agroforestry has a great potential of both restoring and maintaining soil fertility and increasing agricultural production. Tree species are the important component of agroforestry systems. They reduce nutrient losses from the productive system through efficient nutrient cycling, which is most predominant benefit from agroforestry systems in terms of soil quality. In a soil-plant system, plant nutrients are in a state of continuous and dynamic transfer. Plants take up nutrients from the soil and use them for metabolic activities. In-turn, these nutrients are returned back to the soil either naturally as litterfall in unmanaged systems, deliberately as pruning in some agro-forestry systems or through root senescence in both managed and unmanaged systems. These plant parts are decomposed as a result of microbial activities and release the nutrients held in them into the soil. The nutrient then becomes available for plant uptake once again (Nair *et al.*, 1999).

Uptake and release of nutrients are important factors at the stand level, because they represent the major fluxes through the system (Miller and Alpert 1984). The process of taking up nutrients from deeper soil profile and eventually depositing on the surface layers through litter-fall and other mechanisms is referred to as 'nutrient pumping' by trees. This process depends on characteristics of tree species and other soil, climatic and topographic factors. Tree species can play an important role in nutrient cycling through different properties, such as the amount of litter produced, nutrients release and chemical composition of the litter (Rahajoe, 2003). Different tree species involve different nutrient release patterns, which are related to litter quality and seasonal environmental factors (Khiewtam and Ramakrishnan, 1993). Tracking nutrient returns through litter fall under different tree species is important to understand the dynamics of soil fertility. Trees in moisture deficit soils have deep root systems, thereby helping in nutrient and water pumping from deeper soil layers than surplus moisture soils (Makumba *et al.*, 2009; Schroth and Sinclair, 2003; Schroth, 1999). Nutrients released from the fine root biomass are another important pathway of the improving soil nutrient

health. Trees allocate a large portion of gross primary production belowground for the production and maintenance of roots and mycorrhizae. In such conditions, soil organic carbon increased and improved the soil properties (Nair *et al.*, 2009). Hence litter addition, decomposition and nutrient release, biological nitrogen fixing, nutrient pumping and controlling erosion losses are vital processes for improving soil nutrient status for sustainable farm production.

Nutrient concentration in plant biomass is the result of the balance between nutrient uptake, plant growth and nutrient retranslocation and the loss of these processes are likely to be influenced both by plant genetic make-up and soil fertility, as well as other environmental conditions (Hagen-Thorn *et al.*, 2004). Resorption of nutrients is the process by which nutrients are retranslocated from senescing organs to living or storage organs (Aerts, 1996). These nutrients could be used for new growth or stored in vegetative tissue until the next growing season (Van-Heerwaarden *et al.*, 2003). Nutrient resorption is a key component of nutrient cycling and an efficient mechanism for nutrient conservation in temperate deciduous forests. It can affect many ecosystem processes (Vergutz *et al.*, 2012), including enabling plants to reuse nutrients, minimizing nutrient losses (Van Heerwaarden *et al.* 2003) and making plants less dependent on soil nutrients (Aerts 1996), with important ecological consequences for plant competition, nutrient uptake and productivity. Variation in nutrient resorption could also regulate stand-level biogeochemical cycling via its effect on litter-fall quality, which in turn influences litter decomposition and soil nutrient availability (Aerts, 1997). Agroforestry practice in tropical and temperate regions is probably as old as agriculture itself, and it is considered as a way of life of traditional farmers, although research on it started only about 25 years ago. Many of the traditional systems viz; shifting cultivation or slash-and-burn, homegardens and compound farms, forest gardens/agroforests, trees on farmlands (boundary plantings, scattered trees), parkland systems are base to maintain valued biological interactions and biodiversity at higher levels than some of the new agroforestry

technologies (Leakey, 1998). The traditional agroforestry systems identified in Kashmir Valley include; boundary plantations, agri-silviculture on sloping lands, agri-silviculture in plains, horti-silviculture, horti-silvi-pasture, horti-silvi agriculture and homegardens and are being practiced by farmers to meet out their livelihood needs (Mughal and Bhattacharya, 2002), although the marginal and average household size farmers do not reap all the advantages of this integrated system (Bhat et al., 2010).

World over, it has been estimated that the potential area suitable for agroforestry from land-use change could be up to 630 million ha which would result in storing 586 mt C/yr by 2040, mostly in developing countries (Watson *et al.*, 2000). The transformation of low productive crop lands into agroforestry can triple carbon stocks from 23 to 70 t/ha in a 25-year period. Average carbon sequestration potential in agroforestry has been estimated to be 25 t/ha over 96 million ha land in India (Sathaye and Ravindranath, 1998).

Agroforestry is the only land use systems to secure food availability vis a vis creates better living environment keeping in view the needs and changing climatic conditions without compromising the productivity and sustainability of land use system (Jackson *et. al.*, 2007; Jose, 2009; Padmavathy and Poyyamoli, 2013). The monoculture of fruit/fodder/timber trees being risk prone whereas suitable crop combination in the interspaces in the plantations of fruit, timber and fodder and fuel wood tress generate additional income and helps improve productivity per unit area and efficient utilization of natural resources results in improved ecological conditions by locking the atmospheric carbon in woody components for longer period.

Also, increasing concentration of greenhouse gases in the atmosphere and the adverse effects associated with climate change have also necessitated the need for identification of systems with high carbon sink as a mitigation strategy. Tree-based systems either as farm forestry or agroforestry systems have the potential to sequester carbon in a short period. Agroforestry is an ideal land-use option as it

optimizes tradeoffs between increased food production, poverty alleviation and environmental conservation (Izac and Sanchez, 2000). By sequestering carbon in vegetation and soil, produces wood, serving as substitute for similar products that are unsustainably harvested from natural forests and also contributes to farmers's income (Sudha *et al.* 2007). Adoption and sustainability of agroforestry systems depend on the positive interface effects between the physical and biological components both above and below ground. Diagnoses of existing and improved agroforestry land use systems can divulge their production and carbon sequestration potential. Therefore, present study entitled “**Biomass, carbon sequestration and nutrient status of prominent agroforestry systems of district Anantnag of Jammu and Kashmir**” with the major objective to quantify biomass and to measure nutrient status from subsistence agroforestry systems will therefore be a pioneer step towards this and will be conducted with the following objectives:

1. To identify the prevalent agroforestry systems in district Anantnag.
2. To estimate biomass and carbon sequestration of prominent agroforestry systems.
3. To estimate nutrient status of prominent agroforestry systems.

Chapter-2

REVIEW OF LITERATURE

2.1 Prevalent agroforestry systems

Many authors have shown that traditional agroforestry practices contribute to the conservation of biodiversity through *in situ* conservation of tree species on farms, reduction of pressure on remnant forests and the provision of suitable habitat for a number of plant and animal species on farmland. Trees in these systems provide shade, shelter, energy, food, fodder and many other goods and services that enable the farmstead to prosper (McNeely and Schroth, 2006).

Gusain *et al.* (2021) explored the status of existing agroforestry systems on farmland in plain regions of Uttarakhand, North India and reported a wide adoptability (85.68%) of different agroforestry systems in the region. Total eight types of agroforestry systems were adopted by farmers among which agri-silviculture was highly practiced (59.07%), followed by silvopastoral system (24.51%). Poplar and Eucalyptus along with other horticulture tree species were dominant species in identified agroforestry systems. Also, five different types of plantation patterns were recorded, among which boundary plantation pattern was mostly preferred (84.34%), followed by block plantation (12.12).

Yadav *et al.* (2019) identified four traditional major agroforestry systems *viz.*, agrisilviculture, agrihorticulture, agrihortisilviculture and agrisilvihorticulture in the Indian central Himalaya along the elevation. They were investigated for biomass production and carbon stock in vegetation as well as in soil and hence concluded that in Indian Himalayas, vegetation biomass, carbon stock, soil and total carbon (vegetation + soil) stock increased along the elevation.

Dar *et al.* (2018) reported a total of eight agroforestry systems, including, home gardens, horti- agriculture, boundary plantation, horti-silvi-pasture, horti-silviculture, horti-silvi-agriculture, silvopastoral and hortipastoral systems from the Ganderbal district of Kashmir valley. The highest preference was for fruit-

yielding tree species among the woody perennials and the cropping pattern was paddy, maize, vegetables and pulses in kharif and oil seeds, oats, wheat and vegetables in rabi.

Singh *et al.* (2018) carried a study and recorded that 51% of farmers adopted homestead agroforestry, 20% adopted agrisilviculture system, 19% adopted agrihorticulture system, 8.5% adopted silvipastoral and silvihorticulture model was adopted by very few farmers in the selected village in Angara block, Ranchi, Jharkhand.

Sarkar *et al.* (2017) reported that the traditional agroforestry systems of Jharkhand are homestead garden, agrisilvicultural system, agrihorticultural system and silvopastoral system. Agrisilviculture with Lac cultivation was the most important agroforestry systems and plant species like *Schleichera oleosa*, *Zizyphus mauritiana*, *Butea monosperma* and *Flemingia semialata* are most suitable for lac cultivation in agrisilvi system and are found either on field bunds or in scattered patches in and around the hamlets.

Himshikha (2016) recorded that agroforestry is prevalent in the Haridwar region of India with 86% adoption rate. Agrisilviculture and pastoral based practice are widespread in the region with a growing percentage of farmers. Four major Practices types reported were Agri-silviculture and pastoral based (83.05%), Horticulture based home gardens and orchard plantations (3.63%), wood lots (1.94%) and live fences (11.38%). Most of the farmers (91%) are poplar growers.

Banyal *et al.* (2016) observed that there were nine agroforestry systems prevalent in Kashmir province which are: Boundary plantation, Agrisilviculture system, Hortisilviculture System, Hortisilvipasture system, Hortiagrisilviculture system, Silvopastoral system, Hortipastoral system, Homestead agroforestry and other systems like alley cropping, live hedge row, riparian tree buffer, Short Rotation Intensive Culture. The commonly prevalent agroforestry systems in case

of Ladakh province were seven viz., Boundary plantations/Wind breaks, Agrisilviculture system, Agrisilvopastoral, Hortipastoral, Hortisilviculture, Hortiagriculture, Hortisilvopastoral. Agrisilviculture system was the most preferred system in the province whereas, fruit-based systems occur only in low lying areas. Poplar and willows have shown wider adaptability with multiple uses and occur along the rivers, rivulets, nalas, etc. either naturally or planted by the dwellers.

Sabeena *et al.* (2016) performed a study and stated four agroforestry systems viz., Boundary plantation, Homegarden, Horti-agricultural system and Horti-silvi-pasture system were prevalent in the district Budgam and mostly adopted agroforestry system by the farmers was Horti-agricultural system.

Varadaranganatha and Madiwalar (2010) found that there were six prominent agroforestry systems practiced in the three distinct agroecological situations in Uttara kannada district of Karnataka. In all the three situations, bund planting (21.66 to 36.67 %) was the most prominent agroforestry practiced by farmers, followed by hortisilviculture system (3.33 to 23.33 %) and less prominent practice was block plantation (5.0 to 11.66 %).

Mughal and Khan (2007) stated that there were only seven agroforestry systems prevalent in Kashmir province which are: Boundary plantation, Agrisilviculture system, Hortisilviculture System, Hortisilvipasture system, Hortiagrisilviculture system, Silvopastoral system and Hortipastoral system.

Mughal and Bhattacharya (2002) identified several agroforestry systems in the Kashmir valley which includes boundary plantations, agri-silviculture, horti-silviculture, horti-pasture, horti-silvi-agriculture and kitchen gardens and only three tree species i.e. *Populus deltoids*, *Salix alba* and *Robinia pseudoacacia* are extensively planted.

2.2 Biomass production and carbon sequestration

Biomass is one of the very important parameters affecting biosphere-atmosphere interactions. Estimation of woody biomass is a prerequisite for determining the state of flux for biological materials in an ecosystem and for understanding the dynamics of ecosystem. Information on biomass is not only important from the standpoint of fundamental ecology, but also relevant to planning for ecologically sustainable development of a region

Biomass serves as a carbon sink, absorbing carbon from the atmosphere and storing it in the form of living matter and decomposed plant matter in the soils. Vast amount to carbon are continually being exchanged between this biospheric sink and the atmosphere. Approximately 120 billion tonnes of carbon is absorbed annually through photosynthesis and comparable amount is released through respiration and decomposition (Karthi, 2001).

Singh *et al.* (2021) reported that highest aboveground, belowground and total biomass i.e., 70.63, 18.61 and 89.24 t ha⁻¹, respectively, in silvi-pasture in which trees contributed 95.92 % C in aboveground biomass in Giri catchment of North Western Himalayan region of India. Also, aboveground, belowground and total biomass of vegetation decreased in the order: agri-silvi-horticulture > agri-horti-silviculture > agri-silviculture > agri-horticulture. Whereas, maximum soil organic carbon was observed in grass land, which was statistically at par with agri-horticulture and agri-horti-silviculture systems. The carbon stored in vegetation + soil of silvi-pasture (94.38 t C ha⁻¹) was significantly higher than other systems and it was 1.69 times higher than GS (55.91 t C ha⁻¹).

Yasin *et al.* (2020) conducted a study and reported that plant biomass increased with age and maximum biomass (14.91 t ha⁻¹) was estimated at 8 years of age. Aboveground carbon stock and CO₂ sequestration increased from 0.72 t ha⁻¹ and 2.66 t ha⁻¹ at 2 years to 7.17 t ha⁻¹ and 26.27 t ha⁻¹ at 8 years of age. The ecosystem carbon stock varied from 37.23 t ha⁻¹ at 2 years to 91.98 t ha⁻¹ at 8

years of age and also indicated that planting *V. nilotica* along the boundaries of farm crops not only capture carbon to mitigate climate change but also provide long term accumulation of biomass.

Tanwar *et al.* (2019) studied carbon sequestration potential of eight recommended land-use systems of arid western Rajasthan. Biomass C stock was maximum in farm forestry of *Acacia tortilis* (31.4 Mg C ha⁻¹) followed by *Prosopis cineraria* and *Hardwickia binata* based silvoarable systems (8.8 and 10.6 Mg C ha⁻¹). The total C sequestered (biomass + soil) over a period of nineteen years was in the order: farm forestry (49.80) > silvoarable systems (11.0–13.3) > hortipasture system (8.3) > agri-horti (5.5), silvopasture (5.4) and sole pasture (5.3) compared to –1.0 Mg C ha⁻¹ in sole cropping.

Sarangle *et al.* (2018) quantified individual carbon sequestration potential of tree based intercropping systems (*E. tereticornis*, *P. deltoides* and *T. grandis*) and also quantified biomass and carbon stock in a conventional sole cropped wheat system in north western district of Punjab state of India. The results revealed that maximum total biomass (1311.82 t ha⁻¹), total carbon stock (654.91 t ha⁻¹) and total carbon sequestration potential (130.98 t C ha⁻¹yr⁻¹) was observed in pure *E. tereticornis* plantation followed by mixed (*P. deltoides* and *T. grandis*) plantations (210.29 t ha⁻¹, 109.11 t ha⁻¹ and 21.83 t C ha⁻¹yr⁻¹) and poplar-based land use systems (181.01 t ha⁻¹, 97.29 t ha⁻¹ and 18.59 t C ha⁻¹ yr⁻¹). Whereas, total biomass (12.80 t ha⁻¹) and carbon stocks (6.78 t ha⁻¹) was recorded lowest under pure agricultural-based land use system.

Panwar (2017) revealed that biomass decreased by 62.50% in the upper Indo-Gangetic Region when rotation was reduced by three years from 9 to 6 years in Poplar species. Similarly, the decrease was 56.57% and 43.18% in middle and lower Indo-Gangetic Region. The initial soil carbon pools were 7.7, 19.5 and 6.9 Mg ha⁻¹ for upper, middle and lower Indo-Gangetic Region, respectively, which increased to 15.9, 22.792 and 15.092 Mg ha⁻¹ by the end of 9th year; and 10.4, 18.8 and 12.3 Mg ha⁻¹ by the end of the sixth year in first rotation. The net carbon

sequestered was 47.2%, 51.7% and 31.4% less in 6-year rotation in upper, middle and lower Indo-Gangetic Region, respectively, as compared to 9-year rotation when compared for 54 years. The result suggests that in lower Indo-Gangetic Region, shorter duration rotation of 6 years should be preferred and in upper Indo-Gangetic Region, 9-year rotation is beneficial for carbon sequestration.

Patel *et al.* (2017) reported that above ground green and dry biomass and below ground green and dry biomass of different tree species did not differ significantly. The highest C content (41.55 per cent) and CO₂ sequestration (1847.11 kg/tree and 2052.35 t/ha) was recorded under *Prosopis juliflora* tree species. The descending order of carbon content in different tree species was *Prosopis juliflora* > *Azadirachta indica* > *Prosopis cineraria* > *Acacia tortolis*.

Sureshbhai *et al.* (2017) concluded that among seven agroforestry practices such as Agri-silvi-horticultural systems, Agrisilvicultural systems, Agri-horticultural systems and Silvopastoral systems, highest carbon tonnes per hectare (tree + intercrop) was sequestered by agrisilvicultural system.

Arora *et al.* (2014) performed a study and reported that the total aboveground biomass of *Populus deltoides* increased with age and reached its maximum (180.2 Mg ha⁻¹) at 11 years of age. Mean carbon concentration in aboveground components varied from 39.7% to 51.7%. Aboveground carbon stocks in *Populus deltoides* increased from 0.5 Mg ha⁻¹ at 1 year to 90.1 Mg ha⁻¹ at 11 years. The carbon sequestration rate in mature plantations (7–11 years) varied from 5.8 to 6.5 Mg C ha⁻¹ per year.

Shamsudheen *et al.* (2014) reviewed that silvipastoral system sequestered 36.3% to 60.0% more total soil organic carbon stock compared to the tree system and 27.1–70.8% more in comparison to the pasture system. Similarly, Shankar *et al.* (2014) reported that *Dalbergia sissoo* indicated highest total biomass carbon (254.72 kg per tree) followed by *Acacia nilotica* (228.42 kg per tree) and *Albizia lebbek* (219.84 kg per tree) in avenue plantations.

Wani and Qaisar (2014) conducted a study to quantify carbon percent into different tree components of *Cedrus deodara*, *Fraxinus floribunda* and *Ulmus villosa*, an important tree species of Kashmir valley planted in plantation block of Faculty of Forestry at Sher-e-Kashmir University of Agricultural Sciences and Technology, Kashmir, Shalimar. They revealed that carbon percent was significantly higher in *Cedrus deodara* (45.51%) followed by *Fraxinus floribunda* (41.36%) and *Ulmus wallichiana* (40.78%) respectively.

Huber *et al.* (2014) conducted a study to measure aboveground woody biomass production of four-year-old agroforestry systems in southern Germany to compare between organic and integrated cultivation. Biomass production ranged from 3.9 to 10.9 t ha⁻¹ yr⁻¹ with poplar and locust having highest growth rates. Significant variation was observed between tree species but not between management (organic/ integrated), which indicates that organic and integrated agroforestry systems can have a comparable tree biomass production.

Shankar *et al.* (2014) reported that *Dalbergia sissoo* indicated highest total biomass carbon (254.72 kg per tree), *Acacia nilotica* (228.42 kg per tree) and *Albizia lebbek* (219.84 kg per tree) in avenue plantations.

Jayashree *et al.* (2013) estimated carbon sequestration in four-year existing shelterbelts, where *Dalbergia sissoo* showed maximum biomass accumulation of 25.69 ton/ha with carbon sequestration of 12.84 ton/ha. Similarly, Pandya *et al.* (2013) observed the carbon storage by non-destructive or allometric method and found carbon storage in *Tamarindus indica* 55.95 t C, *Terminalia arjuna* 44.81 t C and 1.77 t C/ha in *Emblica officinalis* trees in Gujarat.

Panchal (2013) studied the biomass accumulation in different agroforestry systems with maximum in Agrisilviculture system (*Eucalyptus* + *Spider lily*: 99.72 t ha⁻¹) followed by agrisilviculture system (Teak + Sugarcane: 25.76 t ha⁻¹) and agrisilvihorticultural systems (Mango +Teak + Brinjal: 14.56 t ha⁻¹) respectively.

Labata *et al.* (2012) conducted research on carbon stock assessment of three selected agroforestry systems in Bukidnon, Philippines and observed the following order for carbon accumulation: Taungya agroforestry system (174 MgC ha⁻¹) > mixed multistorey system (162 MgC ha⁻¹) > falcata-coffee multistorey system (92 MgC ha⁻¹) and pools of stored carbon in order of soil (77-92%) > trees (7-22%) > herbaceous vegetation and litter (1%). They concluded that compared to natural forests, agroforestry systems represent 23-44% of the total carbon stock.

Prasad *et al.* (2012) studied biomass productivity and carbon stocks of farm forestry and agroforestry systems of *Leucaena* and *Eucalyptus* in Andhra Pradesh and evaluated the carbon sequestration potential in degraded lands for which two short rotation tree species *Leucaena* and *Eucalyptus* were planted on two land- use systems. Trees in farm forestry systems were planted at close spacing of 1 × 1 m and 3 × 2 m, whereas in agroforestry systems they were planted at wider spacing of 3 × 0.75 m and 7 × 1.5 m in paired rows, in *Leucaena* and *Eucalyptus* respectively. After 4 years of rotation, the carbon stock of *Leucaena* farm forestry system was 62 Mg/ha and for *Eucalyptus* farm forestry system, it was 34 Mg/ha. They concluded that biomass and carbon accumulation was highest during the third year and were relatively higher in farm forestry systems.

Rizvi *et al.* (2012) estimated carbon sequestration in *Eucalyptus tereticornis* based agroforestry system was 6.122 t/ha for 6-year-old, 11.916 t/ha for 8-year-old and 16.649 t/ha for 10-year-old plantation by considering tree density of 200 trees ha⁻¹. CO₂ equivalent carbon came out to be 22.45 t C/ha for 6-year-old, 43.69 t C/ha for 8-year-old and 61.05 t C/ha for 10-year- old plantations.

Rizvi *et al.* (2011) revealed that the biomass production and carbon stock of *Populus deltoides* based agrisilviculture and boundary plantation system were 267.34 kg/tree and 249.01 kg/tree, respectively at the age of 7 years. Total dry biomass was computed from stem wood biomass by assuming it to be 51% of the total biomass, because studies suggested that stem wood biomass accounted for

49.7-51.7% of the total biomass. Thereafter aboveground and belowground biomass have been estimated by considering their contribution to the total biomass in the order of 79 % and 21% respectively.

Kakkar and Nagaraja (2011) found that the above and below ground biomass was maximum in *Acacia auriculiformis* (37.28 t/ha and 10.06 t/ha) followed by *Gmelina arborea* (33.74 t/ha and 9.11 t/ha), thereafter gradual decrease in biomass accumulation rate was observed in *Terminalia chebula* (13.46 t/ha and 3.63 t/ha), *Dalbergia latifolia* (13.42 t/ha and 3.62 t/ha), *Hardwickia binata* (9.37 t/ha and 2.53 t/ha) and *Tectona grandis* (9.29 t/ha and 2.51 t/ha) respectively.

Chauhan *et al.* (2011) studied that the carbon storage potential in agroforestry system was recorded very high in comparison to sole crop. Also, carbon storage in agroforestry system increased with the age of the plantation and the major contribution came from the timber, roots and litter (37.30 mg/ha after six years). However, wheat crop yield decreased under poplar but this may be compensated by the poplar trees in terms of biomass, economic returns and the carbon sequestration potential. The enrichment of soil through litter and roots enhanced the organic carbon in the surface layer of soil (0-15 cm) under poplar blocks as compared to open fields with wheat crop only.

Kaul *et al.* (2010) estimated the carbon sequestration potential of *Shorea robusta*, *Eucalyptus tereticornis*, *Populus deltoides* and *Tectona grandis* forests in India. The net annual carbon sequestration rates were recorded for fast growing short rotation poplar (8 Mg Cha⁻¹yr⁻¹) and Eucalyptus (6 Mg Cha⁻¹yr⁻¹) plantations followed by moderate growing teak forests (2 Mg Cha⁻¹yr⁻¹) and slow growing long rotation Sal forests (1 Mg Cha⁻¹yr⁻¹).

Chauhan *et al.* (2010) accounted poplar and wheat productivity for carbon sequestration in agrisilviculture at seven years and found that poplar timber

carbon content was 23.57 t/ha with an equal amount of contribution by roots, leaves and tree bark.

Yadav (2010) investigated the carbon sequestration potential of Poplar and Eucalyptus based agroforestry systems in terai and found that carbon storage in stem biomass of Eucalyptus trees was 9.59 t/ha and in Poplar trees 21.38 t/ha at the age of 9 years.

Gera (2006) studied the role of farm forestry and agroforestry in carbon sequestration in India on a part of Bajpur block, Uttarakhand. Five plantation models were selected to be studied: Poplar block planting (5x4 m spacing), Eucalyptus bund planting (2 m spacing), Teak block planting (2x2 m followed by 2 thinning and final harvest), Mango orchard plantation (10x10 m spacing) and Litchi orchard plantation (10x10 m spacing). The maximum sequestration potential of 93.14 t C/ha for project period of 2005–2030 was forecasted for Poplar block plantation followed by 79.00 t C/ha, 51.17 t C/ha, 38.06 t C/ha and 38.06 t C/ha for Teak, Eucalyptus, Mango and Litchi plantations, respectively when products are also accounted.

Swamy and Puri (2005) observed that over the period of 5 years, trees had 3.5 Mg/ha more carbon in plantation than agri-silviculture system. Also, carbon increased by 51.2 and 15.5% in plantation and agri-silviculture system, respectively. Total carbon storage in abandoned agriculture lands before planting was 26.3 Mg/ha, which increased to 33.7 and 45.8 Mg/ha after 5 year of plantation and practicing agri-silviculture system, respectively. Net C storage (soil + tree) was 7.4 Mg/ha in AS system compared to 19.5 Mg/ha in *Gmelina arborea* plantation.

Montagini and Nair (2004) revealed that average carbon storage by agroforestry practices has been estimated as 9, 21, 50 and 63 Mg C ha⁻¹ in semiarid, subhumid, humid and temperate regions. For smallholder agroforestry

systems in the tropics, potential C sequestration rates range from 1.5 to 3.5 Mg C ha⁻¹ yr⁻¹.

Studies from Costa Rica have shown that a ten year old alley cropping with *Eucalyptus poeppigiana* sequestered carbon at the rate of 0.4 Mg C/ha/yr in coarse roots and 0.3 Mg C/ha/yr in tree trunks. Further, tree branches and leaves are added to the soil as mulch contributing 1.4 Mg C/ha/yr in addition to 3.0 Mg C/ha/yr from crop residues (Oelbermann *et al.*, 2004).

Kumar (2003) revealed five agroforestry systems viz., horti-pastoral, silvi-pastoral, agri-horticulture, agri-silviculture, agri-horti-silviculture and natural grassland in mid hill conditions of Himachal Pradesh. He reported silvi-pastoral system produced the highest biomass as (59.72 t ha⁻¹), whereas minimum (5.79 t ha⁻¹) was in natural grassland. The agri-horti-silviculture system produced the second highest biomass among the different land use systems despite having lesser number of trees.

Swamy and Puri (2002) reported 24.12 to 31.12 Mg ha⁻¹ carbon storage in Gmelina arborea agroforestry plantations on red lateritic sites in sub humid tropics of Chhattisgarh, India.

A study conducted by Kaur *et al.* (2002) in natural vegetation and silvi-pastoral system on sodic soil at Bichian, Saraswati Reserve Forest, Kurukshetra in NW India revealed that the total carbon storage in silvipastoral system comprised of six-year-old tree species of *Acacia nilotica*, *Dalbergia sissoo* and *Prosopis juliflora* with two grass species *Desmostachya bipinnata* and *Sporobolus marginatus* was 1.18 to 18.55 Mg C/ha.

2.3 Nutrient status of Agroforestry systems

The impact of agroforestry systems on soil fertility in terms of higher organic matter content, total nitrogen, available phosphorus and potash in the top soil and improved microbial activities in the system has been reported. On an average, dry litter production of *Populus deltoides* was 5 kg tree⁻¹ yr⁻¹, soil

organic carbon was enhanced by 33–83% and available nitrogen by 38.1– 68.9% in 0–15 cm soil layer. Agroforestry can both sequester carbon and produce a range of economic, environmental and socioeconomic benefits. For example, trees in agroforestry farms improve soil fertility through control of erosion, maintenance of soil organic matter and physical properties, increase N, extraction of nutrients from deep soil horizons and promotion of more closed nutrient cycling. Agroforestry is an ideal option to increase productivity of wastelands, increase tree cover outside the forest and reduce human pressure on forests under different agro- ecological regions and is a viable option to prevent and mitigate climate-change effects.

Surki *et al.* (2020) analysed the soil properties of three agroforestry systems and reported that after eight years, organic carbon contents of the soil were influenced in the agroforestry systems mainly near the trees. Higher soil carbon stocks (56 t/ha) were observed near the almond trees at the distance of 0.5 m. The highest field capacity (28%) and soil organic carbon (1.82%) were also observed at the same distance, especially for the barley. Although there was no significant difference in the nitrogen amount between the systems, the highest amount of phosphorus was observed in the agroforestry plots with barley and clover at 2.5 m far from the trees. Intercropping with almond also increased the available potassium at both distances from the trees.

Guo *et al.* (2019) investigated the effects of afforestation and agroforestry on the nutrient contents and organic carbon stocks within a 100 cm depth in eastern China. The total nitrogen, total phosphorus and soil organic carbon content contents decreased dramatically at a 20 cm depth and the total potassium content exhibited a different pattern. Compared with adjacent croplands and nurseries, the forest plantation and agroforestry systems had higher soil organic carbon stocks, ranging from 42.9 to 111.6 t h⁻¹ m⁻² in the whole soil profile. The soil organic carbon distribution among the depth gradient varied among planting systems and the topsoil soil organic carbon stocks played crucial roles in total soil

organic carbon storage within a depth of 100 cm in the cropland and nursery systems.

Singh *et al.* (2018) conducted a study to understand the variation in soil organic carbon density under different agroforestry systems (agri-silviculture, agrihorticulture, agri-horti-silviculture, agri-silvi-horticulture, silvipasture and grasslands) prevailing at three elevations in Giri catchment of Himachal Pradesh, Himalaya. The results revealed that significantly higher mean soil organic carbon was observed in agri-horticulture system (2.22%) as compared to other systems. The bulk density of soil was significantly higher at elevation E₃ (1.28 g cm⁻³) as compared to other elevation ranges. Mean maximum soil organic carbon density upto 30 cm soil depth was observed in grassland (53.45 t C ha⁻¹) followed by agrihorti-silviculture (52.57 t C ha⁻¹), agri-horticulture (51.88 t C ha⁻¹), agri-silvi-horticulture (51.18 t C ha⁻¹) and agrisilviculture (50.01 t C ha⁻¹). Higher SOC density (53.91 t C ha⁻¹) was recorded at elevation E₃.

Pardon *et al.* (2017) carried out a study and assessed the influence of rows of trees of varying size on the prevailing soil characteristics in arable agroforestry system. Significantly higher soil organic carbon and soil nutrient concentrations of N, P, K, Mg and Na were observed in the vicinity of trees in field boundaries, most likely resulting from the input of tree litter and nutrient-enriched throughfall water (for K and Na).

Rani *et al.* (2016) studied the leaf litter production, decomposition rate and amount of major nutrient return in *Populus deltoids*, *Eucalyptus tereticornis*, *Tectona grandis* and *Pyrus pyrifolia* based agroforestry land use systems in Taran district which falls in the north western agro-climatic zone of the Punjab state, India. The litter production in selected tree species was quantified using litter traps and decomposition pattern of leaf litter was investigated by litter bag technique. Litterfall in the selected tree species varied significantly during different months of the study period. Among four species, *Populus deltoides* exhibited highest leaf litter production (7.8 tons/ha) followed by *Tectona grandis*

(1.83 tons/ha) and *Eucalyptus tereticornis* (1.77 tons/ha), whereas lower leaf litter production was observed in *Pyrus pyrifolia* (0.34 tons/ha). The nutrient percentage through leaf litter was maximum of nitrogen (2.27 %) followed by potassium (1.90%) and phosphorus (0.32%). Maximum and minimum N input through leaf litter was in *Populus deltoides* (2.27%) and *Pyrus pyrifolia* (1.15%). The K input was maximum in *Tectona grandis* (0.32%) and minimum in *Eucalyptus tereticornis* (0.21%). The maximum input of P through leaf litter was in *Populus deltoides* (1.90%), whereas minimum in *Eucalyptus tereticornis* (1.27%).

Khaki *et al.* (2016) reported that at 0-20 cm depth, soils under natural grassland was having higher bulk density (1.28 g cm^{-3}) among all the systems while lowest bulk density (1.16 g cm^{-3}) was observed under forest. Soil organic carbon at the soil depth 0-20 cm was highest under forest (3.64 %) while silvi-pastoral system showed the lowest (1.30 %). The total soil organic carbon pool for different agroforestry system followed the decreasing order as Pure Forest ($1373.7 \text{ Mg ha}^{-1}$) > horti-silvipastoral (719.6 Mg ha^{-1}) > agri- silviculture system (697.3 Mg ha^{-1}) > natural grass land (696.5 Mg ha^{-1}) > hortipastoral system (646 Mg ha^{-1}) > silvi-pastoral system ($599.10 \text{ Mg ha}^{-1}$).

Das *et al.* (2015) studied fifteen-year-old lower density ($625 \text{ trees ha}^{-1}$) and higher density ($1000 \text{ trees ha}^{-1}$) plantation of *Acacia ventricularis* (L.). The plantation was intercropped with turmeric (*Curcuma domestica* Valetton local cv. Rajendra Sonia). The amount of nutrients that returned through litterfall to the soil was distinctly greater in the high-density plantation. Of the total annual uptake, 67% N, 48% P and 51% K returned to the ground through the leaves, branches, roots and crop residue by the high-density agroforestry system. Whereas, 55% N, 41% P and 39% K returned to the ground by the low density agroforestry system. Total nutrients released through litter and roots were 67% N and 46% P of the total uptake by high density agroforestry system, while 53% N, 39 P and 38% K of the total uptake by low density agroforestry system.

Panwar and Gupta (2015) revealed that the annual leaf-fall recorded in *C. australis* (81.80 g/m²/yr) was maximum followed by miscellaneous litter (60.71 g/m²/yr) and the least was from bark twigs component (3.50 g/m²/yr) and the highest litter-fall (34.17 g/m²) was recorded in the month of october followed by (24.78 g/m²) in November, while the least litterfall (2.00 g/m²) was observed in the month of February. The annual mean concentration values of nitrogen for leaf, twigs and miscellaneous litter were 1.342, 0.818 and 0.857 per cent respectively and comparatively low concentrations of N, P, K in leaf litter were observed during the months from October to December in *Celtis australis*. Total return of nutrients was in the order of Ca > N > Mg > K > P in *Celtis australis*. The order of nutrient input from different components of litter was leaves > miscellaneous litter > twigs.

Becker *et al.* (2015) reported that the annual pattern of litterfall was closely related to rainfall seasonality, exhibiting a large peak towards the end of the dry season (August–October) and this peak decreased at higher elevations with decreasing rainfall seasonality. Macronutrients (N, P, K) in leaf litter increased at mid elevation (2100 m a.s.l) and with land-use intensity. Carbon content and micronutrients (Al, Fe, Mn, Na) were unaffected or decreased with land-use intensity.

Notaro *et al.* (2014) studied coffee-based agroforestry systems with the aim to characterize the stack and nutrients in litter, soil activity and the population of micro-organisms in coffee plantations under the high altitude agroforestry systems in the semi-arid region of the state Pernabru, Brazil. They reported that systems that are exposed to human intervention (agroforestry systems and biodynamic system) differed in their chemical attributes and contained higher levels of nutrients when compared to native forest and coffee control.

Yadav and Bisht (2014) studied litterfall and potential nutrient contents in the litterfall under crown of pecan nut tree in rainfed condition. Total annual accretion of litterfall found was 2143.3 kg ha⁻¹yr⁻¹ and relative abundance of nutrients in

litterfall of pecan nut tree were in order of $C > N > P > K$. The total nutrient buildups from above mentioned litterfall of peacan nut could be carbon ($901.91 \text{ kg ha}^{-1} \text{ yr}^{-1}$), nitrogen ($57.44 \text{ kg ha}^{-1} \text{ yr}^{-1}$), phosphorus ($3.21 \text{ kg ha}^{-1} \text{ yr}^{-1}$) and potassium $43.29 \text{ kg ha}^{-1} \text{ yr}^{-1}$ found in agri-horti-system.

Salehi *et al.* (2013) examined soil nutrient status, nutrient return and retranslocation in poplar species and its clones in northern Iran. They revealed that amount of OC, N and P in soil and live leaves of P.d “Harvard” clone were more than those of the other species and clones. OC, N, P and K returned by senescent leaves were higher and lower for P.d “Harvard” and *Populus caspica* respectively. P retranslocation for all of the clones and species was higher as compared to N and K. The highest retranslocation percentage was observed in *Populus caspica* (N=18.93, P=39.63, K=24.02) and the lowest (N=12.09, P=32.46, K=21.14) in P.d “Harvard” clone.

Kaur and Puri (2013) analysed the organic C, N, P and K distribution at soil depths of 0-15, 15-30 and 30-60 cm. The physico-chemical properties of soil revealed that pH increased from 7.77 to 8.02 and 7.60 to 7.87, electric conductivity decreased from 0.22 to 0.15 dSm^{-1} and 1.18 to 1.06 dSm^{-1} in *Vigna mungo* and *Triticum aestivum* respectively. Bulk density also decreased from top to bottom of soil profile. Organic carbon showed a depth wise decrease from 0.73 to 0.51% and 0.60 to 0.47 % as well as potassium also showed same trend of decrease from 51.65 to 39.84 kg ha^{-1} and 91.18 to 54.02 kg ha^{-1} in *Vigna mungo* and *Triticum aestivum* respectively. Nitrogen showed a depth wise increase. Phosphorus also showed an increase from 0.21 to 0.31 in *Triticum aestivum* but showed reverse trend in case of *Vigna mungo*.

Pawar (2013) reported that litter contributed 26.45 %, followed by twigs 17.95%, and reproductive part 10.43%, while the least 1.23 % was contributed by the bark towards total non-leaf litter in *Acacia chinensis*. The highest litterfall 50.50 and 65.77 g/m^2 was recorded in the month of December and January respectively, thereby together contributed 36.91 per cent of total litter fall in both

the months. The total return of nutrients was in order of Ca>N>K>Mg>P in *Acacia chinensis* and the order of nutrient input from different components of litter was leaves > twigs>miscellaneous litter> reproductive litter> bark. The average annual litterfall production was 314.98 g/m²/year and the total nutrient return was 13.27 g/m²/yr in *Acacia chinensis* and out of this calcium contribution was maximum 6.37 g/m²/yr followed by nitrogen 3.42 g/m²/yr, potassium 1.73 g/m²/yr, magnesium 1.34 g/m²/yr and the least was phosphorus 0.41 g/m²/yr.

Wang *et al.* (2013) worked on three plantations of monoculture and mixed *Pinus massoniana* and *Castanopsis hystrix* to examine soil organic carbon stocks and found that soil organic carbon stock in 0-20 cm layer in the mixed plantation was 14.3% higher than that in the *Pinus massoniana* and 8.1% higher than that in the *Castanopsis hystrix* plantations. Differences in soil organic carbon stock among the plantations were attributed to soil N stock and leaf litterfall input.

Panchal (2013) studied the soil organic carbon in different agroforestry systems and stated that (Eucalyptus + Spider lily) recorded maximum soil organic carbon as 0.82% followed by (Mango + Teak + Brinjal) as 0.75% and (Mango + Sapota + lemon + Coriander) as 0.65% respectively.

Koul and Panwar (2012) studied the accumulation of nitrogen and carbon stock in soil of different land use systems. Nitrogen content decreased with increase in soil depth in all the land uses except tea garden and *Dalbergia sissoo* plantation where nitrogen content increased at 30-40 cm depth due to presence of nitrogen fixing trees in both the land uses which fixes nitrogen at lower depth. An increasing trend in soil organic carbon stock and pool was found as the number of trees increased. Highest average soil organic carbon stock was 17.69 t/ha in Natural forest of *Shorea robusta* followed by *Terminalia arjuna* plantation (13.29 t/ha) and least in paddy field (6.99 t/ha). Higher organic carbon in tree based land use system was due to return of more organic matter to the soil in form of leaves, bark, fruits and flowers.

Kakkar and Nagaraja (2011) analysed different soil parameters and found soil organic carbon percentage was maximum in upper soil layer (0-15cm) and lowest in (30-45 cm) with *Syzygium cumini* (1.23% and 0.52%) likewise in all the tree species like *Gmelina arborea* (1.05% and 0.93%), *Terminalia chebula* (1.09% and 0.85%), *Acacia auriculiformis* (1.04% and 0.75%), *Tectona grandis* (0.75% and 0.54%) and *Dalbergia latifolia* (0.60% and 0.50%), respectively. They also evaluated P and K content in *Acacia auriculiformis* (83.52 and 104.17 Kg ha⁻¹), *Dalbergia latifolia* (66.25 and 86.70 Kg ha⁻¹), *Gmelina arborea* (58.95 and 117.10 Kg ha⁻¹) and *Tectona grandis* (49.37 and 189.60 Kg ha⁻¹) respectively.

Madhusudanan (2011) reported significantly maximum soil carbon sequestration in *Casuarina equisetifolia* (1.79%), followed by *Albizia procera* (1.35%), *Eucalyptus tereticornis* (1.12%) and least in *Gmelina arborea* (0.68%) respectively in South Gujarat area of India.

Kumar (2011) reported that the floral diversity of agroforestry systems creates suitable conditions for soil microbes, which play a major role in litter decomposition and release of nutrients. Litter quality refers to intrinsic chemical and structural characteristics that govern the activity of decomposer organisms, which partly determines the rate of organic matter decay.

Kibria and Saha (2011) reported that the soil pH, moisture content, organic matter, organic carbon, phosphorus and total nitrogen showed statistically significant variation while bulk density, particle density, sulphur and potassium did not show any statistically significant variation among the land uses in Madhupur sal forest. Soil fertility status showed that pineapple agroforestry is more fertile than rest of other land uses.

Niranjana and Viashwanath (2010) studied the contribution made by the different components of nutrient cycling like litterfall, tree lopping, stem flow and through fall to soil nutrient pool and factors influencing the same in *Grevillea robusta* (Silver oak) shade tree in tea estates situated in Western Ghats of Munnar,

Kerela. The annual litter production by *Grevillea robusta* was 4150 kg/ha/yr which was influenced by weather parameters and physico-chemical properties of soil. The *Grevillea robusta* trees added an average 75.15 kg N /ha/yr, 49.19 kg P/ha/yr and 3.51 kg K/ha/yr towards the nutrient pool in the form of litter fall, lopping, through fall and stem flow of the total nutrient added, maximum contribution was from litterfall which was 61% of the total N, 74% P and 38% K.

Chauhan *et al.* (2010) where accounting poplar and wheat based agrisilviculture system for seven years, reported that soil organic carbon increase was substantial under tree crop interface than sole wheat cultivation.

Gupta *et al.* (2009) observed that poplar-based agroforestry system improves aggregation of soil through huge amounts of organic matter in the form of leaf biomass. The extent of improvement may be affected by the age of the poplar trees and soil type. The surface and subsurface soil samples from agroforestry and adjoining non agroforestry sites with different years of poplar plantation (1, 3 and 6 years) and varying soil textures (loamy and sandy clay) were analysed for soil organic carbon and it increased from 0.36 in sole crop to 0.66 % in agroforestry soils. The increase was higher in loamy sand than sandy clay. The soil organic carbon increased with increase in tree age. The soil under agroforestry had higher soil organic carbon than in sole crop. The poplar trees could sequester higher soil organic carbon in 0-30 cm profile during the first year of their plantation (6.07 Mg/ha/yr) than subsequent year (1.95 – 2.65 Mg /ha/yr). The sandy clay soil could sequester higher carbon (2.85 Mg/ha/yr) than loamy sand (2.32 Mg/ha/yr).

Takimoto *et al.* (2009) examined five land use systems in farmer's field, two traditional parkland systems, two improved agroforestry systems (live fence and fodder bank) and a so-called abandoned land. Soil C contents g kg⁻¹, across three depths ranged from 1.33-4.69 in the parkland, 1.11- 4.42 in live fence, 1.87-2.30 in fodder bank and 3.69-5.30 in abandoned land.

Newaj *et al.* (2008) observed that in an agri-silviculture system involving growing of *Albizia procera* with different pruning regimes, the organic carbon of the soil increased by 13-16% from their initial values under different pruning regimes, which was 5-6 times higher than growing of either sole tree or sole crop. Further, soil fertility can also be regained in shifting cultivation areas with suitable species.

Abid (2008) analysed litterfall in *Populous deltoides* and *Ulmus wallichiana* which started by late September and continued upto late November 2006. As per the study, yield of leaf litter in *Populous deltoides* was 4.723 tonnes $\text{ha}^{-1}\text{yr}^{-1}$ and 2642 tonnes $\text{ha}^{-1}\text{yr}^{-1}$ in *Ulmus wallichiana*. Concentration of N, P, K, Ca and Mg in the leaves of *Ulmus wallichiana* and *Populus deltoides* was comparatively higher in May with corresponding decrease in soil nutrient status. On cumulative basis, resorption of nutrients from senescing leaves to storage organs in *Ulmus wallichiana* ha^{-1} was 21.13 kg N (35.4%), 7.98 kg P (51.5 %), 12.68 kg K (27.9%), 2.11 kg Ca (5.60%) and 3.96 kg Mg (42.85%). Similarly in *Populous deltoides*, resorption of nutrients from senescing leaves was 31.64 kg ha^{-1} N (28%), 12.75 kg ha^{-1} P (31.4%), 20.31 kg ha^{-1} K (20.67%), 3.31 kg ha^{-1} Ca (3.74%) and 7.08 kg ha^{-1} Mg (11.8%). Major portion of absorbed nutrients are recycled to the soil through litterfall. Also, *Ulmus wallichiana* returned 120.46 kg of N, P, K, Ca and Mg whereas *Populous deltoides* added 332.01 kg of these nutrients $\text{ha}^{-1}\text{yr}^{-1}$ to the soil pool.

Swamy and Puri (2005) revealed that soil organic C increased by 15.1% to 51.2% and N by 9.3% to 38.4% in plantation and agrisilviculture system, respectively after 5 years. Total C storage in abandoned agricultural land before planting was 26.3 Mg/ha, which increased to 33.7 and 45.8 Mg/ha after 5 years in plantation and agrisilviculture system, respectively. Net C storage (soil + tree) was 7.4 Mg/ha in agrisilviculture system compared to 19.5 Mg/ha in *Gmelina arborea* monoculture stands.

Bhardwaj *et al.* (2005) studied plant nutrient pool represented 5.2 to 8.7%

(P, Ca and Mg) and 20.2 to 23.0% (N and K) of the soil nutrient pool. In the trees, the major nutrient pool was in stems, branches and roots. Crops accounted for 22 to 59% of the total uptake of nutrients by the plants. Annual return of nutrients (kg ha^{-1}) in litterfall and fine roots was: 95.96 N, 8.85 P, 48.08 K, 64.73 Ca and 27.42 Mg. The pattern of release of nutrients from the decomposing litter was $\text{K} > \text{Mg} > \text{Ca} > \text{P} > \text{N}$. Rapid turnover of litter and fine roots favoured rapid intra system cycling. The retention of nutrients in stems, branches and roots of trees varied from 6.66 to 69.80 $\text{kg ha}^{-1} \text{ yr}^{-1}$. About 48 to 58% of N and K and 19 to 24% of P, Ca and Mg of the total nutrient uptake were lost from the system in crop harvest and fuel wood extraction. The nutrient return in litterfall and fine roots almost balanced the removal of nutrients in crop harvest excepting N and K. Thus, the efficient use of nutrients from the soil pool and rapid intra-system cycling maintained high biological productivity of the agroforestry system.

Jha and Gupta (2005) compared carbon storage of top one foot of soil under 6 land use systems viz, Forests, Agroforestry, Plantations, Agriculture, pasture and barren land. Forests showed the best mitigation potential (120.0 t ha^{-1}) followed by agroforestry (83.6 t ha^{-1}), plantations (80.5 t ha^{-1}), agriculture (66.0 t ha^{-1}), pasture (40.0 t ha^{-1}) and barren land (20 t ha^{-1}). Study suggested the permanency of tall vegetal cover be the reason to sequester more carbon.

Kumar (2003) revealed that in western Himalaya, soil organic carbon was influenced significantly due to various agroforestry systems. Soil organic carbon stock was higher under silvi-pasture system (74.82 t ha^{-1}) followed by natural grassland (44.33 t ha^{-1}), agri-horti-silviculture (43.97 t ha^{-1}), horti-pastoral (42.97 t ha^{-1}), agri-horticulture (27.81 t ha^{-1}) and minimum under agri-silviculture (27.33 t ha^{-1}). The soil organic carbon was maximum in surface soils (0-10 cm) whereas minimum was in soils at 30-40 cm profile depth among four profile depths i.e., 0-10 cm, 10-20 cm, 20-30 cm and 30-40 cm. Soil organic carbon pool was also maximum in silvi-pasture system followed by natural grassland and agri-horti-silviculture, minimum was in agri-horticulture system. Another study conducted

in wet temperate north western Himalaya revealed that forest land use system displayed the maximum value of SOC stock (108.99 t ha^{-1}) which was followed by agri- horticulture (51.05 t ha^{-1}), horticulture (46.31 t ha^{-1}), agri-silviculture (40.40 t ha^{-1}), grass land (36.37 t ha^{-1}) and silvi-pasture (33.54 t ha^{-1}) in 0-40 cm layer.

Chapter-3

MATERIALS AND METHODS

The research problem entitled **“Biomass, carbon sequestration and nutrient status of prominent agroforestry systems of district Anantnag of Jammu and Kashmir”** was conducted in Anantnag district of Kashmir valley during the year 2018-2019. The details about the study area, materials used and methodology adopted are presented in this chapter.

3.1 Site description

Anantnag district is in southern sector of Jhelum Valley and is full of natural scenery. The study area is held between geographical coordinates of 74o-30' to 75o-35' East longitude and 33o-20' to 34o-15' North latitude, at an altitude of 5,300. feet (16,00 mts) above mean sea level, at a distance of 33 miles (53kms) from main city Srinagar. The entire Southern sector of the study area, which is contiguous with Tehsils of Reasi, Banihal and Kishtwar of Jammu province, and Eastern sector which is contiguous with Tehsil Kargil of Ladakh division. The Northern and Western sides are bounded by Pulwama district while Kulgam district falls in its west. Of all the districts of the state, Anantnag claims the largest number of streams (Nallas) like Sandran, Brengi, Arpath and Lidder. The most important among these is Lidder which takes off from Sheshnag Lake and irrigates maximum area of the district. Anantnag district is hilly and mountainous towards the north-east and south-west with broad intermountain valley. Soil is poor in hilly areas and fertile in plain areas so productivity is poor in higher ranges and fertile in central regions. Soils developed on Karewa tops and upland areas are medium to fine textured and known as Hapludalf. Soils found on plains are clay loam in nature and are dark brown. District Anantnag covers a total area of 3803 ha, dense built-up 341 ha, mixed built-up 337 ha, agriculture 2176 ha, plantation 480 ha, water bodies 118 ha, wastelands 60 ha, sparse forests 196 ha, dense forests 95 ha (Malik, 2012).

The population of the study area was 1078692 (2011, Census) residing in an area of 257724.4 hectares which constitutes about 1.31 percent of the total area of Jammu and Kashmir state. Major portion of population living in rural areas depend on crops and the main crops of district Anantnag are rice, maize, wheat and mustard. Although shift from agriculture to horticulture had produced gainful employment to sizable section of population, this resulted in decline in production of rice and maize. The decrease of rice and maize has created chronic and severe problems not only to the people who in no case are linked with cultivation, but even to the cultivators themselves, because rice is staple and the only food for the people of district.

District Anantnag comprises a total of 12 tehsils *viz*, Anantnag, Anantnag-East, Bijbehara, Dooru, Kokernag, Larnoo, Pahalgam, Qazigund, Sallar, Shahabad Bala, Shangus and Srigufwara and 16 CD blocks *viz*, Achabal, Anantnag, Bijbehara, Breng, Chittergul, Dachnipora, Hiller Shahabad, Khoveripora, Larnoo, Pahalgam, Qazigund, Sagam, Shahabad, Shangus, Verinag and Vessu.

3.2 Climate

Anantnag features a moderate climate (Koppen climate classification). Its climate is largely defined by its geographic location, with the towering karokaram to its east and the Pirpanjal range to the south. Generally described as cool in the spring and autumn, mild in the summer and cold in the winter. The climate is of temperate type with the upper reaches receiving heavy snowfall during winter. The district receives an average annual precipitation of about 1103 mm in the form of rain and snow for about 70 days in a year. The average annual precipitation of the year 2018 was 115.86 mm and for year 2019 was 126.95 mm.

3.3 Experimental details

The study was based on field survey of all the agroforestry system prevalent in selected representative areas. The objective-wise technical programme followed was as under:

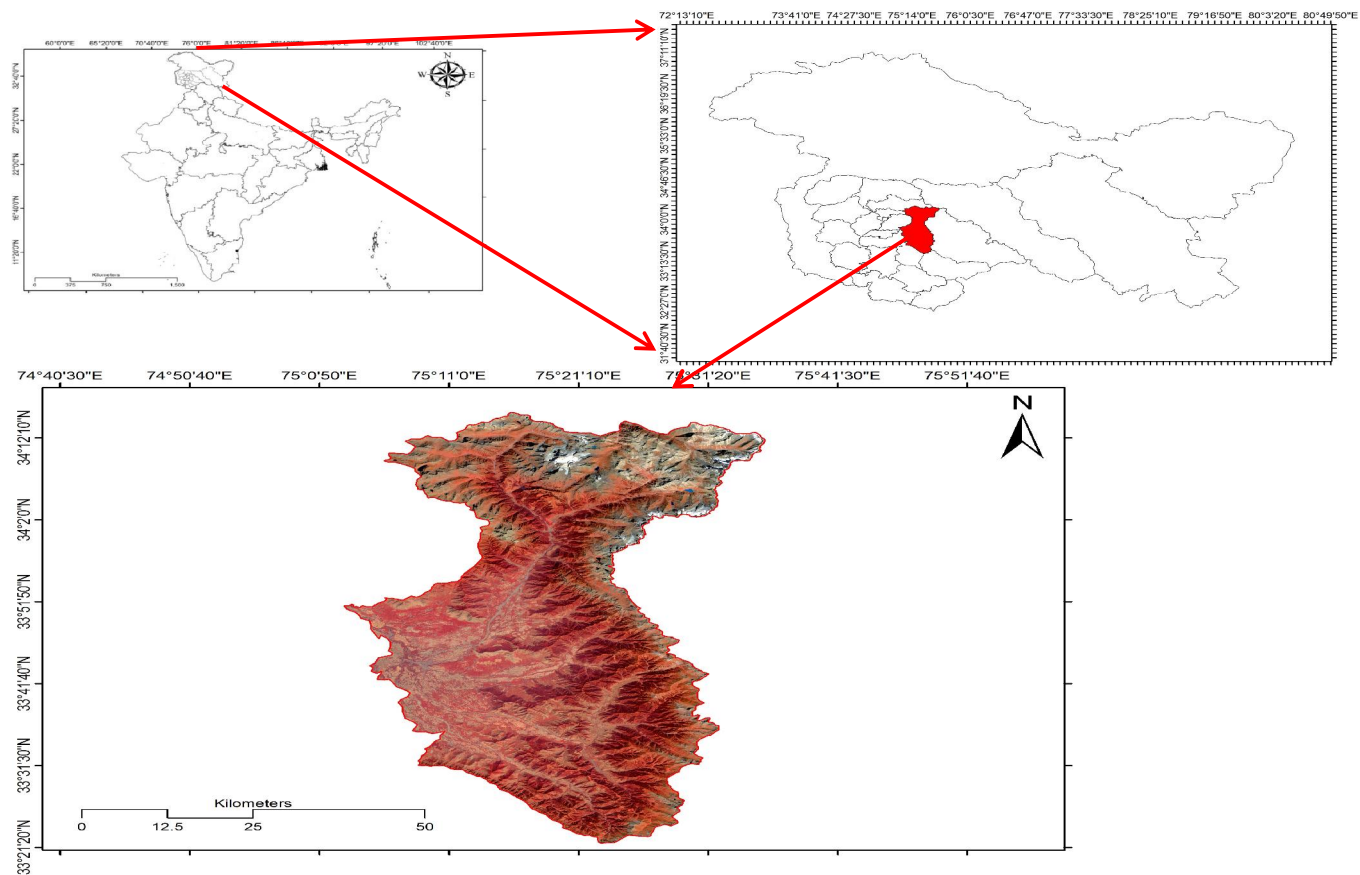


Fig. 1: False Colour Composite imagery of the study area

3.3.1 Identification of prevalent agroforestry systems in district Anantnag.

Out of twelve tehsils, six tehsils namely: Anantnag, Shangus, Kokernag, Dooru, Sallar and Larnu were selected to carry out the above-mentioned research problem. Multistage stratified random sampling was used to select the blocks and villages within tehsils and then farmers within villages. A total of 240 farmers were selected and interviewed through pre-tested questionnaire (Appendix III) regarding different land use patterns (agriculture, agroforestry, horticulture) and their socio-economic status. Each farmer (sample) chosen for further studies were evaluated with respect to prevalent agroforestry systems identified during reconnaissance.

Tehsils →	Anantnag	Shangus	Kokernag	Doru	Sallar	Larnu
Blocks (01) per tehsil	Anantnag	Shangus	Sagam	Shahabad	Pahalgam	Larnu
Villages (04 per block)	1.Ruhoo 2.Dialgam 3.Wanihama 4.Donipawa	1.Shangus 2.Nowgam 3.Kutheir 4.Andoora	1.Hiller 2.Khalhar 3.Sagam 4. Bidder	1.Larkipora 2.Shankerpora 3.Nathipora 4.Bragam	1.Yanner 2.Charigam 3.Movra 4.Wahdan	1.Leesu 2.Dandipora 3. Bidhard 4. Larnu
Farmers (10 per village)	(10x4) =40	(10x4) =40	(10x4) =40	(10x4) =40	(10x4) =40	(10x4) =40

3.3.2 To estimate the biomass production and carbon sequestration potential of prominent agroforestry systems in district Anantnag.

3.3.2.1 Biomass production:

Biomass is a measure of biological matter, customarily expressed in weight. Tree biomass may be that of a single individual or all individuals occupying a unit of area. It includes both aboveground and belowground biomass.

I) Forest tree

Plot size : 20 m × 20 m

Aboveground Biomass (AGB) kg/tree or t/ha

- Stem biomass Kg/tree

- Branch biomass Kg/tree

- Leaf biomass Kg/tree

Belowground biomass (BGB) = AGB x 0.25 (25% of AGB) t/ha (Schulze, 1983)

a) Stem biomass

It includes biomass of the main stem of the tree. The diameter at breast height (dbh) of the trees falling in the plot of size 20×20m was measured with diameter tape and height with Ravi's multimeter respectively. Form factor was calculated by using the Spiegel Relaskope to find out the volume using the formula given by Pressler (1854) and Bitterlich (1984):

$$f=2h_1/3h$$

Where,

f is the form factor, h_1 = height at which diameter is half of dbh and h is the total height.

The volume (V) was calculated by Pressler's formula:

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

Where,

f= form factor

h=total height

g=basal area, but $g=\pi r^2$ or $\pi (dbh/2)^2$ where, r = radius.

Specific gravity

Specific gravity of a piece of wood is defined as a ratio of weight of wood to the weight of the same volume of water. The stem cores were taken to find out specific gravity which was used further to determine the biomass of stem using the maximum moisture method (Smith, 1954).

$$G_f = \frac{1}{\frac{M_n - M_0}{M_0} + \frac{1}{GS_0}}$$

Where,

G_f = specific gravity based on gross volume

M_n = weight of saturated volume sample

M_0 = weight of oven dried sample

G_{s0} = average density of wood substance equal to 1.53

Thus,

Weight of stem wood = specific gravity $\times$ volume

Or

Biomass = specific gravity $\times$ volume

b) Branch biomass

It includes the biomass of the branches of a tree. The total number of branches irrespective of size was counted on each of the sample tree, the branches was categorized on the basis of basal diameter into three groups viz., small, medium and large. Fresh weight of two sampled branches from each group was recorded separately. The following formula (Chidumaya, 1990) was used to determine the dry weight of branches.

$$B_{dwi} = B_{fwi} / (1 + M_{cdbi})$$

Where,

B_{dwi} =oven dry weight of branches

B_{fwi} =Fresh/green weight of branches

M_{cdbi} =Moisture content of branches on oven dry weight basis

Total branch biomass (fresh/dry) per sample tree was determined as given below:

$$B_{bt}=n_1bw_1+n_2bw_2+n_3bw_3\ldots\ldots=\sum_{i=1}^n(n_i b_{wi})$$

Where,

B_{bt} =Branch biomass (fresh/dry) per tree

n_i =Number of branches in the i^{th} branch group

B_{wi} = Average weight of branch of i^{th} group

$I=1, 2, 3\ldots\ldots$ the branch groups.

c) Leaf biomass

Leaf biomass is the biomass of the leaves present on the branches of a tree. The leaf biomass was measured by categorizing the branches of sample tree on the basis of basal diameter into three groups *viz.*, small, medium and large. The leaf biomass of all the representative branches of sample trees in each diameter class was determined just after removing them from branch to calculate the leaf biomass of the whole 20 × 20 m quadrat. The leaf samples were placed in separate bags and oven dried at 65±5°C for period of 72 hours or till the weight became constant (Chapman, 1964).

II) Fruit tree

a) Stem biomass:

$$Y = \exp \{-2.4090 + 0.9522 \ln (D^2HS)\} \text{ (Brown } et al, 1989)$$

Where,

Y = Biomass per tree

D = Collar diameter

H = Tree height

S = Wood Density

b) Canopy biomass:

For biomass estimation, the volume of the crown was multiplied by specific gravity (SG) as shown:

$$\text{Crown volume} = (\pi db^2 L) / 12 \text{ (Avery and Burkhart, 2002)}$$

Where,

db = Diameter(m) at the crown base

L = Crown length

Belowground biomass (BGB) = AGB x 0.33 (t/ha) (Singh, 2010)

III) Crop Biomass (Rabi and kharif crops) kg/m²

Plot size : 1m × 1m

Litter biomass: Plot size: 1m×1m kg/m² (September-mid December)

Total biomass production= Tree + Crop+ Litter kg/m² or t/ha

3.3.2.2 Carbon sequestration of prominent agroforestry systems:

Carbon sequestration is the long-term storage of carbon dioxide or other forms of carbon to mitigate or reverse climate change.

Estimation of carbon

The calculation of carbon stock was determined by multiplying total biomass by a conversion factor that represents the average carbon content in

biomass. The default value of 0.45 for the conversion of biomass to carbon was used (Woomer, 1999).

Therefore, the total carbon stock (C) present in the calculated total biomass was equal to $C = 0.45 \times \text{Biomass (total)}$

The mitigation potential of the system was worked out by calculating equivalent carbon dioxide (eCO₂) as per formula:

$$\text{CO}_2\text{e} = C \times 3.67$$

3.3.3 Nutrient status of identified Agroforestry system

Nutritional status of soil and plant in an agro-forestry system is movement of nutrients as well as inputs to and losses from the ecosystem are essential processes and was carried out in the following ways:

- a) Tree leaf sampling (September-October) for total Nitrogen, Potassium and Phosphorus.
- b) Litter sampling (kg/m²) 1m×1m (September-mid Dec).
- c) Crop sampling (prior to harvesting) for total N, P and K.
- d) Soil sampling (pH, EC, OC, available N, P, K) (mid May/mid July/mid Sept/mid Nov)
- e) Nutrient uptake (N, P, K) Kg/ha
- f) Nutrient re-translocation
- g) Nutrients return (Nutrient return can be calculated by subtracting nutrient uptake by nutrient re-translocation).

3.3.3.1 Nutrient uptake (g/plant)

After estimating nutrient content in the leaves at different stages of growth, nutrient uptake through leaves has been calculated by a method given by Mohsin *et al.* (2005).

$$\text{Nutrient uptake (g/plant)} = \frac{\text{Average nutrient content (\%)} \times \text{total dry matter of leaves (kg)}}{100}$$

3.3.3.2 Nutrient reabsorption efficiency NRE or Re-translocation (Huang *et al.*, 2007)

$$\text{Nutrient reabsorption efficiency} = \frac{\text{Nu live} - \text{Nu dead}}{\text{Nu live}} \times 100$$

Nu_{live}=Nutrient concentration of live leaves (mature leaves)

Nu_{dead}=Nutrient concentration of Senescent leaves (leaf litter)

3.3.3.3 Soil analysis

Soil samples were collected from 5 random places in each system. The soil samples were collected from two depths i.e 0-30 cm and 30- 90 cm. Each sample was thoroughly mixed, air dried, grinded with pestle and mortar, sieved through a 2 mm mesh screen. The sieved soil samples were stored in paper bags for chemical analysis.

Organic carbon was determined by Walkley Black Rapid Titration method (Jackson, 1958), available nitrogen by alkaline permanganate method given by Subbiah and Asija (1956).

Available phosphorous by Olsen's method as described by Olsen *et al.* (1954). Potassium was determined by flame photometry after extraction with neutral normal ammonium acetate (Jackson, 1973).

3.3.3.4 Leaf chemical analysis

Green leaves were collected randomly on each date (samples at each date) from trees. After collection, the leaves were washed with tap water and later dipped in dilute HCL (1 ml concentrated HCL litre⁻¹ of water). Further washing was repeated with de-ionized water. The washed leaf samples were packed in labeled paper bags and dried in hot air oven at 60°C for 48 hours before girding for nutrient analysis.

For determination of total phosphorous, potassium, calcium and magnesium, 0.5g of finely powdered leaf sample was digested in wet diacid mixture of nitric acid (HNO_3) and per chloric acid (HClO_4) in the ratio of 9:4.

Total nitrogen in the leaf samples was determined by Macro Kjeldahl's method, phosphorus by Vanado-molybdo-phosphoric acid yellow colour method, Potassium by Flame photometer.

3.4 Data analysis:

All the data obtained were subjected to the statistical analysis as per procedure given by Gomez and Gomez (1984) using R-software and SAS statistical package.

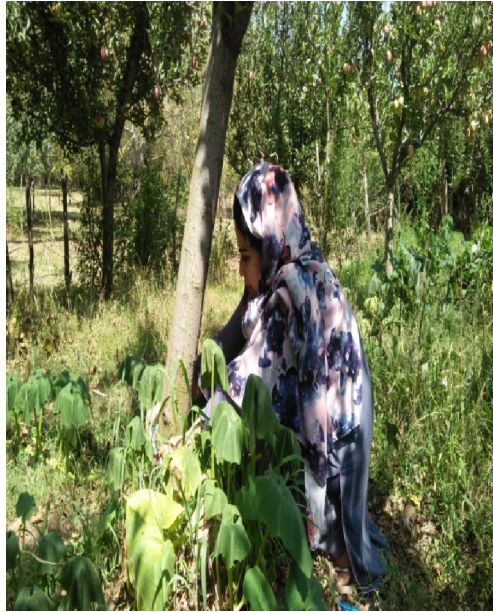


Plate 1: Tree measurements of different agroforestry systems



Laying of 1m×1m quadrant in boundary plantation



Litter traps for collecting litter



Walnut + oats under horti-agriculture



Apple+kale+chilli under horti-agriculture



Apple +beans under horti-agriculture



Apple+radish+ knol-khol + beans under horti-agriculture

Plate 2: Tree-crop combinations in different agroforestry system

Contd....

Plate 2: contd....



**Poplar and mustard under
Boundary plantation**



**Poplar and paddy under Boundary
plantation**



**Poplar, salix and paddy under
Boundary plantation**



**Poplar and oats under Boundary
plantation**



**Poplar, apple, turnip and kale under
Homegardens**



**Poplar, apple, beans and onion
under Homegardens**

Contd....

Plate 2: contd....



Apple, poplar and grasses under Horti-silvi-pasture



Apple, poplar, salix and grasses under Horti-silvi-pasture

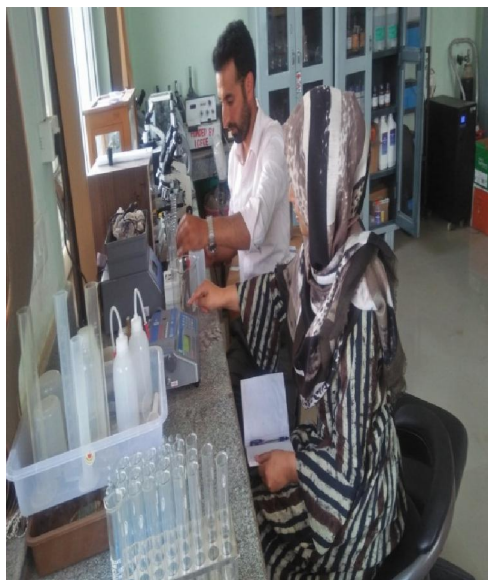


Plate 3: Soil sample preparation and lab analysis

Chapter 4

EXPERIMENTAL FINDINGS

The results obtained from the present investigation “**Biomass, carbon sequestration and nutrient status of prominent agroforestry systems of District Anantnag of Jammu and Kashmir**” are presented in this chapter. The objectives are as follows:

- 4.1 Identification of prevalent agroforestry system.
- 4.2 Biomass production and carbon sequestration of prevalent agroforestry.
- 4.3 Nutrient status of prominent agroforestry systems.

4.1 Identification of prevalent agroforestry system

4.1.1 Classification of farmers in district Anantnag

The information regarding the prevalent landuse patterns/practices, agroforestry systems and components in the study district were generated through pre-tested questionnaire (Annexure-I). Classification of farmers by land holding was carried out in the six tehsils of the Anantnag district. Afterwards, one block was selected from each tehsil and the farmers were classified as marginal (upto 1 ha), small (01-02 ha), medium (2.1-4.0 ha), large 4.1 and above as per Haque *et al* (2010). The district was dominated by 70.83% (170) marginal followed by 20.41% (49) small, 7.08% (17) medium and 1.67% (4) large farmers (Table 1).

4.1.2 Extent of adoption of various agroforestry systems

The extent to which different agroforestry systems were adopted is shown in Table 2. Horti-agriculture system emerged as dominated the agroforestry system adopted by the farmers. The adoption of horti-agricultural systems varied from 62.91 percent (marginal) to 1.67 percent (large farmers). On the other hand, the horti-silvi-pasture was least adopted and its adoption was between 1.25 percent among large farmers and 2.08 percent in marginal farmers. The other agroforestry systems adopted by farmers were agri-silviculture (boundary

plantation) 25.83 percent among marginal farmers and 1.25 percent by large farmers. Agri-silvi-horticulture (homegarden) 12.08 percent among small farmers and 3.33 percent (8) by large farmers. Horti-pastoral 126 percent (10.83) among marginal farmers and 8 percent (3.33) by large farmers. Silvo-pastoral 10 percent among medium farmers and 8 percent by large farmers.

Table 1: Land holding status of surveyed farmers across Anantnag district (numbers)

S.No.	Tehsil	Marginal	Small	Medium	Large	Total
01	Anantnag	30	10	-	-	40
02	Shangus	29	7	3	1	40
03	Kokernag	26	9	4	1	40
04	Doru	31	5	4	-	40
05	Larnu	26	9	3	2	40
06	Salar	28	9	3	-	40
	Total	170 (70.83)	49 (20.41)	17 (7.08)	4 (1.67)	240

Figures in the parentheses represent %age of the total sample (240)

Table 2: Extent of adoption of various agroforestry systems by surveyed farmers (numbers)

S.No.	System	Marginal	Small	Medium	Large	Total
1	Horti-agriculture	151 (62.91)	47 (19.58)	17 (7.08)	4 (1.67)	219 (91.25)
2	Agri-silviculture (boundary plantation)	62 (25.83)	38 (15.83)	11 (4.58)	3 (1.25)	114 (47.5)
3	Agri-horti- silviculture (homegarden)	29 (12.08)	18 (7.5)	10 (4.16)	8 (3.33)	65 (27.08)
4	Horti-silvi- pasture	16 (6.66)	11 (4.58)	8 (3.33)	8 (3.33)	43 (17.91)
5	Horti-pasture	10 (4.16)	11 (4.58)	9 (3.75)	8 (3.33)	38 (15.81)
6	Silvi-pasture	5 (2.08)	8 (3.33)	7 (2.91)	3 (1.25)	23 (9.58)

Figures in the parentheses represent %age of the total sample (240)

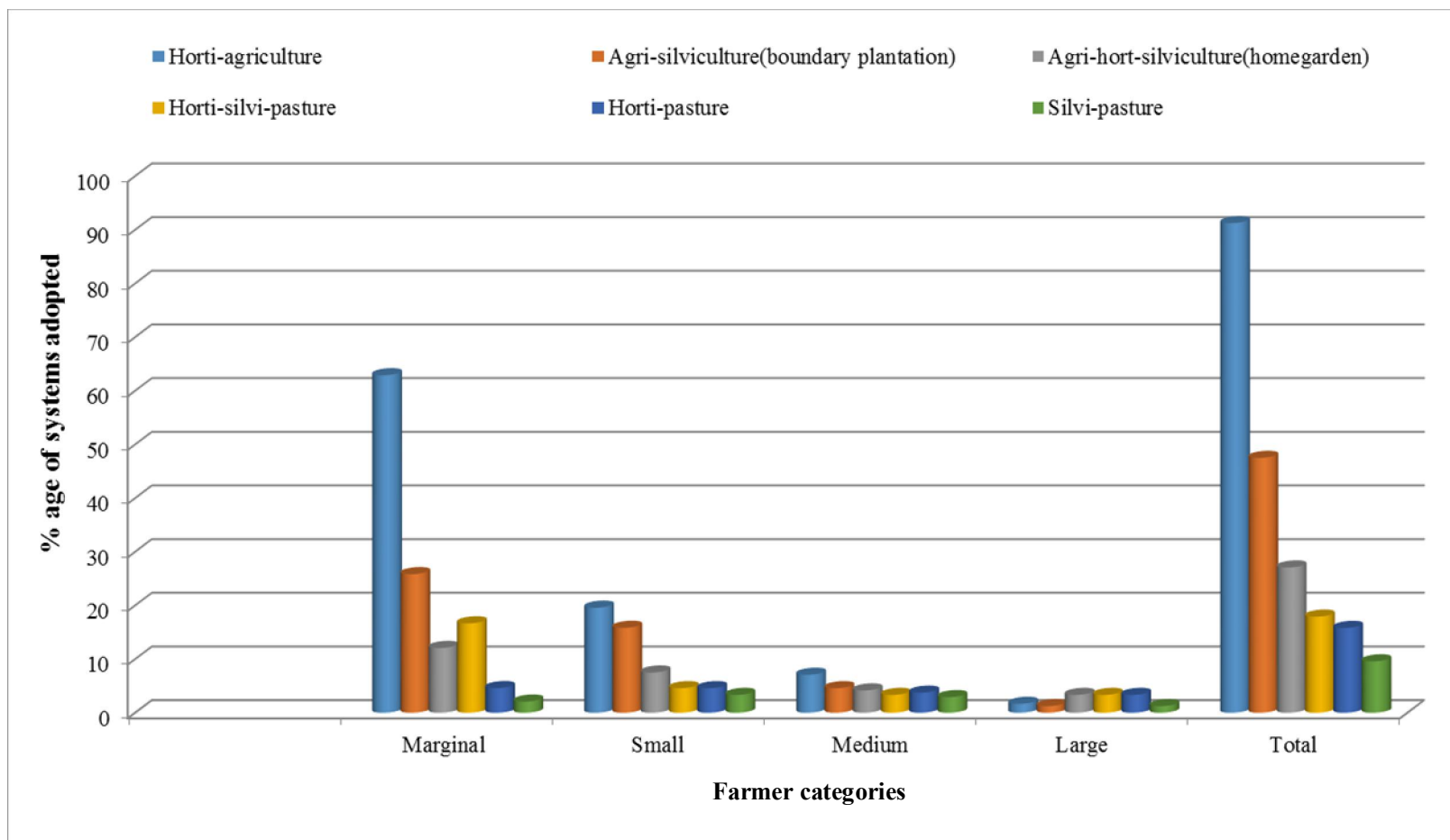


Fig. 2: Adoption of various agroforestry systems by surveyed farmers (percentage)

4.1.3 Plant diversity in prevalent agroforestry systems of district Anantnag

Plant diversity of six prevalent agroforestry systems is presented in Table 3 and reveals the presence of trees, shrubs and herbage layer (both cultivated and wild). Among broad leaved and fruit tree species, a total of 4 genera, 6 species of 3 families and 4 genera, 5 species of 2 families were found, respectively, while 1 genera having 2 species belonging to 1 family were of shrub layer. Herbage represented 33 genera belonging to 38 plant species and 21 families in the study area.

4.1.4 Prominent agroforestry systems

Prominent agroforestry systems selected for evaluation of biomass production, carbon sequestration and nutrient status in the study were horti-agriculture, agri-silviculture (boundary plantation), agri-horti-silviculture (homegarden) and horti-silvi-pasture system (Table 4). The horti-agricultural system was the most prominent system adopted by 91.25 percent of farmers of the district Anantnag, where the horticulture component was *Malus domestica* Borkh and *Juglans regia* L. with intercrop as *Brassica oleracea* var. *acephala*, *Avena sativa* L. and *Raphanus sativus* L. in rabi season and kharif crops grown as intercrops were *Capsicum annum* L., *Brassica oleracea* var. *acephala*, *Vicia feba* L. and *Zea mays* L. Agri-silviculture (boundary plantation) was adopted by 47.5 percent of farmers, where *Populus nigra* Bartr., *Populus deltoides* Bartr. *Salix fragilis* L. and *Salix alba* L. were planted on boundaries and crop components in rabi season included *Avena sativa* L., *Brassica campestris* L., while *Oryza sativa* L. during the kharif season. Agri-horti-silviculture (homegarden) was adopted by 27.08 percent of farmers, where the forest tree species included *Populus nigra* Bartr., *Populus deltoides* Bartr. *Salix fragilis* L. and *Salix alba* L. on the boundaries and fruit trees include *Malus domestica* Borkh. The rabi crop components were *Brassica oleracea* var. *acephala* *Pisum sativum* L., *Brassica rapa* L. and *Allium cepa* L., whereas, *Capsicum annum* L., *Brassica oleracea* var. *acephala*, *Vicia feba* L. in kharif season. The horti-silvi-pasture system was adopted by 17.91

percent of farmers, most of forest tree component included *Populus nigra* Bartr and *Salix alba* L.. The fruit tree mainly included *Malus domestica* Borkh, whereas prominent natural grasses were *Avena sativa*, *Amaranthus*, *Capsella bursa pastoris*, *Cynodon dactylon*, *Medicago polymorpha*, *Oenothera rosea*, *Plantago lanceolata*, *Sonchus oleraceus*, *Stellaria media*, *Trifolium repens*, *Trifolium pretense* and *Taraxacum officinale*,

Table 3: Diversity (Trees, Shrubs and Herbage) recorded in prevalent agroforestry systems in the study area

Table 3: Diversity (Trees, Shrubs and Herbage) recorded in prevalent agroforestry systems in the study area									
S. No.	Plant Names and Family	English/Common Name	Life form	Agroforestry Systems					
				Horti-agricultural System	Boundary Plantation	Homegarden	Horti-silvi-pasture system	Horti-pasture	Silvi-pasture
I) Trees (broad- leaved trees, fruit trees)									
Broad-leaved trees									
1	<i>Populus deltoides</i> Bartr. (Salicaceae)	Eastern cottonwood/Fras	T	-	+	+	+	-	-
2	<i>Populus nigra</i> Bartr. (Salicaceae)	Black poplar/Kashur Fras	T	-	+	-	+	-	+
3	<i>Robinia pseudoacacia</i> L. (Leguminoceae)	Black locust/Kikar	T	-	-	-	+	-	+
4	<i>Salix alba</i> L. (Salicaceae)	White willow/Boti veer	T	-	+	+	+	-	+
5	<i>Salix fragils</i> L. (Salicaceae)	Crack willow/Veer	T	-	+	+	-	-	-
6	<i>Ulmus wallichiana</i> L. (Ulmaceae)	Elm/Bren	T	+	-	-	+	-	+
Fruit trees									
1	<i>Juglans regia</i> L. (Juglandaceae) Walnut/Doon	Walnut/Doon	T	+	-	+	-	+	-
2	<i>Malus domestica</i> Borkh. (Rosaceae)	Apple/Tchoonth	T	+	-	+	+	+	-
3	<i>Prunus domestica</i> L. (Rosaceae)	Plum/Aaer	T	-	-	-	+	+	-
4	<i>Prunus persica</i> L. (Rosaceae)	Peach/Czenun	T	+	-	+	+	+	-
5	<i>Pyrus communis</i> L. (Rosaceae)	Pear/Tang	T	+	-	-	+	+	-
II) Shrubs									
1	<i>Rubus niveus</i> Thunb. (Rosaceae)	Mysore raspberry/Snowpeaks raspberry/Chanch	S	+	-	-	+	+	-
2	<i>Rubus ulmifolius</i> Schott. (Rosaceae)	Elm-leaf blackberry/Chanch	S	+	-	-	+	+	-

Contd...

Table 3: contd....

S. No.	Plant Names and Family	English/Common Name	Life form	Agroforestry Systems					
				Horti-agricultural System	Boundary Plantation	Homegarden	Horti-silvi-pasture system	Horti-pasture	Silvi-pasture
III) Herbage (wild herbage, cultivated herbage)									
Wild herbage									
1	<i>Amaranthus caudatus</i> L. (Amaranthaceae)	Tassel flower/Lissi	H	-	-	+	+	+	-
2	<i>Avena fatua</i> L. (Poaceae)	Wild oat/Jiagassi	H	+	-	-	+	+	+
3	<i>Capsellabursa-pastoris</i> L. (Brassicaceae)	Shepherd’s purse/Kralmond	H	+	-	+	+	+	-
4	<i>Conyza Canadensis</i> L. Cronquist (Asteraceae)	Canadian horseweed/Gur Loute	H	+	+	+	+	+	-
5	<i>Cynodon dactylon</i> L. (Poaceae)	Durva grass/Dramun	H	+	+	+	+	+	+
6	<i>Euphorbia helioscopia</i> L. (Euphorbiaceae)	Mad woman’s milk/Gurduode	H	-	-	+	+	+	-
7	<i>Galium aparine</i> L. (Rubiaceae)	Goose grass/Zoa ghasi	H	+	-	+	+	+	+
8	<i>Hypericum perforatum</i> L. (Hypersiaceae)	St Jhon’s wort/Amber	H	+	-	-	+	+	-
9	<i>Medicago polymorpha</i> L.(Benth.) (Fabaceae)	Toothed bur clover/Poshi- gassi	H	+	-	-	+	+	+
10	<i>Mentha arvensis</i> L. (Lamiaceae)	Mint/Pudhni	H	-	-	+	+	+	-
11	<i>Oenothera rosea</i> L ‘ Her. ex Aiton (Onagraceae)	Evening primrose	H	+	-	-	+	+	+
12	<i>Plantago lanceolata</i> L.(Plantagionaceae)	Ribwort Plantain/Narrowleaf plantain/Lakut – gulli	H	+	+	-	+	+	+
13	<i>Plantago major</i> L. (Plantaginaceae)	Broadleaf plantain/Greater plantain/Veuth – gulli	H	-	+	+	+	+	+

Contd...

Table 3: contd....

S. No.	Plant Names and Family	English/Common Name	Life form	Agroforestry Systems					
				Horti-agricultural System	Boundary Plantation	Homegarden	Horti-silvi-pasture system	Horti-pasture	Silvi-pasture
14	<i>Poa pratense</i> L. (Poaceae)	Smooth meadow grass/Gassi	H	+	-	-	+	+	+
13	<i>Prunella vulgaris</i> L. (Lamiaceae)	Self - heal/Kalevueth	H	-	+	-	+	+	-
14	<i>Stellaria media</i> L.(Vill.) (Caryophyllaceae)	Chickweed/Losdhi	H	+	-	+	+	+	+
15	<i>Sonchus oleraceus</i> L. (Asteraceae)	Sow thistle	H	+	-	-	+	+	+
16	<i>Taraxacum officinale</i> Weber. (Compositae)	Dandelion/Madan hand	H	+	-	+	+	+	+
17	<i>Trifolium pratense</i> L. (Fabaceae)	Red clover/Batakh-nuer	H	+	+	+	+	+	+
18	<i>Trifolium repens</i> L. (Fabaceae)	White clover/Batakh-nuer	H	+	+	+	+	+	+
19	<i>Veronica persica</i> Poiret. (Plantaginaceae)	Bird's-eye/Common field-speedwell	H	+	-	+	+	+	+
Vegetables(cultivated herbage)									
1	<i>Allium sativum</i> L. (Alliaceae)	Garlic/Rohan	H	-	-	+	-	-	-
2	<i>Brassica campestris</i> L. (Brassicaceae)	Mustard/Tiligogul	H	-	+	-	-	-	-
3	<i>Brassica oleracea</i> var. <i>gongylodes</i> L. (Brassicaceae)	Knol-Khol/Munde	H	+	-	+	-	-	-
4	<i>Brassica oleracea</i> var. <i>acephala</i> L. (Brassicaceae)	Kale/Hakh	H	+	-	+	-	-	-
5	<i>Brassica rapa</i> L. (Brassicaceae)	Turnip/Gogij	H	+	-	+	-	-	-
6	<i>Capsicum annum</i> L. (Solanaceae)	Chilli/Marchwagan	H	+	-	+	-	-	-

Contd...

Table 3: contd....

S. No.	Plant Names and Family	English/Common Name	Life form	Agroforestry Systems					
				Horti-agricultural System	Boundary Plantation	Homegarden	Horti-silvi-pasture system	Horti-pasture	Silvi-pasture
7	<i>Solanum lycopersicon</i> L. (Solanaceae)	Tomato/Tamatar	H	+	-	+	-	-	-
8	<i>Solanum melongena</i> L. (Solanaceae)	Brinjal/Wagun	H	-	-	+	-	-	-
9	<i>Cucumis sativus</i> L. (Cucurbitaceae)	Cucumber/Laer	H	-	-	+	-	-	-
10	<i>Vicia faba</i> L. (Fabaceae)	Beans/Razma	H	+	-	+	-	-	-
11	<i>Daucus carota subsp. sativus</i> Hoffm. (Apiaceae)	Carrot/Gazir	H	-	-	+	-	-	-
12	<i>Lagenaria vulgaris</i> Standl. (Molina) (Cucurbitaceae)	Bottle gourd/Aaliae	H	-	-	+	-	-	-
13	<i>Solanum tuberosum</i> L. (Solanaceae)	Potato/Aaelvi	H	-	-	+	-	-	-
14	<i>Spinacia oleracea</i> L. (Chenopodiaceae)	Spinach/Palak	H	-	-	+	-	-	-
15	<i>Raphanus sativus</i> L. (Brassicaceae)	Radish/Muje	H	+	-	+	-	-	-
	Cereals								
17	<i>Avena sativa</i> L. (Poaceae)	Oats/Khaseeli	H	-	+	-	-	-	-
18	<i>Oryza sativa</i> L. (Poaceae)	Paddy/Daani	H	-	+	-	-	-	-
19	<i>Zea mays</i> L. (Poaceae)	Maize/Makai	H	+	-	+	-	-	-

+ = present, - = absent, T = tree, S = shrub, H = herb

Table 4: Prominent Agroforestry systems in district Anantnag

S. No.	System	Extent of adaptation No. of farmers	Forest Tree	Fruit tree	Crop components	
					Rabi	Kharif
01	Horti-agriculture	219 (91.25%)	-	<i>Malus domestica</i> Borkh, <i>Juglans regia</i> L.	<i>Brassica oleracea</i> var. <i>acephala</i> , <i>Avena sativa</i> L., <i>Raphanus sativus</i> L.	<i>Capsicum annum</i> L., <i>Brassica oleracea</i> var. <i>acephala</i> , <i>Vicia feba</i> L., <i>Zea mays</i> L.
02	Agri-silviculture (boundary plantation)	114 (47.5%)	<i>Populus nigra</i> Bartr., <i>Populus deltoides</i> Bartr. <i>Salix fragilis</i> L., <i>Salix alba</i> L.	-	<i>Avena sativa</i> L / <i>Brassica campestris</i> L.	<i>Oryza sativa</i> L.
03	Agri-horti- silviculture (homegarden)	65 (27.08%)	<i>Populus nigra</i> Bartr., <i>Populus deltoides</i> Bartr. <i>Salix fragilis</i> L., <i>Salix alba</i> L.	<i>Malus domestica</i> Borkh	<i>Brassica oleracea</i> var. <i>acephala</i> <i>Pisum sativum</i> L., <i>Brassica rapa</i> L., <i>Allium cepa</i> L.	<i>Capsicum annum</i> L., <i>Brassica oleracea</i> var. <i>acephala</i> , <i>Vicia feba</i> L.
04	Horti-silvi- pasture	43 (17.91%)	<i>Populus nigra</i> Bartr, <i>Salix alba</i> L.	<i>Malus domestica</i> Borkh	<i>Avena Sativa</i> , <i>Amaranthus</i> , <i>Poa pretense</i> , <i>Poa annua</i> <i>Trifolium repens</i> , <i>Trifolium pretense</i> , <i>Oxalis corniculata</i> , <i>Taraxacum officinale</i> , <i>Plantago lanceolata</i> , <i>Clinopodium umbrosum</i> ,	

4.2 Biomass production of prominent agroforestry systems of Anantnag district

4.2.1 Inventory of Horti-agricultural system across study area

Four tree-crop combinations were identified in horti-agriculture system viz., C₁ (Apple+radish-kale), C₂ (Apple+kale-chilli), C₃ (Apple+kale-beans) and C₄ (Walnut+oats-maize). In combination C₁, the average height of apple trees was 4.98 m, collar diameter was 54.5 cm and the total number of 555 trees ha⁻¹. In combination C₂ (Apple+Kale-chilli), the average height of apple trees was 4.73 m, collar diameter 42.33 cm and the total number of 555 trees ha⁻¹. In combination C₃ (Apple+kale-beans), the average height of apple trees was 4.92 m, collar diameter 45.5 cm with total number of 555 trees ha⁻¹. In combination C₄ (Walnut+oats-maize), the average height of walnut trees was 6.85 m, collar diameter 50.5 cm with total number of 80 trees ha⁻¹ (Table 5).

Table 5: Inventory of Horti-agriculture system across study area

Tree crop Combinations	Tree and crop components	Fruit trees		
		Avg. ht. of trees (m) (Mean±S.E)	Collar dia. (cm) (Mean±S.E)	Total no. of trees ha ⁻¹
C ₁	Apple+radish-kale	4.98±0.46	54.5±2.88	555
C ₂	Apple+kale-chilli	4.73±0.411	42.33±2.27	555
C ₃	Apple+kale-beans	4.925±0.412	45.5±3.16	555
C ₄	Walnut+oats-maize	6.85± 0.173	50.5± 3.0	80

4.2.2 Biomass production (t ha^{-1}) under Horti-agriculture system

The data pertaining to biomass production in horti-agriculture system (Table 6) clearly show that maximum fruit tree stem biomass was recorded (15.92 t ha^{-1}) in combination C_1 (Apple+radish-kale) followed by (15.41 t ha^{-1}) biomass in combination C_3 (Apple+kale-beans). Minimum stem biomass (2.33 t ha^{-1}) was recorded in combination C_4 (Walnut+oats-maize). Maximum canopy biomass was recorded as 8.22 t ha^{-1} in combination C_3 followed by 5.40 t ha^{-1} in C_2 (Apple+kale-chilli) and minimum 3.43 t ha^{-1} in C_4 . Maximum above and below ground biomass was recorded as 23.64 t ha^{-1} and 7.80 t ha^{-1} respectively in combination C_3 , whereas, minimum AGB and BGB was recorded as 5.76 t ha^{-1} and 1.90 t ha^{-1} respectively in combination C_4 . The maximum total fruit tree biomass was recorded as 31.44 t ha^{-1} in combination C_3 followed by 28.36 t ha^{-1} in combination C_1 and minimum 7.67 t ha^{-1} in combination C_4 .

The maximum rabi crop biomass was (5.58 t ha^{-1}) recorded in combination C_2 (Apple+kale-chilli) followed by 5.15 t ha^{-1} in combination C_1 , whereas minimum crop biomass 4.99 t ha^{-1} was recorded in combination C_4 (Walnut+oats-maize). During kharif, maximum crop biomass 13.5 t ha^{-1} was recorded in combination C_4 followed by 5.76 t ha^{-1} in combination C_1 , whereas minimum kharif crop biomass 4.95 t ha^{-1} was recorded in combination C_2 (Apple+kale-chilli).

The total maximum biomass production under horti-agriculture system was recorded 41.63 t ha^{-1} in C_3 (Apple+kale-beans) followed by 39.27 t ha^{-1} in C_1 (Apple+radish-kale), while minimum total biomass 26.16 t ha^{-1} was recorded in combination C_4 (Walnut+oats-maize).

Table 6: Average biomass production (t ha⁻¹) under Horti-agriculture system (Pooled data for year 2018-2019)

Tree crop combinations	Fruit trees					Crops		Total biomass
	Stem	Canopy	Aboveground	Belowground	Total	Rabi	Kharif	
C ₁	15.92±0.28	5.39±0.35	21.32±0.63	7.03±0.21	28.36±0.85	5.15±0.07	5.76±0.10	39.27±1.03
C ₂	15.14±0.4	5.40±0.27	20.55±0.68	6.78±0.23	27.34±0.91	5.58±0.14	4.95±0.21	37.87±1.27
C ₃	15.41±0.31	8.22±0.23	23.64±0.54	7.80±0.17	31.44±0.73	5.11±0.24	5.08±0.04	41.63±1.01
C ₄	2.33±0.16	3.43±0.12	5.76±0.28	1.90±0.09	7.67±0.37	4.99±0.3	13.5±0.28	26.16±0.96
Mean	12.2	5.6	17.8	5.87	23.7	5.20	7.32	36.22

Aboveground = stem + canopy; Total = aboveground + belowground

C₁ = Apple+radish-kale

C₂ = Apple+kale-chilli

C₃ = Apple+kale-beans

C₄ = Walnut+oats-maize

4.2.3 Inventory of Agri-silviculture system (boundary plantation)

The data pertaining to agri-silviculture system (boundary plantation) is presented in table 7 which reveals two tree-crop combinations viz., C₁ (Poplar+Salix+oats-paddy) and C₂ (Poplar+mustard-paddy). In C₁, the average height of poplar trees was 17.6 m, dbh 55.25 cm and the total number of trees ha⁻¹ was 108 and in Salix, the average height was 7.5 m, dbh 50.11 cm with 30 trees ha⁻¹. In combination C₂ (Poplar+mustard-paddy), the average height of poplar trees was 17.92 m, dbh 55.27 cm and with 160 trees ha⁻¹.

Table 7: Inventory of Agri-silviculture (boundary plantation) system across study area

Tree crop combinations	Tree and crop components	Forest trees				
		Avg. ht. (m) (Mean±S.E)		dbh (cm) (Mean±S.E)		No. of trees ha ⁻¹
C ₁	Poplar+salix +oats-paddy	17.66 ±1.08	7.5 ±0.74	55.25 ±1.24 (Poplar)	50.11 ±1.50 (Salix)	108 +30 (Poplar +Salix)
C ₂	Poplar+musta rd-paddy	17.92 ± 1.33		55.27± 0.79		160

4.2.4 Biomass production (t ha⁻¹) under Agri-silviculture system (boundary plantation)

The data pertaining to biomass production in agri-silviculture system (boundary plantation) (Table 8) clearly shows that maximum forest tree stem biomass was 15.09 t ha⁻¹ in C₂ (Poplar+mustard-paddy) followed by 12.12 t ha⁻¹ in combination C₁ (Poplar+Salix+oats-paddy). Maximum branch biomass was recorded as 2.00 t ha⁻¹ in C₂ followed by 1.19 t ha⁻¹ in combination C₁. The maximum leaf biomass was recorded as 0.28 t ha⁻¹ in combination C₂ followed by

0.20 t ha⁻¹ in combination C₁. Maximum above and below ground biomass was recorded as 17.38 t ha⁻¹ and 4.34t ha⁻¹ respectively in combination C₂. The maximum total fruit tree biomass was recorded as 21.72 t ha⁻¹ in combination C₂ followed by 16.91 t ha⁻¹ in combination C₁.

The maximum rabi crop biomass was recorded 5.99 t ha⁻¹ in combination C₂ (Poplar+mustard-paddy) followed by 5.34 t ha⁻¹ in combination C₁ (Poplar+salix+oats-paddy). During kharif, maximum crop biomass 10.01 t ha⁻¹ was recorded in combination C₁ followed by 9.89 t ha⁻¹ in combination C₂. The total maximum biomass production under agri- silviculture (boundary plantation) was recorded 37.51 t ha⁻¹ in C₂ followed by 32.26 t ha⁻¹ in C₁.

4.2.5 Inventory of Agri-horti-silviculture system (homegarden)

Three tree-crop combinations were identified in agri-horti-silviculture system (homegarden) viz., C₁ (Poplar+Apple+kale-beans), C₂ (Poplar+Apple+kale-chilli), C₃ (Poplar+Apple+turnip-kale). In C₁ (Poplar+Apple+kale-beans), the average height of poplar trees was 22.9 m, dbh 54.56 cm with total number of 180 trees ha⁻¹ while as the average height of apple trees was 4.0 m, collar diameter 32.5 cm and the total number of trees ha⁻¹ was 156. In combination C₂ (Poplar+apple+kale-chilli), the average height of poplar trees was 18.7 m, dbh 59.22 cm with total number of 200 trees ha⁻¹. The average height of apple trees was 4.41 m, collar diameter 40.08 cm and the total number of 180 trees ha⁻¹. In combination C₃ (Poplar+apple+turnip-kale), the average height of poplar trees was 20.4 m, dbh 53.1 cm with total number of 240 trees ha⁻¹. The average height of apple trees was 4.38 m, collar diameter 37.63 cm with total number of 204 trees ha⁻¹ (Table 9).

Table 8: Average biomass production (t ha⁻¹) under Agri-silviculture (boundary plantation) system (Pooled data for year 2018-2019)

Tree crop combination	Forest trees						Crops		Total biomass
	Stem	Branch	Leaf	Above ground	Below ground	Total	Rabi	Kharif	
C ₁	12.12±0.3 2	1.19±0.10	0.20±0.01	13.52±0.4 4	3.382± 0.11	16.9 ±0.56	5.34±0.17	10.01±0.0 9	32.26±0.8 3
C ₂	15.09±0.2 0	2.00±0.14	0.28±0.03	17.38 ±0.39	4.34 ±0.09	21.72 ±0.48	5.99±0.15	9.80±0.41	37.51±1.0 5
Mean	13.6	1.6	0.22	15.44	3.84	19.3	5.64	9.9	34.87

Aboveground = stem + canopy; Total = aboveground + belowground

C₁ = Poplar+Salix+oats-paddy

C₂ = Poplar+Mustard-paddy

Table 9: Inventory of Agri-horti-silviculture (homegardens) system across study area

Tree crop combination	Forest trees				Fruit trees			Total no. of trees ha ⁻¹
	Tree and crop components	Avg. ht. (m) (Mean±S.E)	Dbh (cm) (Mean±S.E)	No. of trees ha ⁻¹	Avg. ht (m) (Mean±S.E)	Collar dia (cm) (Mean±S.E)	No. of trees ha ⁻¹	
C ₁	Poplar+apple+kale-beans	22.9±1.09	54.5±1.32	180	4.0± 0.346	32.5±2.82	156	336
C ₂	Poplar+apple+kale-chilli	18.7±1.61	59.22±0.99	200	4.41±0.29	40.08±2.81	180	380
C ₃	Poplar+apple+turnip-kale	20.4±0.98	53.1±0.932	240	4.38±0.27	37.63±3.53	204	444

4.2.6 Biomass production (t ha⁻¹) under Agri-horti-silviculture system (homegarden)

Data pertaining to biomass in agri-horti-silviculture system (homegarden) has been given in Table 10 which clearly showed that maximum stem biomass of forest trees was recorded as 23.78 t ha⁻¹ in combination C₃ (Poplar+apple+turnip-kale) followed by 23.44 t ha⁻¹ biomass in C₁ (Poplar+apple+kale-beans). Minimum stem biomass was recorded as 22.60 t ha⁻¹ in combination C₂ (Poplar+apple+kale-chilli). Maximum branch biomass of forest trees was recorded as 1.40 t ha⁻¹ followed by 1.20 t ha⁻¹ and 1.07 t ha⁻¹ (minimum) in C₁, C₃ and C₂ respectively. The maximum leaf biomass was recorded as 0.40 t ha⁻¹ in combination C₃ followed by 0.35 t ha⁻¹ in combination C₁ and its minimum was recorded as 0.31 t ha⁻¹ in combination C₂. The combination C₃ recorded maximum above and below ground biomass as 25.38 t ha⁻¹ and 6.34 t ha⁻¹ respectively, followed by 25.20 t ha⁻¹ and 6.30 t ha⁻¹ in combination C₁ respectively, whereas minimum was reported as 23.98 t ha⁻¹ and 5.99 t ha⁻¹ in C₂. The maximum total forest tree biomass was recorded as 31.72 t ha⁻¹ in combination C₃ followed by 31.50 t ha⁻¹ in combination C₁, whereas minimum biomass was recorded as 29.97 t ha⁻¹ in combination C₂.

In fruit tree biomass, maximum stem biomass was recorded 5.40 t ha⁻¹ in combination C₃ (Poplar+apple+turnip-kale) followed by 4.83 t ha⁻¹ biomass in combination C₂ (Poplar+apple+kale-chilli). Minimum stem biomass was recorded as 3.97 t ha⁻¹ in combination C₁ (Poplar+apple+kale-beans). Maximum canopy biomass was recorded as 1.54 t ha⁻¹ in combination C₃ followed by 1.31 t ha⁻¹ in C₂ (Poplar+apple+kale-chilli) and minimum 0.83 t ha⁻¹ in C₁. Maximum above and belowground biomass was recorded as 6.94 t ha⁻¹ and 2.29 t ha⁻¹ in combination C₃, whereas minimum AGB and BGB was recorded 4.80 t ha⁻¹ and 1.58 t ha⁻¹ respectively in combination C₁. The maximum total fruit tree biomass was recorded as 9.24 t ha⁻¹ in combination C₃ followed by 8.17 t ha⁻¹ in combination C₂ and minimum 6.39 t ha⁻¹ in combination C₁.

Table 10: Average biomass production (t ha⁻¹) under Agri-horti-silviculture (homegardens) system (Pooled data for year 2018-2019)

Tree crop combn.	Forest trees						Fruit trees					Crops		Total biomass
	Stem	Branch	Leaf	Above ground	Below ground	Total	Stem	Canopy	Above ground	Below ground	Total	Rabi	Kharif	
C ₁	23.44 ±0.2	1.40 ±0.08	0.35 ±0.006	25.20 ±0.3	6.30 ±0.07	31.50 ±0.37	3.97 ±0.18	0.83 ±0.06	4.80 ±0.25	1.58 ±0.08	6.39 ±0.34	5.18 ±0.01	5.13 ±0.05	48.2 ±0.87
C ₂	22.60 ±0.5	1.07 ±0.034	0.31 ±0.03	23.98 ±0.54	5.99 ±0.13	29.97 ±0.67	4.83 ±0.25	1.31 ±0.08	6.14 ±0.33	2.02 ±0.1	8.17 ±0.45	5.51 ±0.17	5.62 ±0.25	49.27 ±1.54
C ₃	23.78 ±0.4	1.20 ±0.1	0.40 ±0.01	25.38 ±0.55	6.34 ±0.14	31.72 ±0.7	5.40 ±0.08	1.54 ±0.08	6.94 ±0.16	2.29 ±0.05	9.24 ±0.22	5.99 ±0.17	6.14 ±0.06	53.09 ±1.14
Mean	23.27	1.22	0.36	24.85	6.21	31.04	4.71	1.2	5.95	1.95	7.91	5.53	5.62	50.18

Aboveground (forest trees) =stem+branch+leaf; Aboveground (fruit trees) =stem+canopy; Total=aboveground+belowground

C₁ = Poplar+apple+kale-beans

C₂ = Poplar+apple+kale-chilli

C₃ = Poplar+apple+turnip-kale

The maximum rabi crop biomass was recorded 5.99 t ha⁻¹ in combination C₃ (Poplar+apple+turnip-kale) followed by 5.51 t ha⁻¹ in combination C₂ (Poplar+apple+kale-chilli), whereas minimum crop biomass 5.18 t ha⁻¹ was recorded in combination C₁ (Poplar+apple+kale-beans). During kharif, maximum crop biomass 6.14 t ha⁻¹ was recorded in combination C₃ followed by 5.62 t ha⁻¹ in combination C₂, whereas minimum kharif crop biomass 5.13 t ha⁻¹ was recorded in combination C₁.

The total maximum biomass production under agri-horti-silviculture was recorded as 53.09 t ha⁻¹ in combination C₃ ((Poplar+apple+turnip-kale) followed by 49.27 t ha⁻¹ in combination C₂ (Poplar+apple+kale-chilli), while total minimum biomass production 48.2 t ha⁻¹ was recorded in combination C₁ (Poplar+apple+kale-beans).

4.2.7 Inventory of Horti-silvi-pasture system across study area

In horti-silvi-pasture system, two tree-crop combinations were identified viz., C₁ (Apple+poplar+grasses), C₂ (Apple+poplar+salix+grasses). In C₁ (Apple+poplar+grasses), the average height of apple trees was 4.71 m, collar diameter 39.07 cm and the total number of trees ha⁻¹ was 625 (Table 11), while in forest trees, the average height of trees was 25.36 m, collar diameter 58.5 cm with total number of 128 trees ha⁻¹. In combination C₂ (Apple+poplar+salix+grasses), the average height of apple trees was 4.11 m, collar diameter 31.56 cm and the total number of 625 trees ha⁻¹, while in forest trees, the average height of poplar trees was 19.6 m, collar diameter 62.77 cm with total number of 111 trees ha⁻¹. In salix, the average height was 8.92 m, collar diameter 56.5 cm with 20 trees ha⁻¹.

Table 11: Inventory of Horti-silvi-pasture system across study area

Tree crop combn.	Tree and crop components	Fruit trees			Forest trees						Total no. of trees ha ⁻¹
		Avg. ht. (m) (Mean±S.E)	Collar dia (cm) (Mean±S.E)	No. of trees ha ⁻¹	Avg. ht. (m) (Mean±S.E)		dbh (cm) (Mean±S.E)		No. of trees ha ⁻¹		
C ₁	Apple+poplar +grasses	4.71± 0.34	39.07± 3.5	625	25.36± 1.76		58.5± 4.86		128		753
C ₂	Apple+poplar +salix+ grasses	4.11± 0.22	31.56 ± 3.04	625	19.6 ±3.11	8.92 ±1.04	62.77 ±3.3	56.5 ±1.84	111 Poplar	20 Salix	756

4.2.8 Biomass production (t ha^{-1}) under Horti-silvi-pasture system

The data pertaining to biomass production in horti-silvi-pasture system (Table 12) clearly showed maximum stem biomass of fruit trees was recorded 16.67 t ha^{-1} in combination C_1 (Apple+poplar+grasses) followed by 16.63 t ha^{-1} biomass in combination C_2 (Apple+poplar+salix+grasses). Maximum canopy biomass was recorded as 6.78 t ha^{-1} in combination C_1 followed by 5.83 t ha^{-1} in C_2 . Maximum above and below ground biomass was recorded as 23.45 t ha^{-1} and 7.74 t ha^{-1} respectively in combination C_1 , followed by 22.47 t ha^{-1} and 7.41 t ha^{-1} respectively in C_2 . The maximum total fruit tree biomass was recorded as 31.19 t ha^{-1} in combination C_1 followed by 29.89 t ha^{-1} in combination C_2 .

In forest tree biomass, the maximum stem biomass 22.74 t ha^{-1} was recorded in combination C_1 (Apple+poplar+grasses) followed by 14.21 t ha^{-1} biomass in C_2 (Apple+poplar+salix+grasses). Maximum branch biomass was recorded as 1.65 t ha^{-1} in combination C_1 followed by 0.97 t ha^{-1} in C_2 . The maximum leaf biomass was recorded as 0.44 t ha^{-1} in combination C_1 followed by 0.26 t ha^{-1} in combination C_2 . Maximum above and below ground biomass was recorded as 24.84 t ha^{-1} and 6.21 t ha^{-1} in combination C_1 followed by 15.46 t ha^{-1} and 3.86 t ha^{-1} in combination C_2 . The maximum total forest tree biomass was recorded as 31.06 t ha^{-1} in combination C_1 followed by 19.32 t ha^{-1} in combination C_2 .

The different perennial grasses present in orchards are usually harvested in two cuts i.e June and September. The maximum biomass of perennial grasses during June cut was recorded 7.51 t ha^{-1} in combination C_1 (Apple+poplar+grasses) followed by 6.89 t ha^{-1} in C_2 (Apple+poplar+salix+grasses). The maximum biomass of perennial grasses during September cut was recorded as 4.11 t ha^{-1} in combination C_1 followed by 3.2 t ha^{-1} in C_2 . The total maximum biomass of combination C_1 was recorded as 73.86 t ha^{-1} followed by 59.3 t ha^{-1} in combination C_2 .

Table 12: Average biomass production (t ha⁻¹) under horti-silvi-pasture system (Pooled data for year 2018-2019)

Tree crop combn.	Fruit trees					Forest trees						*Crops		Total biomass
	Stem	Canopy	Above ground	Below ground	Total	Stem	Branch	Leaf	Above ground	Below ground	Total	**1 st cut	***2 nd cut	
C ₁	16.67 ±0.29	6.78 ±0.3	23.45 ±0.59	7.74 ±0.19	31.19 ±0.8	22.74 ±0.51	1.65 ±0.19	0.44 ±0.01	24.84 ±0.73	6.21 ±0.18	31.06 ±0.91	7.51 ±0.23	4.11 ±0.06	73.86 ±1.99
C ₂	16.63 ±0.4	5.83 ±0.13	22.47 ±0.54	7.41 ±0.17	29.89 ±0.71	14.21 ±0.31	0.97 ±0.13	0.26 ±0.02	15.46 ±0.46	3.86 ±0.11	19.32 ±0.58	6.89 ±0.32	3.2 ±0.1	59.29 ±1.73
Mean	16.64	6.29	22.96	7.56	30.54	18.47	1.31	0.35	20.15	5.02	25.19	7.18	3.64	66.55

Aboveground(forest trees)=stem+branch+leaf; Aboveground(fruit trees)=stem+canopy; Total=aboveground+belowground

C₁ = Apple+poplar+grasses

C₂ = Apple+poplar+salix+grasses

*Crop biomass of perennial grasses

**1st cut- June

***2nd cut- September

4.2.9 Carbon stock (t ha^{-1}) under Horti-agriculture system

The data pertaining to carbon stock (t ha^{-1}) under horti-agriculture system (Table 13) clearly showed maximum fruit tree stem carbon stock was recorded 7.16 t ha^{-1} in combination C_1 (Apple+radish-kale) followed by combination C_3 (Apple+kale-beans) in which carbon stock was recorded as 6.93 t ha^{-1} . Minimum stem carbon stock was recorded as 1.04 t ha^{-1} in combination C_4 (Walnut+ oats-maize). Maximum canopy carbon stock was recorded as 3.70 t ha^{-1} in combination C_3 followed by 2.43 t ha^{-1} in C_2 and minimum 1.55 t ha^{-1} in C_4 . Maximum above and below ground carbon stock was recorded as 10.63 t ha^{-1} and 3.51 t ha^{-1} respectively in combination C_3 , whereas minimum above and below ground carbon stock was recorded as 2.59 t ha^{-1} and 0.85 t ha^{-1} respectively in combination C_4 . The maximum total fruit tree carbon stock was recorded as 14.15 t ha^{-1} in combination C_3 followed by 12.76 t ha^{-1} in combination C_1 and minimum 3.45 t ha^{-1} in combination C_4 .

The maximum rabi crop carbon stock was recorded 2.51 t ha^{-1} in combination C_2 (Apple+kale-chilli) followed by 2.31 t ha^{-1} in combination C_1 (Apple+radish-kale), whereas minimum crop carbon stock 2.24 t ha^{-1} was recorded in combination C_4 (Walnut+ oats-maize). During kharif, maximum crop carbon stock 6.07 t ha^{-1} was recorded in combination C_4 followed by 2.59 t ha^{-1} in combination C_1 , whereas minimum kharif crop carbon stock 2.23 t ha^{-1} was recorded in combination C_2 .

The total maximum carbon stock under horti-agriculture system was recorded 18.74 t ha^{-1} in C_3 (Apple+beans+kale+chilli) followed by 17.67 t ha^{-1} in C_1 (Apple+radish-kale), while minimum total carbon stock 11.77 t ha^{-1} was recorded in combination C_4 (Walnut+oats-maize).

Table 13: Average carbon stock (t ha⁻¹) under Horti-agriculture system (Pooled data for year 2018-2019)

Tree crop combinations	Fruit trees					Crops		Total carbon stock
	Stem	Canopy	Aboveground	Belowground	Total	Rabi	Kharif	
C₁	7.16±0.126	2.42±0.15	9.59±0.28	3.16±0.09	12.76±0.38	2.31±0.03	2.59±0.05	17.67±0.46
C₂	6.81±0.18	2.43±0.12	9.25±0.30	3.05±0.10	12.30±0.41	2.51±0.06	2.23±0.09	17.04±0.57
C₃	6.93±0.14	3.70±0.10	10.63±0.24	3.51±0.07	14.15±0.33	2.29±0.10	2.28±0.02	18.74±0.39
C₄	1.04±0.072	1.55±0.05	2.59±0.12	0.85±0.04	3.45±0.16	2.24±0.13	6.07±0.12	11.77±0.43
Mean	5.48	2.52	8.01	2.64	10.66	2.33	3.29	16.28

Aboveground = stem + canopy; Total = aboveground + belowground

C₁ = Apple+radish-kale

C₂ = Apple+kale-chilli

C₃ = Apple+kale-beans

C₄ = Walnut+oats-maize

4.2.10 Carbon stock (t ha^{-1}) under Agri-silviculture system (boundary plantation)

The data pertaining to in carbon stock (t ha^{-1}) under agri-silviculture system (boundary plantation) (Table 14) clearly showed maximum forest stem carbon stock was recorded 6.79 t ha^{-1} in combination C_2 (Poplar+mustard-paddy) followed by 5.45 t ha^{-1} in combination C_1 (Poplar+salix+oats-paddy). Maximum branch carbon stock was recorded as 0.90 t ha^{-1} in C_2 followed by 0.53 t ha^{-1} in combination C_1 . The maximum leaf carbon stock was recorded as 0.12 t ha^{-1} in combination C_2 followed by 0.09 t ha^{-1} in combination C_1 . Maximum above and below ground carbon stock was recorded as 7.82 t ha^{-1} and 1.95 t ha^{-1} respectively in combination C_2 . The maximum total fruit tree carbon stock was recorded as 9.77 t ha^{-1} in combination C_2 followed by 7.60 t ha^{-1} in combination C_1 .

The maximum rabi crop carbon stock was recorded 2.69 t ha^{-1} in combination C_2 (Poplar+mustard-paddy) followed by 2.40 t ha^{-1} in combination C_1 (Poplar+salix+oats-paddy). During kharif, maximum crop carbon stock 4.50 t ha^{-1} was recorded in combination C_1 followed by 4.41 t ha^{-1} in combination C_2 . The total maximum carbon stock under Boundary plantation was recorded 16.87 t ha^{-1} in C_2 followed by 14.51 t ha^{-1} in C_1 .

4.2.11 Carbon stock (t ha^{-1}) under Agri-horti-silviculture system (homegarden)

Data pertaining to carbon stock in agri-horti-silviculture system (homegarden) has been given in Table 15 which clearly showed that maximum stem carbon stock of forest trees was recorded as 10.70 t ha^{-1} in combination C_3 (Poplar+apple+turnip-kale) followed by 10.54 t ha^{-1} carbon stock in C_1 (Poplar+apple+kale-beans), Minimum stem carbon stock was recorded as 10.17 t ha^{-1} in combination C_2 (Poplar+apple+kale-chilli), Maximum branch carbon stock of forest trees was recorded as 0.63 t ha^{-1} followed by 0.54 t ha^{-1} and 0.48 t ha^{-1} (minimum) in C_1 , C_3 and C_2 respectively. The maximum leaf carbon stock was recorded as 0.18 t ha^{-1} in combination C_3 followed by 0.16 t ha^{-1} in C_1 and its minimum was recorded as 0.14 t ha^{-1} in combination C_2 . The combination

Table 14: Average carbon stock (t ha⁻¹) under agri-silviculture system (boundary plantation) (Pooled data for year 2018-2019)

Tree crop combinations	Forest trees						Crops		Total carbon stock
	Stem	Branch	Leaf	Above ground	Below ground	Total	Rabi	Kharif	
C ₁	5.45±0.14	0.53±0.045	0.09±0.004	6.08±0.20	1.52±0.05	7.60±0.25	2.40±0.08	4.50±0.04	14.51±0.32
C ₂	6.79±0.09	0.90±0.06	0.12±0.013	7.82±0.17	1.95±0.04	9.77±0.22	2.69±0.05	4.41±0.20	16.87±0.50
Mean	6.12	0.71	0.10	6.95	1.73	8.68	2.54	4.45	15.67

C₁ = Poplar+salix+oats-paddy

C₂ = Poplar+mustard-paddy

C₃ recorded maximum above and below ground carbon stock as 11.42 t ha⁻¹ and 2.85 t ha⁻¹ followed by 11.34 t ha⁻¹ and 2.83 t ha⁻¹ in combination C₁ respectively, whereas minimum was reported as 10.79 t ha⁻¹ and 2.69 t ha⁻¹ in C₂. The maximum total forest tree carbon stock was recorded as 14.27 t ha⁻¹ in combination C₃ followed by 14.17 t ha⁻¹ in combination C₁, whereas minimum carbon stock was recorded as 13.48 t ha⁻¹ in combination C₂.

In fruit tree carbon stock, maximum stem carbon stock was recorded 2.43 t ha⁻¹ in combination C₃ (Poplar+apple+turnip-kale) followed by 2.17 t ha⁻¹ biomass in combination C₂ (Poplar+apple+kale-chilli). Minimum stem carbon stock was recorded as 1.78 t ha⁻¹ in combination C₁ (Poplar+apple+kale-beans). Maximum canopy carbon stock was recorded as 0.69 t ha⁻¹ in combination C₃ followed by 0.58 t ha⁻¹ in C₂ and minimum 0.37 t ha⁻¹ in C₁. Maximum above and below ground carbon stock was recorded as 3.12 t ha⁻¹ and 1.03 t ha⁻¹ in combination C₃, whereas minimum above and below ground carbon stock was recorded 2.16 t ha⁻¹ and 0.71 t ha⁻¹ respectively in combination C₁ respectively. The maximum total fruit tree carbon stock was recorded as 4.15 t ha⁻¹ in combination C₃ followed by 3.67 t ha⁻¹ in combination C₂ and minimum 2.87 t ha⁻¹ in combination C₁.

The maximum rabi crop carbon stock was recorded 2.69 t ha⁻¹ in combination C₃ (Poplar+apple+turnip-kale) followed by 2.47 t ha⁻¹ in combination C₂ (Poplar+apple+kale-chilli), whereas minimum crop carbon stock 2.33 t ha⁻¹ was recorded in combination C₁ (Poplar+apple+kale-beans). During kharif, maximum crop carbon stock 2.76 t ha⁻¹ was recorded in combination C₃ followed by 2.53 t ha⁻¹ in combination C₂, whereas minimum kharif crop carbon stock 2.30 t ha⁻¹ was recorded in combination C₁.

The total maximum carbon stock under agri-horti-silviculture was recorded as 23.87 t ha⁻¹ in combination C₃ (Poplar+apple+turnip-kale) followed by 22.15 t ha⁻¹ in combination C₂ (Poplar+apple+kale-chilli), while total minimum carbon stock 21.67 t ha⁻¹ was recorded in combination C₁ (Poplar+apple+kale-beans).

Table 15: Average carbon stock (t ha⁻¹) under Agri-horti-silviculture system (homegardens) (Pooled data for year 2018-2019)

Tree crop combn.	Forest trees						Fruit trees					Crops		Total carbon stock
	Stem	Branch	Leaf	Above ground	Below ground	Total	Stem	Canopy	Above ground	Below ground	Total	Rabi	Kharif	
C ₁	10.54 ±0.09	0.63 ±0.03	0.16 ±0.03	11.34 ±0.13	2.83 ±0.03	14.17 ±0.16	1.78 ±0.18	0.37 ±0.03	2.16 ±0.11	0.71 ±0.03	2.87 ±0.15	2.33 ±0.04	2.30 ±0.02	21.67 ±0.39
C ₂	10.17 ±0.21	0.48 ±0.01	0.14 ±0.01	10.79 ±0.24	2.69 ±0.06	13.48 ±0.30	2.17 ±0.11	0.58 ±0.04	2.76 ±0.15	0.90 ±0.04	3.67 ±0.20	2.47 ±0.07	2.53 ±0.11	22.15 ±0.70
C ₃	10.70 ±0.19	0.54 ±0.04	0.18 ±0.003	11.42 ±0.23	2.85 ±0.06	14.27 ±0.31	2.43 ±0.03	0.69 ±0.03	3.12 ±0.07	1.03 ±0.02	4.15 ±0.10	2.69 ±0.07	2.76 ±0.03	23.87 ±0.51
Mean	10.47	0.55	0.16	0.26	11.1	13.97	2.12	0.54	2.68	0.88	3.56	2.49	2.53	22.56

Aboveground (forest trees) =stem+branch+leaf; Aboveground (fruit trees) =stem+canopy; Total=aboveground+belowground

C₁ = Poplar+apple+kale-beans

C₂ = Poplar+apple+kale-chilli

C₃ = Poplar+apple+turnip-kale

4.2.12 Carbon stock (t ha^{-1}) under Horti-silvi-pasture system

The data pertaining to carbon stock in horti-silvi-pasture system (Table 16) clearly showed maximum stem carbon stock of fruit trees was recorded as 7.50 t ha^{-1} in combination C_1 (Apple+poplar+grasses) followed by 7.48 t ha^{-1} in combination C_2 (Apple+poplar+salix+grasses). Maximum canopy carbon stock was recorded as 3.04 t ha^{-1} in combination C_1 followed by 2.62 t ha^{-1} in C_2 . Maximum above and below ground carbon stock was recorded as 10.55 t ha^{-1} and 3.48 t ha^{-1} respectively in combination C_1 , followed by 10.11 t ha^{-1} and 3.33 t ha^{-1} respectively in C_2 . The maximum total fruit tree carbon stock was recorded as 14.03 t ha^{-1} in combination C_1 followed by 13.45 t ha^{-1} in combination C_2 .

In forest tree biomass, the maximum stem carbon stock 10.23 t ha^{-1} was recorded in combination C_1 (Apple+poplar+grasses), followed by 6.39 t ha^{-1} carbon stock in C_2 (Apple+poplar+salix+grasses). Maximum branch carbon stock was recorded as 0.74 t ha^{-1} in combination C_1 followed by 0.44 t ha^{-1} in C_2 . The maximum leaf carbon stock was recorded as 0.19 t ha^{-1} in combination C_1 followed by 0.12 t ha^{-1} in combination C_2 . Maximum above and below ground carbon stock was recorded as 11.18 t ha^{-1} and 2.79 t ha^{-1} in combination C_1 followed by 6.95 t ha^{-1} and 1.73 t ha^{-1} in combination C_2 . The maximum total forest tree carbon stock was recorded as 13.97 t ha^{-1} in combination C_1 followed by 8.69 t ha^{-1} in combination C_2 .

The different perennial grasses present in orchards were usually harvested in two cuts i.e June and September. The maximum carbon stock of perennial grasses during June cut was recorded 3.37 t ha^{-1} in combination C_1 (Apple+poplar+grasses), followed by 3.10 t ha^{-1} in C_2 (Apple+poplar+salix+grasses). The maximum carbon stock of perennial grasses during September cut was recorded as 1.85 t ha^{-1} in combination C_1 followed by 1.44 t ha^{-1} in C_2 . The total maximum carbon stock of combination C_1 (Apple+poplar+grasses) was recorded as 30.67 t ha^{-1} followed by 26.25 t ha^{-1} in combination C_2 (Apple+poplar+salix+grasses).

Table 16: Average carbon stock (t ha⁻¹) under Horti-silvi-pasture system (Pooled data for year 2018-2019)

Tree crop combn.	Fruit trees					Forest trees						*Crops		Total carbon stock
	Stem	Canop y	Aboveg round	Belowg round	Total	Stem	Branch	Leaf	Aboveg round	Belogr ound	Total	**1 st cut	***2 nd cut	
C ₁	7.50 ±0.13	3.04 ±0.27	10.55± 0.26	3.48 ±0.08	14.03 ±0.35	10.23 ±0.23	0.74 ±0.08	0.19 ±0.04	11.18 ±0.33	2.79 ±0.08	13.97 ±0.41	3.37 ±0.10	1.85 ±0.03	30.67 ±0.9
C ₂	7.48 ±0.20	2.62 ±0.06	10.11± 0.41	3.33 ±0.07	13.45 ±0.39	6.39 ±0.14	0.44 ±0.05	0.12 ±0.09	6.95 ±0.20	1.73 ±0.05	8.69 ±0.26	3.10 ±0.04	1.44 ±0.04	26.25 ±0.8
Mean	7.49	2.83	10.33	3.40	13.74	8.31	0.59	0.59	0.15	2.26	11.33	3.23	1.64	28.46

Aboveground(forest trees)=stem+branch+leaf; Aboveground(fruit trees)=stem+canopy; Total=aboveground+belowground

C₁ = Apple+poplar+grasses

C₂ = Apple+poplar+salix+grasses

*Crop carbon stock of perennial grasses

**1st cut- June

***2nd cut- September

4.2.13 Carbon sequestration potential of horti-agriculture system (t ha^{-1})

The data pertaining to carbon sequestration (t ha^{-1}) under horti-agriculture system (Table 17) clearly showed maximum fruit tree stem carbon sequestration was recorded 26.30 t ha^{-1} in combination C_1 (Apple+radish-kale) followed by combination C_3 (Apple+kale-beans) in which carbon sequestration was recorded as 25.45 t ha^{-1} . Minimum stem carbon sequestration was recorded as 3.84 t ha^{-1} in combination C_4 (Walnut+oats-maize). Maximum canopy carbon sequestration was recorded as 13.58 t ha^{-1} in combination C_3 followed by 8.93 t ha^{-1} in C_2 (Apple+kale-chilli) and minimum 5.67 t ha^{-1} in C_4 . Maximum above and below ground carbon sequestration was recorded as 39.04 t ha^{-1} and 12.88 t ha^{-1} respectively in combination C_3 , whereas minimum above and below ground carbon sequestration was recorded as 9.52 t ha^{-1} and 3.14 t ha^{-1} respectively in combination C_4 . The maximum total fruit tree carbon sequestration was recorded as 51.93 t ha^{-1} in combination C_3 followed by 46.83 t ha^{-1} in combination C_1 and minimum 12.67 t ha^{-1} in combination C_4 .

The maximum rabi crop carbon sequestration was recorded 9.22 t ha^{-1} in combination C_2 (Apple+kale-chilli) followed by 8.51 t ha^{-1} in combination C_1 (Apple+radish-kale), whereas minimum crop carbon sequestration 8.24 t ha^{-1} was recorded in combination C_4 (Walnut+oats-maize). During kharif, maximum crop carbon sequestration 22.30 t ha^{-1} was recorded in combination C_4 followed by 9.51 t ha^{-1} in combination C_1 , whereas minimum kharif crop carbon sequestration 8.17 t ha^{-1} was recorded in combination C_2 .

The total maximum carbon sequestration under Horti-agriculture system was recorded 68.76 t ha^{-1} in C_3 (Apple+kale-beans) followed by 64.84 t ha^{-1} in C_1 (Apple+radish-kale), while minimum total carbon sequestration 43.21 t ha^{-1} was recorded in combination C_4 (Walnut+oats-maize).

Table 17: Average carbon sequestration (t ha⁻¹) under Horti-agriculture system (Pooled data for year 2018-2019)

Tree crop combinations	Fruit trees					Crop		Total carbon sequestration
	Stem	Canopy	Above ground	Below ground	Total	Rabi	Kharif	
C₁	26.30±0.45	8.91±0.58	35.21±1.04	11.62±0.35	46.83±1.4	8.51±0.12	9.51±0.18	64.84±1.7
C₂	25.01±0.66	8.93±0.45	33.94±1.11	11.20±0.34	45.15±1.5	9.22±0.23	8.17±0.36	62.54±2.11
C₃	25.45±0.51	13.58±0.38	39.04±0.91	12.88±0.28	51.93±1.21	8.44±0.4	8.39±0.07	68.76±1.68
C₄	3.84±0.25	5.67±0.2	9.52±0.46	3.14±0.15	12.67±0.6	8.24±0.5	22.30±0.48	43.21±1.6
Mean	20.11	9.24	29.39	9.68	39.12	8.55	12.07	59.83

Aboveground = stem + canopy; Total = aboveground + belowground

C₁ = Apple+radish-kale

C₂ = Apple+kale-chilli

C₃ = Apple+kale-beans

C₄ = Walnut+oats-maize

4.2.14 Carbon sequestration potential under Agri-silviculture system (boundary plantation) (t ha^{-1})

The data pertaining to carbon sequestration under agri-silviculture system (boundary plantation) (Table 18) clearly showed maximum forest stem carbon sequestration was recorded 24.92 t ha^{-1} in combination C_2 (Poplar+mustard-paddy) followed by 20.02 t ha^{-1} in combination C_1 (Poplar+salix+oats-paddy). Maximum branch carbon sequestration was recorded as 3.30 t ha^{-1} in C_2 followed by 1.97 t ha^{-1} in combination C_1 . The maximum leaf carbon sequestration was recorded as 0.47 t ha^{-1} in combination C_2 followed by 0.33 t ha^{-1} in combination C_1 . Maximum above and below ground carbon sequestration was recorded as 28.70 t ha^{-1} and 7.17 t ha^{-1} respectively in combination C_2 . The maximum total fruit tree carbon sequestration was recorded as 35.88 t ha^{-1} in combination C_2 followed by 27.93 t ha^{-1} in combination C_1 .

The maximum rabi crop carbon sequestration was recorded 9.89 t ha^{-1} in combination C_2 followed by 8.82 t ha^{-1} in combination C_1 . During kharif, maximum crop carbon sequestration 16.53 t ha^{-1} was recorded in combination C_1 followed by 16.18 t ha^{-1} in combination C_2 . The total maximum carbon sequestration under boundary plantation was recorded as 61.95 t ha^{-1} in C_2 (Poplar+mustard-paddy) followed by 53.28 t ha^{-1} in C_1 (Poplar+mustard-paddy).

4.2.15 Carbon sequestration potential under Agri-horti-silviculture system (homegarden) (t ha^{-1})

Data pertaining to carbon sequestration in agri-horti-silviculture system (homegarden) has been given in Table 19 which clearly showed that maximum stem carbon sequestration of forest trees was recorded as 39.3 t ha^{-1} in combination C_3 (Poplar+apple+turnip-kale) followed by 38.71 t ha^{-1} biomass in C_1 (Poplar+apple+kale-beans). Minimum stem carbon sequestration was recorded as 37.3 t ha^{-1} in combination C_2 (Poplar+apple+kale-chilli). Maximum branch carbon sequestration of forest trees was recorded as 2.32 t ha^{-1} followed by

Table 18: Average carbon sequestration (t ha^{-1}) under Agri-silviculture system (boundary plantation) (Pooled data for year 2018-2019)

Tree crop combinations	Forest trees						Crop		Total carbon sequestration
	Stem	Branch	Leaf	Above ground	Below ground	Total	Rabi	Kharif	
C₁	20.02±0.55	1.97±0.17	0.33±0.02	22.33±0.73	5.59±0.18	27.93±0.92	8.82±0.29	16.53±0.15	53.28±1.37
C₂	24.92±0.31	3.30±0.24	0.47±0.05	28.70±0.64	7.17±0.15	35.88±0.79	9.89±0.25	16.18±0.66	61.95±1.73
Mean	22.46	2.60	0.36	25.50	6.35	31.85	9.32	16.33	57.58

Aboveground = stem+branch+leaf; Total=aboveground+belowground

C₁ = Poplar+salix+oats-paddy

C₂ = Poplar+mustard-paddy

1.99 t ha⁻¹ and 1.77 t ha⁻¹ (minimum) in C₁, C₃ and C₂ respectively. The maximum leaf carbon sequestration was recorded as 0.66 t ha⁻¹ in combination C₃ followed by 0.59 t ha⁻¹ in combination C₂ and its minimum was recorded as 0.51 t ha⁻¹ in combination C₁. The combination C₃ recorded maximum above and below ground carbon sequestration as 41.91 t ha⁻¹ and 10.45 t ha⁻¹ followed by 41.62 t ha⁻¹ and 10.40 t ha⁻¹ in combination C₁ respectively, whereas minimum was reported as 39.6 t ha⁻¹ and 9.87 t ha⁻¹ in combination C₂. The maximum total forest tree carbon sequestration was recorded as 52.37 t ha⁻¹ in combination C₃ followed by 52.02 t ha⁻¹ in combination C₁, whereas minimum carbon sequestration was recorded as 49.47 t ha⁻¹ in combination C₂.

In fruit tree, maximum stem carbon sequestration was recorded 8.93 t ha⁻¹ in combination C₃ followed by 7.98 t ha⁻¹ biomass in combination C₂ (Poplar+apple+kale-chilli). Minimum stem carbon sequestration was recorded as 6.55 t ha⁻¹ in combination C₁ (Poplar+apple+kale-beans). Maximum canopy carbon sequestration was recorded as 2.54 t ha⁻¹ in combination C₃ (Poplar+apple+turnip-kale) followed by 2.16 t ha⁻¹ in C₂ and minimum 1.37 t ha⁻¹ in C₁. Maximum above and below ground carbon sequestration was recorded as 11.47 t ha⁻¹ and 3.78 t ha⁻¹ in combination C₃, whereas minimum above and below ground carbon sequestration was recorded 7.93 t ha⁻¹ and 2.61 t ha⁻¹ respectively in combination C₁. The maximum total fruit tree carbon sequestration was recorded as 15.25 t ha⁻¹ in combination C₃ followed by 13.5 t ha⁻¹ in combination C₂ and minimum 10.55 t ha⁻¹ in combination C₁.

The maximum rabi crop carbon sequestration was recorded 9.89 t ha⁻¹ in combination C₃ (Poplar+apple+turnip-kale) followed by 9.1 t ha⁻¹ in combination C₂ (Poplar+apple+kale-chilli), whereas minimum crop carbon sequestration 8.55 t ha⁻¹ was recorded in combination C₁ (Poplar+apple+kale-beans). During kharif, maximum crop carbon sequestration 10.1 t ha⁻¹ was recorded in combination C₃ followed by 9.28 t ha⁻¹ in combination C₂, whereas minimum kharif crop carbon sequestration 8.47 t ha⁻¹ was recorded in combination C₁.

Table 19: Average carbon sequestration (t ha⁻¹) under Agri-horti-silviculture system (homegardens) (Pooled data for year 2018-2019)

Tree crop combination	Forest trees						Fruit trees					Crop		Total carbon sequestration
	Stem	Branch	Leaf	Above ground	Below ground	Total	Stem	Canopy	Above ground	Below ground	Total	Rabi	Kharif	
C ₁	38.71 ±0.33	2.32 ±0.13	0.59 ±0.01	41.62 ±0.5	10.40 ±0.12	52.02 ±0.61	6.55 ±0.3	1.37 ±0.1	7.93 ±0.41	2.61 ±0.13	10.55±0.56	8.55 ±0.16	8.47 ±0.08	79.59 ±1.44
C ₂	37.3 ±0.78	1.77 ±0.06	0.513 ±0.05	39.6 ±0.89	9.87 ±0.21	49.47 ±1.11	7.98 ±0.41	2.16 ±0.13	10.1 ±0.54	3.34 ±0.17	13.5 ±0.74	9.1 ±0.28	9.28 ±0.41	81.35 ±2.55
C ₃	39.3 ±0.73	1.99 ±0.17	0.66 ±0.01	41.91 ±0.91	10.45 ±0.23	52.37 ±1.14	8.93 ±0.14	2.54 ±0.13	11.47 ±0.26	3.78 ±0.08	15.25 ±0.37	9.89 ±0.28	10.1 ±0.1	87.64 ±1.88
Mean	38.42	2.018	0.58	0.95	40.73	51.27	7.78	1.98	9.83	3.23	13.06	9.14	9.28	82.8

Aboveground(forest trees)=stem+branch+leaf; Aboveground(fruit trees)=stem+canopy; Total=aboveground+belowground

C₁ = Poplar+apple+kale-beans

C₂ = Poplar+apple+kale-chilli

C₃ = Poplar+apple+turnip-kale

The total maximum carbon sequestration under agri-horti-silviculture (homegardens) was recorded as 87.64 t ha⁻¹ in combination C₃ ((Poplar+apple+turnip-kale) followed by 81.35 t ha⁻¹ in combination C₂ (Poplar+apple+kale-chilli), while total minimum carbon sequestration 79.59 t ha⁻¹ was recorded in combination C₁ (Poplar+apple+kale-beans).

4.2.16 Carbon sequestration potential under horti-silvi-pasture system (t ha⁻¹)

The data pertaining to carbon sequestration in horti-silvi-pasture system (Table 20) clearly showed maximum stem carbon sequestration of fruit trees was recorded as 27.53 t ha⁻¹ in combination C₁ (Apple+poplar+grasses) followed by 27.47 t ha⁻¹ carbon sequestration in combination C₂ (Apple+poplar+salix+grasses). Maximum canopy carbon sequestration was recorded as 11.20 t ha⁻¹ in combination C₁ followed by 9.63 t ha⁻¹ in C₂. Maximum above and below ground carbon sequestration was recorded as 38.74 t ha⁻¹ and 12.78 t ha⁻¹ respectively in combination C₁, followed by 37.11 t ha⁻¹ and 12.24 t ha⁻¹ respectively in C₂. The maximum total fruit tree sequestration was recorded as 51.52 t ha⁻¹ in combination C₁ followed by 49.36 t ha⁻¹ in combination C₂.

In forest tree biomass, the maximum stem carbon sequestration 37.56 t ha⁻¹ was recorded in combination C₁ (Apple+poplar+grasses), followed by 23.47 t ha⁻¹ in C₂ (Apple+poplar+salix+grasses). Maximum branch carbon sequestration was recorded as 2.74 t ha⁻¹ in combination C₁ followed by 1.62 t ha⁻¹ in C₂. The maximum leaf carbon sequestration was recorded as 0.73 t ha⁻¹ in combination C₁ followed by 0.44 t ha⁻¹ in combination C₂. Maximum above and below ground carbon sequestration was recorded as 41.04 t ha⁻¹ and 10.26 t ha⁻¹ in combination C₁ followed by 25.53 t ha⁻¹ and 6.38 t ha⁻¹ in combination C₂. The maximum total forest tree carbon sequestration was recorded as 51.3 t ha⁻¹ in combination C₁ followed by 31.91 t ha⁻¹ in combination C₂.

Table 20: Average carbon sequestration (t ha⁻¹) under Horti-silvi-pasture system (Pooled data for year 2018-2019)

Tree crop combination	Fruit trees					Forest trees						*Crop biomass		Total carbon sequestration
	Stem	Canopy	Above ground	Below ground	Total	Stem	Branch	Leaf	Above ground	Below ground	Total	**1 st cut	***2 nd cut	
C ₁	27.53 ±0.48	11.20 ±0.5	38.74 ±0.97	12.78 ±0.31	51.52 ±1.29	37.56 ±0.84	2.74 ±0.31	0.73 ±0.02	41.04 ±1.21	10.26 ±0.3	51.3 ±1.5	12.4 ±0.38	6.78 ±0.1	122.0 ±3.29
C ₂	27.47 ±0.66	9.63 ±0.21	37.11 ±0.89	12.24±0.29	49.36 ±1.19	23.47 ±0.51	1.62 ±0.21	0.44 ±0.03	25.53 ±0.76	6.38 ±0.18	31.91 ±0.96	11.38 ±0.53	5.28 ±0.17	97.93 ±2.86
Mean	27.5	10.4	37.9	12.5	31.8	30.5	2.16	2.16	0.55	8.3	41.6	11.9	6.03	104.4

Aboveground(forest trees)=stem+branch+leaf; Aboveground(fruit trees)=stem+canopy; Total=aboveground+belowground

C₁ = Apple+poplar+grasses

C₂ = Apple+poplar+salix+grasses

*Crop carbon sequestration of perennial grasses

**1st cut- June

***2nd cut- September

The different perennial grasses present in orchards were usually harvested in two cuts i.e June and September. The maximum carbon sequestration of perennial grasses during June cut was recorded 12.4 t ha⁻¹ in combination C₁ (Apple+poplar+grasses) followed by 11.38 t ha⁻¹ in C₂ (Apple+poplar+salix+grasses). The maximum perennial grasses during September cut was recorded as 6.78 t ha⁻¹ in combination C₁ followed by 5.28 t ha⁻¹ in C₂. The total maximum carbon sequestration of combination C₁ was recorded as 122.0 t ha⁻¹ followed by 97.93 t ha⁻¹ in combination C₂.

4.2.17 Biomass production, carbon stock and carbon sequestration (t ha⁻¹) under prominent agroforestry systems

The data pertaining to biomass production, carbon stock and carbon sequestration of prominent agroforestry systems of Anantnag district is presented in Table 21. The comparative analysis of data clearly illustrates that the horti-silvi-pasture recorded maximum total biomass production (66.55 t ha⁻¹), carbon stock (28.46 t ha⁻¹) and carbon sequestration (104.4 t ha⁻¹), which was followed by agri-horti-silviculture (homegardens) having biomass (50.18 t ha⁻¹), carbon stock (22.56 t ha⁻¹) and carbon sequestration (82.86 t ha⁻¹). Horti-agriculture and agri-silviculture (boundary plantation) recorded minimum values for biomass production, carbon stock and carbon sequestration. The major contribution was shown by forest/fruit trees followed by crop components. In horti-silvi-pasture system, fruit trees recorded (45.86%) of biomass production, carbon stock and carbon sequestration followed by forest trees (37.83%) and minimum (16.29%) gain was recorded by crop/perennial grass component, this was closely followed by agri-horti-pasture (homegarden), where forest trees added maximum (61.90%) biomass production, carbon stock and carbon sequestration followed by crop (22.29%) and minimum in fruit trees (13.27%).

Table 21: Mean biomass production, carbon stock, carbon sequestration potential (t ha⁻¹) under prominent agroforestry systems

Systems	Biomass production				Carbon stock				Carbon sequestration			
	Forest trees	Fruit trees	Crops (Rabi+ Kharif)	Total	Forest trees	Fruit trees	Crops (Rabi+ Kharif)	Total	Forest trees	Fruit trees	Crops (Rabi+ Kharif)	Total
Horti-agriculture	-	23.70 (65.42)	12.52 (34.55)	36.22	-	10.66	5.62	16.28	-	39.12	20.62	59.83
Agri-silviculture(boundary plantation)	19.31 (55.36)	-	15.54 (44.61)	34.87	8.68	-	6.99	15.67	31.85	-	25.65	57.58
Agri-horti-silviculture(homesteads)	31.04 (61.90)	7.91 (13.27)	11.15 (22.29)	50.18	13.97	3.56	5.02	22.56	51.27	13.06	18.42	82.86
Horti-silvi-pasture system	25.19 (37.83)	30.54 (45.86)	10.82 (16.29)	66.55	11.33	13.74	4.87	28.46	41.60	50.44	17.92	104.4

Figures in parentheses represent %age of the total biomass in prominent agroforestry systems

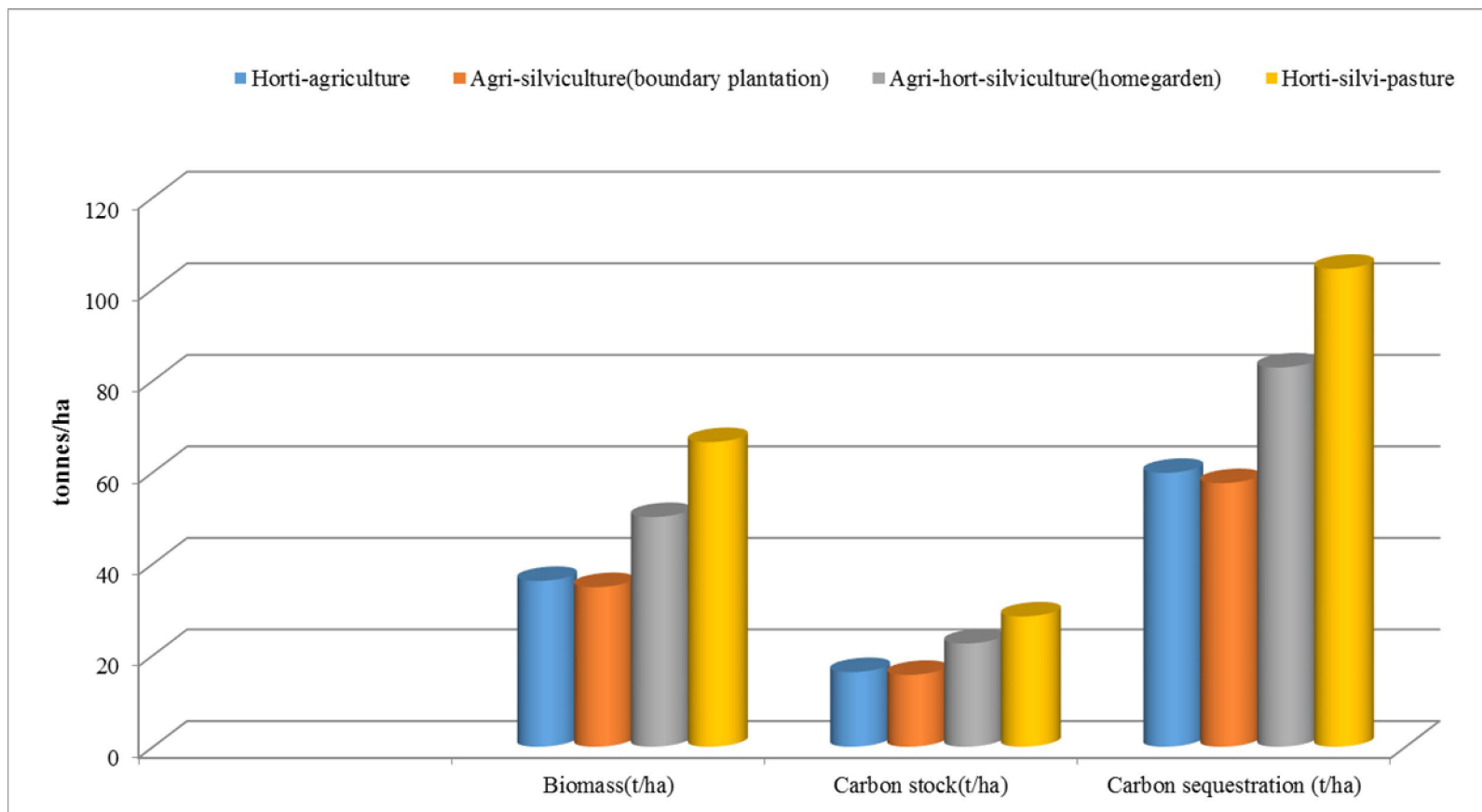


Fig 3: Mean biomass production, carbon stock, CO₂ sequestration potential (t ha⁻¹) under prominent agroforestry systems

4.3 Nutrient status of prominent agroforestry systems

4.3.1 Soil reaction (pH) in prominent agroforestry systems

The data recorded on soil reaction (pH) under prominent agroforestry systems are presented in table 22. Among four different systems under study, agri-silviculture (boundary plantation) recorded maximum pH of 6.96, 7.14 and 7.05 in year 2018, 2019 and pooled, respectively at depth D₁ and was found significantly superior to all other agroforestry systems. Horti-agriculture was however found next to boundary plantation recording 6.83, 7.01 and 6.92 and agri-horti-silviculture with 6.73, 6.84 and 6.79 in year 2018, 2019 and pooled respectively at depth D₁, while as lowest soil pH was recorded in horti-silvi-pasture recording 6.69, 6.83 and 6.76 in year 2018, 2019 and pooled respectively at depth D₁. Also, soil reaction (pH) was higher at depth D₂ than depth D₁ in all agroforestry systems

4.3.2 Electrical conductivity EC (dSm⁻¹) in soil under prominent agroforestry systems

The data recorded on soil electrical conductivity under prominent agroforestry systems are presented in Table 23. Among four different systems under study, horti-silvi-pasture recorded maximum soil electrical conductivity of 0.29, 0.34 and 0.32 dSm⁻¹ in year 2018, 2019 and pooled, respectively at depth D₁ and was found significantly superior to all other agroforestry systems. Agri-horti-silviculture was however found next to horti-silvi-pasture system recording 0.275 dSm⁻¹, 0.325 dSm⁻¹ and 0.30 dSm⁻¹ and horti-agriculture with 0.25 dSm⁻¹, 0.3 dSm⁻¹ and 0.27 dSm⁻¹ in year 2018, 2019 and pooled respectively at depth D₁, while as lowest soil electrical conductivity was recorded in agri-silviculture (boundary plantation) recording 0.23, 0.28 and 0.26 dSm⁻¹ in year 2018, 2019 and pooled, respectively at depth D₁. Also, soil electrical conductivity was higher at depth D₁ than depth D₂ in all agroforestry systems.

Table 22: Soil reaction (pH) in soil under prominent agroforestry systems

Systems	2018			2019			Pooled		
	*D ₁	**D ₂	Mean	*D ₁	**D ₂	Mean	*D ₁	**D ₂	Mean
Horti-agriculture	6.74	6.93	6.835	6.86	7.15	7.005	6.8	7.04	6.92
Agri-silviculture(boundary plantation)	6.81	7.11	6.96	7.07	7.21	7.14	6.94	7.16	7.05
Agri-horti-silviculture(homegarden)	6.68	6.79	6.735	6.74	6.95	6.845	6.71	6.87	6.79
Horti-silvipasture	6.61	6.77	6.69	6.75	6.91	6.83	6.68	6.84	6.76
C.D(p<0.05)									
D	0.04			0.06			0.05		
S	0.06			0.08			0.07		
D × S	0.08			0.02			0.09		

S = System, D = Depth, *D₁= (0-30)cm, **D₂= (30-60)cm

Table 23: Electrical conductivity EC (dSm⁻¹) in soil under prominent agroforestry systems

Systems	2018			2019			Pooled		
	*D ₁	**D ₂	Mean	*D ₁	**D ₂	Mean	*D ₁	**D ₂	Mean
Horti-agriculture	0.28	0.22	0.25	0.34	0.26	0.3	0.31	0.24	0.27
Agri-silviculture(boundary plantation)	0.27	0.2	0.23	0.33	0.24	0.28	0.3	0.22	0.26
Agri-horti-silviculture(homegarden)	0.33	0.22	0.27	0.39	0.26	0.32	0.36	0.24	0.3
Horti-silvipasture	0.35	0.24	0.29	0.41	0.28	0.34	0.38	0.26	0.32
C.D(p<0.05)									
D	0.09			0.08			0.08		
S	0.01			0.06			0.02		
D × S	0.1			0.2			0.1		

S = System, D = Depth, *D₁= (0-30)cm, **D₂= (30-60)cm

4.3.3 Status of soil organic carbon (OC %) in prominent agroforestry systems

The data recorded on soil organic carbon under prominent agroforestry systems are presented in Table 24. Among four different systems under study, horti-silvi-pasture recorded maximum soil organic carbon of 1.51 %, 1.6 % and 1.55 % in year 2018, 2019 and pooled respectively at depth D₁ which were found significantly superior to other three agroforestry systems. Agri-horti-silviculture system was found next to horti-silvi-pasture system by giving organic carbon 1.31 %, 1.43 % and 1.37 % and horti-agriculture with 1.06 %, 1.18 % and 1.12 % in year 2018, 2019 and pooled respectively at depth D₁. The lowest soil organic carbon was in agri-silviculture (boundary plantation) viz., 0.87 %, 0.99 % and 0.93 % in year 2018, 2019 and pooled respectively at depth D₁. Soil organic carbon was higher at depth D₁ than depth D₂ in all agroforestry systems

4.3.4 Available nitrogen (kg ha⁻¹) in soil under prominent agroforestry systems

The data recorded on available soil nitrogen under prominent agroforestry systems is presented in Table 25. Among four different systems under study, horti-silvi-pasture recorded maximum available nitrogen of 310.95 kg ha⁻¹, 316.4 kg ha⁻¹ and 313.6 kg ha⁻¹ in year 2018, 2019 and pooled respectively at depth D₁ and was found significantly superior to all other agroforestry systems. Agri-horti-silviculture was however found next to horti-silvi-pasture system recording 296.05, 301.3 and 298.7 kg ha⁻¹ and horti-agriculture with 289.9, 294.5 and 292.2 kg ha⁻¹ in year 2018, 2019 and pooled respectively at depth D₁, while as lowest available soil nitrogen was recorded in agri-silviculture (boundary plantation) recording 278.75, 284.0 and 281.4 kg ha⁻¹ in year 2018, 2019 and pooled respectively at depth D₁. Also, available soil nitrogen was higher at depth D₁ than depth D₂ in all agroforestry systems.

Table 24: Status of soil organic carbon (OC %) in soil under prominent agroforestry systems

Systems	2018			2019			Pooled		
	*D ₁	**D ₂	Mean	*D ₁	**D ₂	Mean	*D ₁	**D ₂	Mean
Horti-agriculture	1.13	0.99	1.06	1.27	1.09	1.18	1.2	1.04	1.12
Agri-silviculture(boundary plantation)	1.12	0.62	0.87	1.24	0.74	0.99	1.18	0.68	0.93
Agri-horti-silviculture(homegarden)	1.59	1.02	1.31	1.73	1.12	1.43	1.66	1.07	1.36
Horti-silvipasture	1.93	1.09	1.51	2.03	1.17	1.6	1.98	1.13	1.55
C.D(p<0.05)									
D	0.01			0.01			0.01		
S	0.01			0.01			0.01		
D × S	0.02			0.02			0.014		

S = System, D = Depth, *D₁= (0-30)cm, **D₂= (30-60)cm

Table 25: Status of available nitrogen (kg ha⁻¹) in soil under prominent agroforestry systems

Systems	2018			2019			Pooled		
	*D ₁	**D ₂	Mean	*D ₁	**D ₂	Mean	*D ₁	**D ₂	Mean
Horti-agriculture	314.1	265.7	289.9	318.3	270.7	294.5	316.2	268.2	292.2
Agri-silviculture(boundary plantation)	299.5	258.0	278.75	305.1	263.0	284.0	302.3	260.5	281.4
Agri-horti-silviculture(homegarden)	318.4	273.7	296.05	323.8	278.9	301.3	321.1	276.3	298.7
Horti-silvi-pasture	336.2	285.6	310.95	342.4	290.4	316.4	339.3	288.0	313.6
C.D(p<0.05)									
D	0.87			0.81			0.83		
S	1.23			1.15			1.17		
D × S	1.74			1.63			1.66		

S = System, D = Depth, *D₁= (0-30)cm, **D₂= (30-60)cm

4.3.5 Available Phosphorus (kg ha⁻¹) in soil under prominent agroforestry systems

The data recorded on available soil phosphorus under prominent agroforestry systems is presented in Table 26. Among four different systems under study, horti-silvi-pasture recorded maximum available phosphorus of 37.4 kg ha⁻¹, 41.8 kg ha⁻¹ and 39.6 kg ha⁻¹ in year 2018, 2019 and pooled respectively at depth D₁ and was found significantly superior to all other agroforestry systems. Agri-horti-silviculture was however found next to horti-silvi-pasture system recording 34.7 kg ha⁻¹, 36.9 kg ha⁻¹ and 35.8 kg ha⁻¹ and horti-agriculture with 28.2, 33.25 and 30.7 kg ha⁻¹ in year 2018, 2019 and pooled respectively at depth D₁. The lowest value for available soil phosphorus was recorded in agri-silviculture (boundary plantation) recording 20.6, 23.7 and 22.1 kg ha⁻¹ in year 2018, 2019 and pooled respectively at depth D₁. Also, available soil phosphorus was higher at depth D₁ than depth D₂ in all agroforestry systems

4.3.6 Available Potassium (kg ha⁻¹) in soil under prominent agroforestry systems

The data recorded on available soil potassium under prominent agroforestry systems is presented in Table 27. Among four different systems under study, horti-silvi-pasture recorded maximum available potassium of 289.0 kg ha⁻¹, 295.2 kg ha⁻¹ and 292.15 kg ha⁻¹ in year 2018, 2019 and pooled respectively at depth D₁ and was found significantly superior to all other agroforestry systems. Agri-horti-silviculture was however found next to horti-silvi-pasture system recording 249.7 kg ha⁻¹, 255.4 kg ha⁻¹ and 252.65 kg ha⁻¹ and horti-agriculture with 235.1 kg ha⁻¹, 241.1 kg ha⁻¹ and 238.15 kg ha⁻¹ in year 2018, 2019 and pooled respectively at depth D₁, while lowest available soil potassium was recorded in agri-silviculture (boundary plantation) recording 229.0 kg ha⁻¹, 233.9 kg ha⁻¹ and 231.5 kg ha⁻¹ in year 2018, 2019 and pooled respectively at depth D₁. Also, available soil potassium was higher at depth D₁ than depth D₂ in all agroforestry systems.

Table 26: Status of available Phosphorus P_2O_5 (kg ha⁻¹) in soil under prominent agroforestry systems

Systems	2018			2019			Pooled		
	*D ₁	**D ₂	Mean	*D ₁	**D ₂	Mean	*D ₁	**D ₂	Mean
Horti-agriculture	31.9	24.5	28.2	37.2	29.3	33.25	34.5	26.9	30.7
Agri-silviculture(boundary plantation)	24.0	17.2	20.6	26.7	20.7	23.7	25.3	18.9	22.1
Agri-horti-silviculture(homegarden)	40.0	29.4	34.7	42.0	31.8	36.9	41.1	30.6	35.8
Horti-silvipasture	41.2	33.7	37.4	45.8	37.8	41.8	43.5	35.8	39.6
C.D(p<0.05)									
D	0.38			0.46			0.41		
S	0.54			0.64			0.58		
D × S	0.77			0.91			0.83		

S = System, D = Depth, *D₁= (0-30)cm, **D₂= (30-60)cm

Table 27: Status of available pottassium K₂O (kg ha⁻¹) in soil under prominent agroforestry systems

Systems	2018			2019			Pooled		
	*D ₁	**D ₂	Mean	*D ₁	**D ₂	Mean	*D ₁	**D ₂	Mean
Horti-agriculture	260.2	210.0	235.1	266.3	215.9	241.1	263.3	213.0	238.15
Agri-silviculture(boundary plantation)	248.1	209.9	229	253.2	214.67	233.9	250.7	212.3	231.5
Agri-horti-silviculture(homegarden)	275.0	224.5	249.7	280.9	230.02	255.4	278.0	227.3	252.65
Horti-silvipasture	311.0	267.1	289.0	317.4	273.1	295.2	314.2	270.1	292.15
C.D(p<0.05)									
D	0.25			0.25			0.22		
S	0.36			0.36			0.31		
D × S	0.51			0.51			0.44		

S = System, D = Depth, *D₁= (0-30) cm, **D₂= (30-60) cm

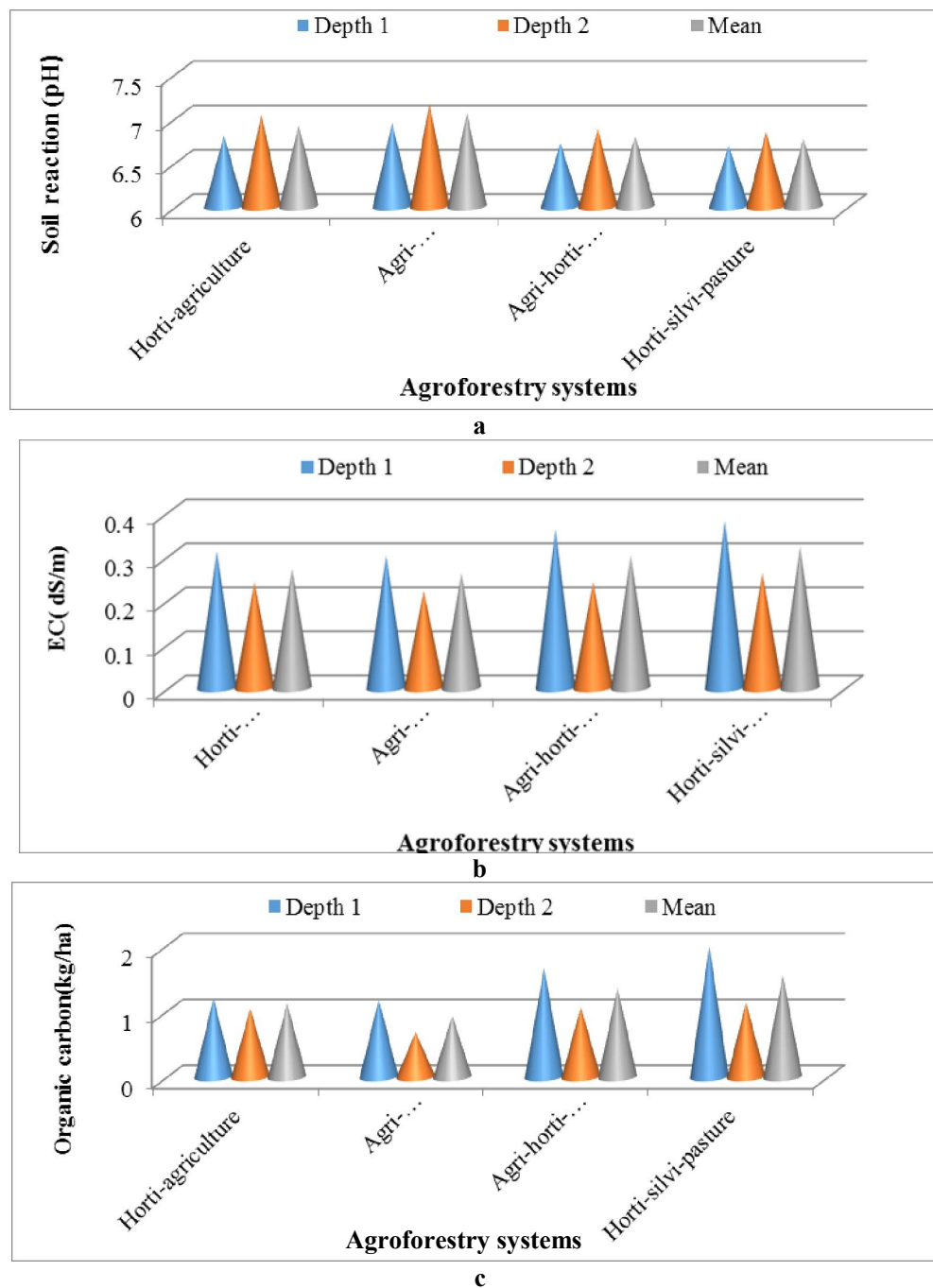
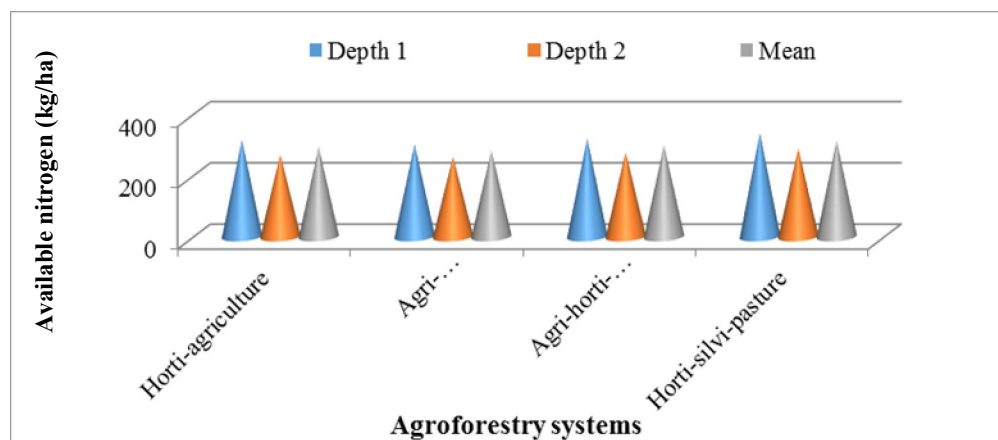
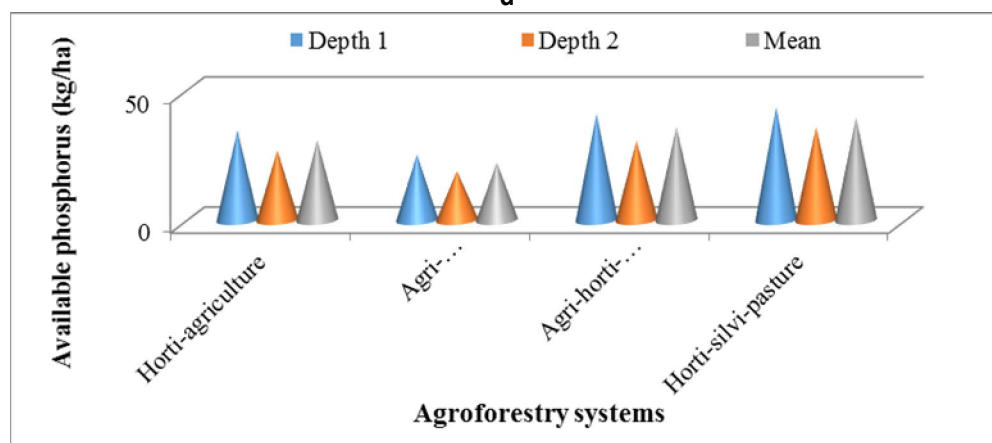


Fig. 4: Comparison of soil chemical properties (a) Soil pH (b) Electrical conductivity (c) Organic carbon (d) Nitrogen, (e) Phosphorous, (f) Potassium

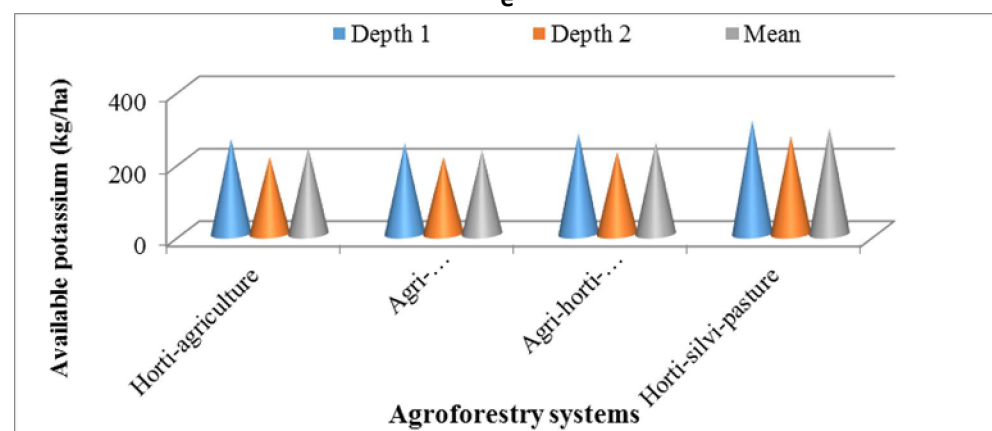
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d



e



f

4.3.7 Nitrogen, phosphorus and potassium concentration (%) and their uptake (kg ha⁻¹) in companion crops under horti-agriculture system

Persual of data in Table 28 reveals that in horti-agriculture system, the maximum nitrogen, phosphorus and potassium content was recorded as 1.24%, 0.26% and 1.23% and their uptake as 167.4 kg ha⁻¹, 35.1 kg ha⁻¹ and 166.05 kg ha⁻¹ respectively in maize whereas, minimum nitrogen, phosphorus and potassium content and their uptake was recorded in chilli as 0.73%, 0.16% and 0.60% and their uptake as 36.13 kg ha⁻¹, 7.92 kg ha⁻¹ and 29.7 kg ha⁻¹ respectively.

Table 28: Nitrogen, phosphorus and potassium concentration (%) and their uptake (kg ha⁻¹) in companion crops under horti-agriculture system (Pooled data for year 2018-2019)

Crop	Nitrogen		Phosphorus		Pottassium	
	(%) (Mean±S.E)	Uptake (kg ha ⁻¹)	(%) (Mean±S.E)	Uptake (kg ha ⁻¹)	(%) (Mean±S.E)	Uptake (kg ha ⁻¹)
Rabi crops						
Radish	0.81±0.12	41.71	0.20±0.008	10.03	0.71±0.11	36.56
Kale	0.90±0.01	49.35	0.21±0.034	11.51	0.79±0.08	43.29
Oats	1.17±0.03	58.38	0.24±0.014	11.97	1.11±0.07	55.38
Kharif crops						
Chilli	0.73±0.51	36.13	0.16±0.01	7.92	0.60±0.15	29.7
Beans	0.76±0.05	38.60	0.18±0.017	9.14	0.66±0.05	33.52
Maize	1.24±0.12	167.4	0.26±0.023	35.1	1.23±0.06	166.05

4.3.8 Nitrogen, phosphorus and potassium concentration (%) and their uptake (kg ha⁻¹) in companion crops under agri-silviculture system (boundary plantation)

In agri-silviculture system (boundary plantation), the maximum nitrogen content was recorded in mustard as 1.39 % and its uptake 124.74 kg ha⁻¹ in paddy respectively, while the minimum nitrogen content 1.21% and its uptake 64.61 kg ha⁻¹ in oats. Similarly, the maximum phosphorus content and uptake was 0.25% and 14.97 kg ha⁻¹ respectively in mustard, while as the minimum phosphorus content was recorded in paddy as 0.11 % and its minimum uptake was 10.14 kg ha⁻¹ in oats. Maximum potassium content was recorded in mustard as 2.12% and its uptake was maximum in paddy as 135.63 kg ha⁻¹, while minimum potassium content 1.37 % was recorded in paddy and minimum uptake in oats as 82.23 kg ha⁻¹ (Table 29).

Table 29: Nitrogen, phosphorus and potassium concentration (%) and their uptake (kg ha⁻¹) in companion crops under Agri-silviculture system (boundary plantation) (Pooled data for year 2018-2019)

Crop	Nitrogen		Phosphorus		Pottassium	
	(%) (Mean±S.E)	Uptake (kg ha ⁻¹)	(%) (Mean±S.E)	Uptake (kg ha ⁻¹)	(%) (Mean±S.E)	Uptake (kg ha ⁻¹)
Rabi crop						
Oats	1.21±0.05	64.61	0.19±0.017	10.14	1.54±0.05	82.23
Mustard	1.39±0.07	83.26	0.25±0.02	14.97	2.12±0.20	126.98
Kharif crop						
Paddy	1.26±0.03	124.74	0.11±0.01	10.89	1.37±0.03	135.63

4.3.9 Nitrogen, phosphorus and potassium concentration (%) and their uptake (kg ha⁻¹) in companion crops under agri-horti-silviculture system (homegardens)

In agri-horti-silviculture system (homegardens), the maximum nitrogen, phosphorus and potassium content was recorded as 0.94%, 0.27% and 0.81% and their uptake as 52.73 kg ha⁻¹, 15.14 kg ha⁻¹ and 45.44 kg ha⁻¹ respectively in kale whereas, minimum nitrogen, phosphorus and potassium content and their uptake was recorded in chilli as 0.75%, 0.19% and 0.62% and their uptake as 38.4 kg ha⁻¹, 9.72 kg ha⁻¹ and 31.74 kg ha⁻¹ respectively.

Table 30: Nitrogen, phosphorus and potassium concentration (%) and their uptake (kg ha⁻¹) in companion crops under Agri-horti-silviculture system (homegarden) (Pooled data for year 2018-2019)

Crop	Nitrogen		Phosphorus		Pottassium	
	(%) (Mean±S.E)	Uptake (kg ha ⁻¹)	(%) (Mean±S.E)	Uptake (kg ha ⁻¹)	(%) (Mean±S.E)	Uptake (kg ha ⁻¹)
Rabi crops						
Kale	0.94±0.16	52.73	0.27±0.03	15.14	0.81±0.07	45.44
Turnip	0.83 ±0.34	45.56	0.24±0.03	13.17	0.76±0.23	41.72
Kharif crops						
Chilli	0.75±0.028	38.4	0.19±0.011	9.72	0.62±0.13	31.74
Beans	0.79±0.017	40.92	0.21±0.011	10.87	0.69±0.04	35.98

4.3.10 Nitrogen, phosphorus and potassium concentration (%) and their uptake (kg ha⁻¹) in companion crops under horti-silvi-pasture system.

Persual of data in Table 31 revealed that in horti-silvi-pasture system, in perennial grasses, the nitrogen content was 1.59% and its uptake 86.01 kg ha⁻¹. The phosphorus content and its uptake as 0.07% and 3.78 kg ha⁻¹ respectively and the potassium content as 0.12% and its uptake as 6.49 kg ha⁻¹.

Table 31: Nitrogen, phosphorus and potassium concentration (%) and their uptake (kg ha⁻¹) in companion crops under Horti-silvi-pasture system (Pooled data for year 2018-2019)

Crop	Nitrogen		Phosphorus		Potassium	
	(%) (Mean±S.E)	Uptake (kg ha ⁻¹)	(%) (Mean±S.E)	Uptake (kg ha ⁻¹)	(%) (Mean±S.E)	Uptake (kg ha ⁻¹)
Perennial grass	1.59±0.02	86.01	0.07±0.01	3.78	0.12±0.01	6.49

4.3.11 Nitrogen, phosphorus and potassium concentration (%) in tree leaves and their annual uptake, retranslocation and return (kg ha⁻¹) under horti-agriculture system

Persual of data in Table 32 revealed that in horti-agricultural system, average N, P, K content in apple leaves was 1.79%, 0.06%, 1.19% while nitrogen uptake from the soil was recorded as 26.69 kg ha⁻¹. On the basis of nutrient analysis of senescing leaves, it was found that 41.40 % of nitrogen returned back to soil in the form of litter, therefore 58.60% of nitrogen from leaves was retranslocated to the storing organs of apple trees. With respect to phosphorus, out of the total uptake 0.87 kg ha⁻¹, 38.96 % was retranslocated and 62.06 % returned back to soil in the form of litter. For potassium, 62.11% returned back to soil and 37.88 % retranslocated out of total uptake 17.74 kg ha⁻¹.

Similarly, average N, P, K content of leaves in walnut trees was 2.2%, 0.27%, 0.85%, out of the total uptake 70.71, 44.98% was retranslocated and 55.01 % was returned back to soil in the form of litter. With respect to phosphorus, 36.38 % returned back to soil and 63.61% retranslocated out of total uptake 8.67

kg ha⁻¹. For potassium 63.91 % returned back to soil and 36.11% retranslocated out of total uptake 27.32 kg ha⁻¹.

Table 32: Nitrogen, Phosphorus and Potassium content (%) in tree leaves and their uptake, retranslocation, and return (kg ha⁻¹) under Horti-agriculture system (Pooled data for the year 2018-2019)

Species	Parameter	N	P	K
Apple	Nutrient(%)	1.79	0.059	1.19
	Uptake	26.69	0.87	17.74
	Retranslocation	15.64 (58.60)	0.33 (38.96)	6.72 (37.88)
	Return	11.05 (41.40)	0.54 (62.06)	11.02 (62.11)
Walnut	Nutrient (%)	2.2	0.27	0.85
	Uptake	70.71	8.67	27.32
	Retranslocation	31.81 (44.98)	5.92 (63.61)	10.58 (36.11)
	Return	38.9 (55.01)	3.38 (36.38)	18.74 (63.91)

(Figures in parentheses represent %age of the total uptake)

4.3.12 Nitrogen, phosphorus, potassium content (%) in tree leaves and their annual uptake, retranslocation and return (kg ha⁻¹) by trees under agri-silviculture system (boundary plantation)

The data pertaining to agri-silviculture system (boundary plantation) reveals that average N, P, K content in poplar leaves was 1.75 %, 0.51%, 0.89% while uptake of nitrogen from the soil was 56.35 kg ha⁻¹. On the basis of nutrient analysis of senescing leaves, it was found that 41.18 % of this nitrogen returned back to the soil (in form of litter). Therefore 58.81 % of nitrogen from leaves was retranslocated to storing organs of poplar. With respect to phosphorus, out of total uptake 16.42 kg ha⁻¹, 71.64% was retranslocated and 28.38 % was returned back to the soil in form of litter. For potassium, 33.33 % returned back to soil and 66.67 % retranslocated out of total uptake 28.65 kg ha⁻¹.

In Salix, the average leaf N, P, K content was 1.17%, 0.06%, 0.95% with total uptake of 26.72 kg ha⁻¹ nitrogen, out of which 31.25 % returned back to the soil in form of litter and 68.75 % was retranslocated to woody components. With respect to phosphorus, out of total uptake 1.34 kg ha⁻¹, 63.24 % was retranslocated

and 37.31 % returned back to soil. For potassium, 46.65 % returned back to soil and 53.38 % retranslocated out of total uptake of 21.69 kg ha⁻¹ (Table 33)

Table 33: Nitrogen, Phosphorus and Potassium content (%) in tree leaves and their uptake, retranslocation, and return (kg ha⁻¹) under Agri- silviculture system (boundary plantation) (Pooled data for the year 2018-2019)

Species	Parameter	N	P	K
Poplar	Nutrient (%)	1.75	0.51	0.89
	Uptake	56.35	16.42	28.65
	Retranslocation	33.14 (58.81)	11.76 (71.64)	19.10 (66.67)
	Return	23.21 (41.18)	4.66 (28.38)	9.55 (33.33)
Salix	Nutrient (%)	1.17	0.059	0.95
	Uptake	26.72	1.34	21.69
	Retranslocation	18.37 (68.75)	0.84 (63.24)	11.57 (53.38)
	Return	8.35 (31.25)	0.50 (37.31)	10.12 (46.65)

(Figures in parentheses represent %age of the total uptake)

4.3.13 Nitrogen, phosphorus, potassium content (%) in tree leaves and their annual uptake, retranslocation and return (kg ha⁻¹) by trees under agri-horti-silviculture system (homegarden).

Persual of data in Table 34 reveals that in agri-horti-silviculture (homegarden), the average N, P, K content in leaves in poplar was 1.69 %, 0.57 %, 0.96 %, while uptake of nitrogen from the soil was 35.54 kg ha⁻¹. On the basis of nutrient analysis of senescing leaves, it was found that 50.05 % of this nitrogen returned back to the soil (in form of litter). Therefore, 49.94% of nitrogen from leaves was retranslocated to storing organs of poplar. With respect to phosphorus, out of total uptake of 11.99 kg ha⁻¹, 58.52 % was retranslocated and 41.45 % was returned back to the soil in form of litter. For potassium, 45.86 % returned back to soil and 54.13 % retranslocated out of total uptake 20.19 kg ha⁻¹.

In Salix, the average leaf N, P, K content was 1.11 %, 0.07%, 1.07% with total uptake of 19.22 kg ha⁻¹ nitrogen from soil, 38.60 % returned back to the soil in form of litter and 61.40 % was retranslocated to woody components. With

respect to phosphorus, out of total uptake 1.11 kg ha^{-1} , 54.05 % was retranslocated and 45.94 % returned back to soil. For potassium, 58.82 % returned back to the soil and 41.23 % retranslocated out of total uptake of 17.0 kg ha^{-1} .

In apple tree, the average content of N, P, K in leaves was 1.82 %, 0.05%, 1.09% with total uptake of nitrogen was 18.44 kg ha^{-1} from the soil. It was found that 37.47 % of this nitrogen returned back to the soil (in form of litter) and about 62.52 % of nitrogen from leaves was retranslocated to storing organs of apple trees. With respect to phosphorus, out of total uptake 0.52 kg ha^{-1} , 54.84 % was retranslocated and 46.76% was returned back to the soil in form of litter. For potassium, 49.36 % returned back to soil and 50.69 % retranslocated out of total uptake 11.04 kg ha^{-1} .

Table 34: Nitrogen, Phosphorus and Potassium content (%) in tree leaves and their uptake, retranslocation, and return (kg ha^{-1}) under Agri-horti-silviculture system (homegardens) (Pooled data for the year 2018-2019)

Species	Parameter	Nitrogen	Phosphorus	Potassium
Poplar	Nutrient (%)	1.69	0.57	0.96
	Uptake	35.54	11.99	20.19
	Retranslocation	17.75 (49.94)	7.02 (58.52)	10.93 (54.13)
	Return	17.79 (50.05)	4.97 (41.45)	9.26 (45.86)
Salix	Nutrient (%)	1.11	0.07	1.07
	Uptake	19.22	1.11	17
	Retranslocation	11.80 (61.40)	0.6 (54.05)	7.00 (41.23)
	Return	7.42 (38.60)	0.51 (45.94)	10.0 (58.82)
Apple	Nutrient (%)	1.82	0.052	1.09
	Uptake	18.44	0.526	11.04
	Retranslocation	11.53 (62.52)	0.28 (54.84)	5.59 (50.69)
	Return	6.91 (37.47)	0.246 (46.76)	5.45 (49.36)

(Figures in parentheses represent %age of the total uptake)

4.3.14 Nitrogen, phosphorus, potassium content (%) in tree leaves and their annual uptake, retranslocation and return (kg ha^{-1}) by trees under horti-silvi-pasture system

Table 35 revealed data pertaining to horti-silvi-pasture system, the average leaf N, P, K content in poplar leaves was 1.83%, 0.61% and 1.18% while uptake of nitrogen was 68.51 kg ha^{-1} from the soil. On the basis of nutrient analysis of senescing leaves, it was found that 52.15 % of this nitrogen returned back to the soil (in form of litter) and 47.85 % of nitrogen from leaves was retranslocated to storing organs of apple trees. With respect to phosphorus, out of total uptake 22.83 kg ha^{-1} , 53.85 % was retranslocated and 46.16 % was returned back to the soil in form of litter. For potassium, 48.21% returned back to soil and 51.79% retranslocated out of total uptake 44.18 kg ha^{-1} .

In salix, the average nitrogen content in leaves was 1.20 % with total uptake of 29.62 kg ha^{-1} . On the basis of nutrient analysis of senescing leaves, it was found that 40.91% of this nitrogen returned back to the soil (in form of litter). Therefore, 59.08% of nitrogen from leaves was retranslocated to storing organs of poplar. With respect to phosphorus, out of total uptake 2.22 kg ha^{-1} , 50.0% was retranslocated and 49.54 % was returned back to the soil in form of litter. For potassium, 64.59% returned back to soil and 35.36% retranslocated out of total uptake of 26.41 kg ha^{-1} .

In apple trees, the average leaf N, P, K was 1.91 %, 0.06%, 1.36 % with total uptake of 32.57 kg ha^{-1} nitrogen, 45.34 % returned back to the soil in form of litter and 54.65 % was retranslocated to woody components. With respect to phosphorus, out of total uptake 1.04 kg ha^{-1} , 31.52 % was retranslocated and 68.55 % returned back to soil. For potassium, 66.70% returned back to the soil and 33.29% retranslocated out of total uptake of 23.19 kg ha^{-1} .

Table 35: Nitrogen, Phosphorus and Potassium content (%) in tree leaves and their uptake, retranslocation, and return (kg ha⁻¹) under Horti-silvi-pasture system (Pooled data for the year 2018-2019)

Species	Parameter	N	P	K
Poplar	Nutrient (%)	1.83	0.61	1.18
	Uptake	68.51	22.83	44.18
	Retranslocation	32.78 (47.85)	12.29 (53.85)	22.88 (51.79)
	Return	35.73 (52.15)	10.54 (46.16)	21.3 (48.21)
Salix	Nutrient (%)	1.20	0.09	1.07
	Uptake	29.62	2.22	26.41
	Retranslocation	17.5 (59.08)	1.11 (50.0)	9.34 (35.36)
	Return	12.12 (40.91)	1.10 (49.54)	17.06 (64.59)
Apple	Nutrient (%)	1.91	0.061	1.36
	Uptake	32.57	1.04	23.19
	Retranslocation	17.80(54.65)	0.327(31.52)	7.72(33.29)
	Return	14.77(45.34)	0.713(68.55)	15.47(66.70)

(Figures in parentheses represent %age of the total uptake)

4.3.15 Average nutrient concentration (%), uptake (kg ha^{-1}), retranslocation (kg ha^{-1}) and return (kg ha^{-1}) in four prominent agroforestry systems

The perusal of Table 36 clearly reveals that in crop components, average maximum nitrogen content was recorded in horti-silvi-pasture system as 1.75 %, while minimum 0.95% was recorded in agri-silviculture (boundary plantation). Similarly, maximum (0.19%) phosphorus content and 1.87% potassium content was recorded in agri-silviculture (boundary plantation). In tree components of different agroforestry systems, the maximum average nitrogen content 1.99% was recorded in horti-agriculture system, while minimum 1.46 % recorded in agri-silviculture (boundary plantation). Similarly maximum 0.28% phosphorus was recorded in agri-silviculture (boundary plantation) and minimum 0.16% in horti-agricultural system. Maximum 1.20% potassium was recorded in horti-silvi-pasture system and minimum 0.92% in agri-silviculture (boundary plantation). The overall average comparison of agroforestry systems practiced by the farmers of Anantnag district did not show clear trend in nutrient uptake, retranslocation and return. However, the maximum nitrogen uptake in crop was 98.7 kg ha^{-1} under horti-silvi-pasture system, while minimum 54.30 kg ha^{-1} in agri-silviculture (boundary plantation). Maximum uptake of phosphorus 11.12 kg ha^{-1} and potassium $126.72 \text{ kg ha}^{-1}$ was recorded in horti-agriculture and agri-silviculture (boundary plantation) respectively. In tree component, the maximum nitrogen and phosphorus uptake was recorded as 130.7 kg ha^{-1} and 26.09 kg ha^{-1} respectively in horti-silvi-pasture system and maximum potassium uptake as 50.34 kg ha^{-1} in agri-silviculture (boundary plantation) was recorded. The maximum nitrogen, phosphorus and potassium retranslocation was recorded as 61.99%, 70.95% and 60.92% respectively under agri-silviculture (boundary plantation). Maximum nitrogen and potassium return was recorded as 50.63 kg ha^{-1} and 64.13 kg ha^{-1} respectively in horti-agriculture, while maximum phosphorus return was recorded as 47.34 kg ha^{-1} in horti-silvi-pasture system.

Table 36: Average nutrient concentration (%), uptake (kg ha⁻¹), retranslocation (kg ha⁻¹) and return(kg ha⁻¹) of crops and tree leaves in four prominent agroforestry systems

System	Nutrient %						Uptake(kg ha ⁻¹)						Retranslocation			Return		
	Crop			Tree			Crop			Tree			Tree			Tree		
	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
Horti-agriculture	1.11	0.19	1.27	1.99	0.16	1.02	70.58	11.12	81.34	114.3	10.18	47.06	60.91 (53.29)	6.25 (61.39)	16.88 (35.87)	57.87 (50.63)	3.92 (38.51)	30.18 (64.13)
Agri-silviculture (boundary plantation)	0.95	0.19	1.87	1.46	0.28	0.92	54.30	1.22	126.72	83.07	17.76	50.34	51.5 (61.99)	12.6 (70.95)	30.67 (60.92)	31.56 (37.99)	5.16 (29.05)	19.67 (39.07)
Agri-horti-silviculture homegardens	1.15	0.18	1.08	1.54	0.23	1.04	57.71	9.16	50.28	24.4	4.54	16.07	13.69 (56.10)	2.63 (57.9)	7.84 (48.78)	10.70 (43.85)	1.90 (41.85)	8.23 (51.21)
Horti-silvi-pasture system	1.75	0.07	0.12	1.64	0.25	1.20	98.7	4.06	6.76	130.7	26.09	31.26	68.08 (52.08)	13.72 (52.59)	13.31 (42.57)	62.62 (47.91)	12.35 (47.34)	17.94 (57.38)

Values in parentheses represents percentage of retranslocation and return in prominent agroforestry systems of study area

Chapter-5

DISCUSSION

The study on “**Biomass, carbon sequestration and nutrient status of prominent agroforestry systems of district Anantnag of Jammu and Kashmir**” was carried out during year 2018-19. The pertinent results have been discussed in this chapter, establishing a cause-and-effect relationship whenever necessary or feasible in the light of available literature, under following headings:

5.1 Prevalent agroforestry systems of district Anantnag

Agroforestry is the key path to prosperity for farmers and rural people, leading to the generation of employment and revenue; food and nutritional security; meeting the other basic human needs on the sustainable basis and cushioning farmers from the harshness of climate change. Agroforestry practices vary from region to region and mainly depends on edapho-climatic, socio-economic status and basic needs of local people which results in variation in structure and composition of recommended technologies. The maximum farmers 70.83% (170) fall under the marginal category followed by 20.41% (49) under small, 7.08% (17) under medium and 1.67% (4) under large farmers as per their land holdings. Six prevalent agroforestry systems were identified as horti-agriculture, agri-silviculture (boundary plantation), agri-horti-silviculture (homegardens), horti-silvi-pasture, horti-pasture and silvi-pasture but four of them viz., horti-agriculture, agri-silviculture (boundary plantation), agri-horti-silviculture (homegardens) and horti-silvi-pasture were prominent. Horti-agriculture system was practised by 91.25 % (219) farmers followed by agri-silviculture (boundary plantation) 47.5 % (114), agri-horti-silviculture (homegardens), 27.08 % (65), horti-silvi-pasture 17.91 % (43), horti--pasture 15.81 % (38), silvipasture 9.58 % (23). Horticulture being the backbone of economy of Jammu and Kashmir, is widely being practised in almost all areas of state and same was found in the studied area which provide multiple benefits to

farmers. They usually allot some area in interspaces between fruit trees for cultivation of agricultural crops to meet their domestic needs besides fulfilling the cash needs of family through production of fruits. The results are in agreement with findings of Sabeena *et al.* (2016) who reported four prevalent agroforestry systems in district Budgam and Horti-agricultural being the most prominent system followed by agri-silviculture (boundary plantation), agri-horti-silviculture (homegarden) and horti-silvi-pasture system. Also, findings of Varadaranganatha and Madiwalar (2010) have reported six prominent agroforestry systems in three distinct agroecological situations in Uttara Kannada district, where bund planting was most prominent agroforestry system practiced by farmers followed by horti-silviculture and least prominent practice was block plantation. Similar findings were also reported by other researchers in their studies like Mughal and Khan 2007; Dwivedi *et al.*, 2007; Mughal and Bhattacharya 2002. Furthermore, Gusain *et al.*, (2021) reported eight types of agroforestry systems in plain regions of Uttarakhand, North India, among which agri-silviculture was highly practiced (59.07%) followed by silvopastoral system (24.51%) where Poplar and Eucalyptus along with horticulture trees were dominant species in agroforestry systems and five types of plantation patterns were recorded, among which boundary plantation pattern was mostly preferred (84.34%), followed by block plantation (12.12%).

5.1.1 Horti-agricultural system

The farmers grow agricultural crops along with fruit trees in the orchards in order to serve both needs like fruits as well as agricultural crops. The vegetable crops, like garlic, turnip, radish, carrot, kale, knol-khol, chilli, beans and tomato were cultivated under fruit trees mainly apple trees in alleys (Table 3). This system was practiced in areas where irrigation facility was available round the year as it was essential for the proper growth of agricultural crops. About 91.25 % of the farmers adopted this type of system as its main purpose was the production of fruits for marketing besides providing agricultural crops for subsistence use.

Farmers replace agricultural crops by grass species when trees attain maturity as their production begins to decline when trees grow bigger in size. Also, trees are felled for timber and fuelwood when the fruit yields decline. Similar type of agroforestry systems was reported by Khanal (2011), Bijalwan *et al.* (2009), Simon *et al.* (2015), Das *et al.*, (2020) and Riyadh *et al.*, (2020) but there were slight differences in their tree crop composition due to the differences in their agro-climatic zones.

5.1.2 Agri-silviculture (boundary plantation)

Agri-silviculture (boundary plantation) includes trees planted along boundaries or on bunds in such a way to holding the soil against erosion and improving soil fertility (by fixing nitrogen or bringing minerals from deep in soil and depositing them by leaf litter fall. As it is one of the oldest traditional system that has been practised around the paddy fields and trees are planted on bunds in Kashmir. About 47.5 % of the total farmers studied in the area adopted this type of system as rice has remained the staple food for the populace and is an important part of traditional food of Kashmir. It is also available alongside the road and canal/irrigation channels and in the vicinity of agricultural fields to meet the diverse needs like fuel, fodder and small timber. *Salix alba* is preferred in and around the irrigation channel whereas *Populus deltoids* Bartr, *Populus nigra* Bartr. and *Salix fragilis* L., find place on other existing lands at different spacings (Table 3). Farmers being aware about the shading effect of trees on paddy crop which can lower its productivity and could be the reason for planting trees on boundaries. Moreover, these tree species stabilize the bunds and offers protection to crop fields from erosion. Farmers preferred oats and mustard during the winter season and paddy during summer season. People were growing trees for getting timber for construction, packing cases, fodder for cattle, fuelwood, protection purposes etc. Our findings are in confirmity with the findings of Chauhan *et al.* (2009), Kumar and Nandal (2004), Sarvade *et al.* (2014), Singh *et al.* (2016), Raj *et al.* (2017), Wagle, (2005) and Chauhan *et al.* (2012) who reported that yield of

crops increased progressively with the increase in distance from tree line. Further, results are also in line with the findings of Neupane, 1999 who documented same type of system commonly found in Bari land, where maize, millet and vegetables are cultivated along with fodder and fuel wood/timber species like *Ficus hispida* L.f. (khasreto), *Bridelia retusa* (Gayo), *Bauhinia purpuria* (Tanki), *Litsea monopetala* (Kutmiro) and *Ficus semicordata* (Khanyo) planted in uncultivated areas, borders and terrace risers

5.1.3 Agri-horti-silviculture (homegarden)

Most common system in both rural and urban areas owing to marginal land holdings were homegardens. Homegardens in district Anantnag confirms wisdom and crises management situation of the people in a way that the multipurpose tree species and shrubs are grown in intimate association with crops and livestock within the premises of household to enhance the value of total production through marketing of multiple products from a given piece of land. People grow tree species with agricultural crops of rabi and kharif seasons. The forest trees commonly found in this system were *Salix* species, *Populus* species, *Ulmus villosa* and *Robinia pseudoacacia* L. at a closer spacing in single or double rows (Table 3). Different agriculture crops in both seasons (rabi+kharif) along with forest tree species on boundaries and fruit trees having greater diversity and highly productive in nature are grown in agri-horti-silviculture (homegardens) for meeting family needs and also surplus for sale. Commonly grown fruit trees were *Malus domestica* L., *Pyrus communis* L., *Prunus persica* L., *Prunus domestica* L. etc in this system. Vegetable crops such as kale, spinach, beans, onion, chilli, knol-khol, tomato, radish and turnip were cultivated and it depends on need and requirements of the inhabitants present in the area. In general, both cultivated and naturally growing plants are present in agri-horti-silviculture (homegardens), but most of naturally growing plants are not managed by agri-horti-silviculture (homegardens). The results are in accordance with Neupane (1999), Rana *et al.* (2016), Galhena *et al.* (2013), Blanckaert *et al.*, (2004), Kehlenbeck and Maass,

2004) and Ninez (1987) who reported that home gardens are having rich diversity and composition of species and generally provide varied and stable supply of socio-economic benefits to the families with relatively low labour, cash or other inputs.

5.1.4 Horti-silvi-pastoral system

It is popular land use system among farmers because of the problem of fodder scarcity in the district. It includes all components of horti-silviculture system along with some grass species. Farmers preferred grasses like *Amaranthus caudatus* L., *Cynodon dactylon* L., *Capsella bursa pastoris* L., *Trifolium repens* L., *Trifolium pretense* L., *Sonchus oleraceus* L. (Asteraceae) *Plantago lanceolata* L., *Oenothera rosea* L. Her.ex Aiton, *Taraxacum officinale* Weber, *Medicago polymorpha* L., *Cynodon dactylon* L., *Capsella bursa pastoris* L. etc. in addition to forest trees. Forest trees includes *Salix alba* L., *Populus deltoides* Bartr., *Populus nigra* Bartr., *Ulmus villosa*, *Robinia pseudoacacia* L. etc and fruit trees include *Malus domestica* L., *Pyrus communis* L., *Prunus persica* L. etc but mainly apple trees are present (Table 3). The forest tree species were grown by farmers on boundaries and fruit trees in blocks, where intercrops were mostly fodder species. The acceptance of this system among local inhabitants in district Anantnag can be supported by the fact that it embraces an huge potential to meet the cash needs of the family from the sale of fruits as well as provision to meet the fodder requirements of households in lean winter months. Similar trend of results was concluded by Pardon *et al.* (2018), Bhandari *et al.*, (2014) and Sanchez (1995) that horticulture-based agroforestry systems are possible multifunctional key for global food security, ecological protection and climatic variation adaptation by using well-adapted tree-crop combinations, thus restraining competition for resources and make best use of interactions.

5.1.5 Horti-pastoral system

Mostly prevalent in uplands of valleys and in some cases also found in plain lands and includes horticulture along with grass species. *Malus domestica* L., *Pyrus communis* L., *Prunus persica*, *Juglans regia* etc were found as fruit trees and *Cynodon dactylon* L., *Poa annua* L., *Plantago lanceolata* L., *Sorghum halepensis*, *Amaranthus caudatus* L., *Trifolium repens* L., *Trifolium pretense* L., *Oenothera rosea* L. Her.ex Aiton, *Taraxacum officinale* Weber, *Medicago polymorpha* L., *Stellaria media* L. (Vill), *Veronica persica* Poiret. etc were found as grass species (Table 3). The most commonly fodders grown as intercrops were clovers and it may be due to awareness among farmers of its N-fixing nature. The introduction of pasture component in the fruit tree-based agroforestry system makes them more beneficial to farmers as they serve both fodder needs for their cattle as well as production of apple fruits for increasing their cash needs, thus ensuring food and nutritional security. Due to increased population, it is essential for farmers to utilize the interspaces in the horticultural orchards for rise of forage resource availability due to poor production of grassland resource and shortage in forage supply and farmers incapability to spare their cultivated land for forage production. Similar role of effective strategy for proper orchard floor management has been advocated by Ahmad *et al.* (2018), Shukla *et al.* (2014), Kumar and Choubey (2009) and Shukla and Kumar (2007) and concluded that grass/legume intercropping not only augments forage availability but also enhances system productivity as a whole

5.1.6 Silvo-pasture system

In this system, main tree species include *Populus deltoids* Bartr., *Salix alba* L. and *Ulmus villosa* and grass species include *Amaranthus caudatus* L., *Cynodon dactylon* L., *Capsella bursa pastoris* L., *Trifolium repens* L., *Trifolium pretense* L., *Convolvulus arvensis*, *Sonchus oleraceus* L., *Plantago lanceolata* L., *Oenothera rosea* L. Her.ex Aiton, *Taraxacum officinale* Weber., *Medicago polymorpha* L., *Cynodon dactylon* L., *Chenopodium album* and *Capsella bursa*

pastoris L. etc (Table 3). Such systems occurred in lowlying areas where forest trees were found to grow in pasture lands. These systems were both forage based as well as timber producing agroforestry systems as farmers collect foliage from raised fodder trees and ground grasses to supply nutritious fodder for the livestock and use timber trees for household construction. Grass component in these two systems (horti-pasture and silvo-pasture system) can be made more productive by introducing high yielding pasture grasses with high forage content in our traditional agroforestry systems as in these two systems mostly focus on our tree component and not on the grass component and also, orchard grass has been reported as one of the most tolerant grass species in temperate agroforestry systems and as a suitable species for introduction in silvo-pasture systems (Peri *et al.* 2007 and Kyriazopoulos *et al.* 2013). Our results are also in agreement with Nepal (2005) and Mathew *et al.* (1992) who reported that silvopastoral systems maintain high productivity in a sustained manner at relatively low input levels even on poor substrates and are primarily on account of the vertical stratification of the shoot and root systems of different components.

The four prominent agroforestry systems selected for further evaluation include horti-agriculture, agri-silviculture (boundary plantation), agri-horti-silviculture (homegardens) and horti-silvipasture systems (Table 4).

5.2 Biomass production and carbon sequestration of prominent agroforestry systems

5.2.1 Biomass production (t ha^{-1}) in horti-agriculture, agri-silviculture, agri-horti-silviculture and horti-silvi-pasture systems

The biomass production in each agroforestry system has been categorised as forest trees, fruit trees and crop biomass. Crop biomass on the other hand was categorised as rabi and kharif (Tables 6, 8, 10, 11). The biomass of tree in different parts *viz.*, stem, branch wood, leaves and fruits depend upon number of factors *viz.*, growth habit of the species, site quality, soil on which it is growing,

age of the tree, management practices, frequent intercultural operations and moisture conservation and its interaction with intercrop (Albrecht and kandji, (2003) and yadava (2011). Similarly crop biomass production depends on the edapho-climatic factors and nature of the crop in different agroforestry systems. Aboveground biomass is the most important visible and dominant carbon pool in vegetation systems. Among four agroforestry systems, maximum average aboveground biomass (forest trees+fruit trees) was found in horti-silvi-pasture as 43.11 t ha^{-1} , followed by 30.81 t ha^{-1} in agri-horti-silviculture (homegardens), 23.70 t ha^{-1} in horti-agriculture and minimum 15.44 t ha^{-1} in agri-silviculture (boundary plantation). Maximum below ground biomass was found in Horti-silvi-pastoral as 12.58 t ha^{-1} followed by 8.16 t ha^{-1} in agri-horti-silviculture (homegardens) and minimum was found in agri-silviculture (boundary plantation) as 3.84 t ha^{-1} . The reason for maximum biomass in horti-silvi-pasture system and agri-horti-silviculture (homegardens) can be attributed to presence of both forest trees as well as fruit trees, with maximum number, average height and dbh, which contributed maximum biomass, while minimum was found in horti-agriculture and agri-silviculture (boundary plantation) and it was due to presence of lesser number of trees per hectare. This means that horti-silvipasture and agri-horti-silviculture (homegardens) are most efficient and horti-agriculture and agri-silviculture (boundary plantation) are less efficient from biomass production point of view. Our findings were supported by Dar *et al.* (2019); Yadav (2010); Koul and Panwar (2008); Fang *et al.* (2007) and Swamy *et al.* (2003) who reported that number of woody perennials involved in the system and the management practices plays a major role in influencing biomass of a particular system.

Total aboveground biomass in forest trees and contribution by different components to total biomass was in the order of stem>branch>leaf, while in fruit trees, the contribution of different components was in order of stem>canopy. In horti-silvi-pasture system, the contribution of forest tree stem biomass was 73.32 %, branch 5.2 % and leaf 1.39 %, while in fruit trees, stem biomass contribution

was 54.48 % and canopy biomass contribution was 20.59%. The trend remains same in all the other agroforestry systems. This is due to the fact that aboveground biomass is a key pool for most land use systems, so more biomass is allocated to aboveground parts. Similar trend of results was reported by Lodhiyal *et al.* (1995); Tokey *et al.* (1989) and Swamy *et al.* (2003) who reported that the contribution of bole to total above ground biomass was maximum followed by branches in woody species.

The above results have indicated that biomass component *viz.*, above ground biomass, belowground biomass and total biomass produced by particular agroforestry system is influenced by the age of the components-annual or perennial, type of crop, structure of the system, nature and number of woody components, etc. Similarly, observations were recorded by Nayak (1996) and Deshmukh (1998) who found above ground biomass influenced due to species, density and management practices under different agroforestry systems.

The crop biomass does not show any definite trend. Maximum crop biomass was found in horti-agriculture system (Oats-maize) as 4.99 t ha⁻¹ and 13.5 t ha⁻¹ followed by agri-silviculture (boundary plantation) (Oats-paddy) as 5.34 t ha⁻¹ and 10.01 t ha⁻¹ in rabi and kharif season under the influence of lowest number of trees per hectare and had more cropping area under these systems. This was due to the uninterrupted and adequate amount of incident sunlight besides, greater exposed photosynthetic area, zero tree-crop competition for moisture, light, nutrient and space etc. In horti-silvi-pastoral system, the mean perennial grass biomass were 7.18 t ha⁻¹ and 3.64 t ha⁻¹ and in agri-horti-silviculture (homegarden), mean crop biomass was found 5.53 t ha⁻¹ and 5.62 t ha⁻¹ in rabi and kharif season respectively. Minimum mean rabi and kharif biomass might be due to reduction in crop biomass as a result of competition between trees and crops for sharing different resources like sunlight, water and nutrients. Our results are in confirmity with Yadava (2010), Chauhan *et al.* (2008), Handa *et al.* (2004), Nandal and Singh (2001) and Burgess *et al.* (1996) who revealed better

performance and higher yield of crops with increase in distance from tree in all tree crop combination. Similarly, our results are also in agreement with Solanki (2018), Vanlalhluna and Sahoo (2010), Venugopal *et al.* (2008), Parekh and Patil (2003) and Jaimini *et al.* (2003) who reported that maximum fresh and dry weight per plant was recorded in sole crop as compared to intercrop in any land use system. The results are also more or less in accordance with the values obtained by Yadav (2011) and Dar *et al.* (2019) in their studies where they reported biomass of lemongrass was 6.49 t ha⁻¹ to 7.79 t ha⁻¹ under *Dalbergia sissoo* block plantation and 6.52 t ha⁻¹ and 5.94 t ha⁻¹ biomass in perennial grass in horti-silvi-pasture system in district Ganderbal of Jammu and Kashmir, respectively.

Total biomass production which followed more or less same trend as recorded in respect of above and below ground biomass and are in the order of horti-silvi-pastoral (66.55 t ha⁻¹) > agri-horti-silviculture (homegardens) (50.18 t ha⁻¹) > horti-agriculture (36.22 t ha⁻¹) > agri-silviculture (boundary plantation) (34.87 t ha⁻¹). The differences in the productivity of agroforestry systems may also be due to differences in soil conditions, phenology of dominant species, better root net working as well as efficient and economical use of limited resources for maintaining higher photosynthetic activities, leaf area index, better light interceptions and water use efficiency.

5.2.2 Carbon stock and carbon sequestration (t ha⁻¹) in horti-agriculture, agri-silviculture, agri-horti-silviculture and horti-silvi-pasture systems

Carbon stock is the absolute carbon quantity contained in a pool meaning a reservoir or system which has the capacity to accumulate or release carbon. In a particular agroforestry system, carbon stock depends on its biomass. Carbon variability in plant biomass can be high within complex agroforestry system and productivity depends on several factors including age, nature of the crop, growing habit, intensity of the management and soil types.

It is evident from the data presented in table 13-16 that in all the

treatments, the stem, branch, leaf, canopy, the above and below ground carbon stock were influenced by its components and structure in agroforestry system. Among four agroforestry system, it was found maximum in horti-silvi-pasture system (28.46 t ha^{-1}) followed by agri-horti-silviculture (homegardens) (22.56 t ha^{-1}), horti-agriculture system (16.28 t ha^{-1}) and agri-silviculture (boundary plantation) (15.67 t ha^{-1}). The main reason of maximum carbon stock in case of hortisilvipasture system and agri-horti-silviculture (homegardens) may be due to accumulation of biomass in the perennial tree components, inclusion of forest trees in the agroforestry system which results in continuous locking up of carbon in trees and regular addition of leaf litter to soil which helps in build-up of carbon in soil layers and in-turn helps in greater productivity of systems, whereas in case of horti-agriculture and agri-silviculture (boundary plantation), most of the biomass is removed annually by various practices like harvesting, pruning and felling.

The findings of Dar *et al.* (2019); Tumwebaze *et al.* (2012); Koul and Panwar (2008) and Oelbermann *et al.* (2004) are in corroboration with the present findings who reported that carbon stock depends heavily on tree density and carbon concentrations in each component of a tree species. Also, similar trend of results was recorded by Rajput (2010) who reported maximum rate of carbon stock (8.40 t ha^{-1}) in the Orchard+Cereal-Cereal land use system, which was 4-5 times higher than other land use system and also revealed that rate of carbon stock was higher (6.93 t ha^{-1}) in agrihorticulture land use system which was followed by horticulture (2.21 t ha^{-1}) and forest (2.15 t ha^{-1}) land use.

Carbon sequestration

It is evident from the data that all the traits for carbon sequestration potential were influenced due to different agroforestry systems, its components and structure. Maximum (89.0 t ha^{-1}) aboveground CO_2 sequestration (CO_2 equivalent) was found in horti-silvi-pasture than other agroforestry systems, whereas minimum (48.77 t ha^{-1}) aboveground carbon sequestration by horti-

agriculture. Maximum average carbon sequestration potential (89.0 t ha^{-1}) was recorded under horti-silvi-pasture, followed by (77.77 t ha^{-1}) in agri-horti-silviculture (homegardens) (56.45 t ha^{-1}) in agri-silviculture (boundary plantation) and minimum in horti-agriculture as 48.77 t ha^{-1} . The carbon sequestration potential for stem, branch, leaf, aboveground, belowground followed the same trend as respective values of carbon stock because the carbon sequestration potential is proportional to biomass accumulated and its carbon stock.

It can be inferred from the above result that variability in the carbon dioxide sequestration potential under various land use systems depends primarily on species, genetic makeup, its age, structure, functional components and their number etc. Though tree plantation sequester more carbon and hence are better option for reducing atmospheric carbon, they cannot be extended to large areas due to population pressure and high demand of land for agriculture purposes. Therefore, agroforestry system seems to be a better option and simultaneously harness the opportunity for biodiversity conservation and economic benefits to the society. Similar results were found by Nair *et al.*, 2009 as the potential of C sequestration in agroforestry systems (AFS) is dependent on the tree component. Results correspond to the carbon sequestration of agroforestry systems and alternative land use systems in India, as 25 tonnes C per hectare has been estimated to be an average sequestration potential in agroforestry systems as reported by Sathaye and Ravindranath (1998). Moreover, our results are similar to the findings of Sureshbhai *et al.* (2017), Bhalawe (2014), Khaki and Wani (2011), Rajput (2010) and Yadava (2011) who reported higher carbon sequestration potential in land use systems with maximum woody component than other land use systems with lesser woody component.

Carbon sequestration estimates of all the systems were in line with their biomass production potential as it is directly related to biomass production of the different plant components.

The overall comparison of agroforestry systems practised by the farmers of Anantnag district clearly shows that the horti-silvi-pastoral are the most productive in terms of total biomass accumulation (53.89 t ha^{-1}), carbon stock (22.75 t ha^{-1}) and CO_2 mitigation potential of 89.0 t ha^{-1} . The contribution of forest trees in the horti-silvi-pastoral was 46.73 percent, fruit trees 33.13 percent and crop (rabi and kharif) contributed 20.13 percent in biomass, carbon stock and CO_2 mitigation potential. Agri-silviculture (boundary plantation), on the other hand, was least productive in terms of total biomass (29.53 t ha^{-1}), carbon stock (13.28 t ha^{-1}) and CO_2 sequestration potential of 48.77 t ha^{-1} . The contribution of fruit trees was 57.60 percent and crops contribute 42.60 percent. In our study, there was significant variation in carbon sequestration potential of different agroforestry practices. The amount of C sequestered largely depends on the agroforestry system placed, the structure and function are largely determined by environmental and socio-economic factors. Other factors which may influence carbon storage in agroforestry systems include tree species and system management.

5.3 Nutrient status of prominent agroforestry systems

5.3.1 Soil reaction (pH) in prominent agroforestry systems

The pH is an index of soil reaction which has profound effect on soil properties as well as on crop growth. The pH of soils being an important chemical property influences the suitability of soil for crop production, availability of nutrients, microbial activity and soil physical properties like structure, permeability, etc. Variations in pH among land use systems reflect differences in production of litter high in organic acid content, uptake of exchangeable bases and stimulation of mineral weathering as reported by Githae *et al.* (2011). It is evident from data presented in table 22, that soil pH varied between 6.76 in horti-silvi-pasture to 7.05 in agri-silviculture (boundary plantation). The soil pH increased with the increase in soil depth. The occurrence of slightly acidic pH in horti-silvi-pasture system can be attributed to the presence of high organic matter, its accumulation and subsequent slow decomposition, which releases organic acids

that lowers pH. Similar findings were observed by Uthappa *et al.*, 2015; Prasandini and Sreemannarayana, 2007 and Kumar *et al.*, 2008 who reported lower pH under high density canopy cover than less canopy cover due to accumulation of organic substances and its release during litter decomposition beneath trees. The value of 7.05 in agri-silviculture (boundary plantation) may be due to presence of greater quantities of bases (higher base cation content) like calcium and magnesium in a soil. Our results are also in conformity with results of Maqbool *et al.* (2017) Rathore *et al.* (2011); Mushki (1994); Ganai *et al.* (1991); Adejuwon and Ekanade (1988) and Yadav (1968). The findings of our study are further supported by the observations of Sharma (1991), Raina and Kumar (2000), Xu *et al.* (2006) and Raina *et al.* (2001) who reported that litter quality changes soil pH differently with increasing acidity for coniferous species and acidity for deciduous and herbaceous litter. Also, agroforestry systems showed lower pH at 0-30 cm depth because tree root abundance is high at this depth (Bowden, 1985). Similar results were found by Saralch (1994) and Murthy *et al.* (1985). In general, soil reaction was neutral which is ideal for uptake of most of the nutrients from the soil.

5.3.2 Electrical conductivity EC (dSm^{-1}) in soil under prominent agroforestry systems

Electrical conductivity of soil is a measure of concentration of ions in soil and is generally used as an indicator of salinity but, where nitrate levels are high and depending on the time of year and the climatic zone, EC can be an indicator of soil nitrate status. Generally, there is a positive correlation between EC and salt concentration. Soluble salts present in the soil, when come in contact with soil solution, dissociate into respective cations and anions. Higher the concentration of ions in the soil solution, higher is its electric conductivity (Ashraf *et al.*, 2012). Therefore, the measurement of EC is a relative measure of the total quantity of ions in the soil sample. Soil generally differs in their salt content which affect

their ability to grow crops and excess salts interfere with water as well as their nutrient uptake.

The EC in soil under different agroforestry systems is shown in table 23. The maximum EC was recorded in horti-silvi-pasture as 0.32 dSm^{-1} , whereas, minimum was found in agri-silviculture (boundary plantation) as 0.26 dSm^{-1} and it declined with increasing depth. This may be ascribed to high density of trees in horti-silvi-pasture and hence high litter fall and accumulation of calcium carbonate in soils, which in-turn leads to maximum EC in the soil, whereas in case of agri-silviculture (boundary plantation), density of trees is less, which results in less salt accumulation due to leaf litter and hence lower EC. Similar results were reported by Raina and Kumar (2000), Verma (2003) and Minhas *et al.* (1997). Furthermore, our findings are in parallel with the study carried out by various authors like Ashraf (2016); Shiekh (2006) and Bhat (2001).

5.3.3 Status of soil organic carbon (OC %) in prominent agroforestry systems

Soil organic carbon plays an important role in the carbon balance of global terrestrial ecosystems and is considered as a critical component of soil fertility and productivity (Ibrahim *et al.*, 2011) as it has direct role in root penetration, water movement and soil physical structure and possess an indirect role in soil microbial activity (Zabiniski *et al.*, 2002). According to table 24, the organic carbon declined with increasing depth in all agroforestry systems. The maximum organic carbon was recorded in horti-silvi-pasture as 1.55 %, whereas, minimum was found in agri-silviculture (boundary plantation) as 0.93 %. This maximum value of horti-silvi-pasture may be due to abundant tree leaf litter biomass returns to soil, combined with decay of roots which contribute to the improvement of organic matter, whereas the minimum value in agri-silviculture (boundary plantation) may be due to lopping of branches and removal of leaves and twigs from the field. Also, trees use a greater volume of soil to build up soil organic matter than herbaceous crops and explore soils farther from the tree trunk and to

greater depth to enhance belowground organic matter depositions. Similar findings were observed by Gupta *et al.* (2019), Bhusara (2014), Howlett *et al.* (2011) Moreno *et al.* (2005), Tandel (2003), Yihenew (2002) and Pandey *et al.* (2000) who reported that agroforestry system contributes towards nutrient conservation, soil amelioration and nutrient availability through huge amount of organic matter in the form of leaf biomass, mostly from tree canopy than herbaceous crops. Our observations are also in line with the findings carried out by Olorunfemi *et al.* (2018); Nawaz *et al.* (2017); Najar *et al.* (2009); Dandroo (2001 and Fassbender (1998). Wankhede and Jagdish (2008) and Chander *et al.* (1998) who reported higher organic C and total N, microbial biomass C, basal soil respiration and activities of dehydrogenase and alkaline phosphatase in treatments with tree-crop combination than in the treatment without trees which is also in harmony with our findings. The findings of our study are also in agreement with Rajput (2010) who reported similar results with maximum soil organic carbon (2.50 %) in the forest land use system, which was followed by agri-horticulture (0.89 %), horticulture (0.87%), silvipasture (0.81 %) and agriculture (0.68 %), respectively in the descending order. Low amounts of soil organic carbon under the agriculture land use system can be ascribed to intensive cropping as reported by Lal *et al.* (1998) and other workers from time to time. Our results indicate that adoption of the agroforestry practices with fast growing trees led to an improved organic matter status of the soil, which is also reflected in the increased nutrient pool necessary for long-term productivity of the soil.

5.3.4 Available nitrogen (kg ha^{-1}) in soil under prominent agroforestry systems

Nitrogen is an important building block of proteins, nucleic acid and other cellular constituents which are essential for all forms of life. Nitrogen is such an important key nutrient element for plants that it warrants careful management and if unmanaged, it can lead to severe environmental problems. Available N is the mineral form of nitrogen that can be readily absorbed by plant roots and is

available to plants by mineralization of organically bounded material or organic matter. It is explicit from the table 25 that the maximum nitrogen content was recorded in horti-silvi-pasture as 313.6 kg ha⁻¹ at depth D₁, whereas, minimum was found in agri-silviculture (boundary plantation) as 281.4 kg ha⁻¹. Higher available nitrogen in horti-silvi-pasture and agri-horti-silviculture (homegardens) was due to higher organic carbon in these systems as compared to that of other systems as high density of trees (both forest trees and fruit trees) were found in these systems.

Higher amount of tree leaf litter biomass returns to soil, combined with decay of roots contribute to the improvement of nitrogen status in soil as well as higher availability of cellulose and hemicelluloses in leaf litter, easy decay and release nutrient availability in soil as well in cropping. The available nitrogen content declined with increasing depth in all agroforestry systems. This can be attributed to addition and accumulation of leaf litter in top soil layers as availability of N depends to a great extent on the quantity and properties of organic matter. Comparable observations were reported by Singh *et al.* (2010), Tandel (2003) and De-hann (1977) who reported that good environmental conditions for nitrification and ammonification at surface layers are responsible for high content of available nitrogen in it than at lower layers or depths.

The intensity of the cultivation is very high in the boundary plantation as a result of which N is lost through removal of biomass, soil erosion and volatilization. The findings of our study are in accordance with Murphy, (2015), Kusumo *et al.* (2011), and Pandey *et al.* (2000) who observed that the decomposition of soil organic matter releases nutrients including nitrogen into the soil and hence a soil with a higher SOC concentration result in a greater release of organic N to the soil than a soil with lower SOC. Also, Venkanna *et al.* (2014) studied the different land use systems under semiarid tropical region of South India and observed higher nitrogen (0.0877%) in forest land followed by grass land (0.0822%) and lowest in paddy field (0.0622%).

5.3.5 Available phosphorus (kg ha⁻¹) in soil under prominent agroforestry systems

Phosphorus is found in soils both in an organic form and an in-organic (mineral) form and its solubility is low in soil. Phosphorus next to nitrogen is often the most limiting nutrient for crop and forage production.

The available phosphorus level varied in all four agroforestry systems. Horti-silvi-pasture recorded maximum phosphorus as 39.6 kg ha⁻¹ and minimum was in agri-silviculture (boundary plantation) as 22.1 kg ha⁻¹. Changes in nutrients status were due to decomposition rate of organic matter added through the leaf litter. The higher content of available phosphorus under horti-silvi-pasture and agri-horti-silviculture (homegardens) systems might be due to higher organic biomass added as leaf litter with their subsequent decomposition under these systems. This may be also be due to high organic carbon in this practice which prevents precipitation of iron, manganese and aluminium with phosphorus as compared to that of other system. The results are fully supported by the findings of Khanday *et al.* (2018); Meena (2012); Rathore *et al.* (2011); Madhusudanan (2011); Dhaliwal *et al.* (2008); Kumar *et al.* (2006); Ahmad (2003); Tandel (2003) and Akhtar (1997). Similar findings were also recorded by Yitbarek *et al.*, 2013 who reported that phosphorus availability may be due to dense finer roots, rapid microbial activity, higher proportion of leaf litter and the effect of plant root on soil. The low phosphorus in the lower soil depth D₂ in all prominent land use systems could be surface enrichment due to litter production and decomposition in tree-based production systems as similar results were documented by Starr *et al.* (2005).

Our findings are in agreement with Johannessen (1958) who reported that phosphorus is greater in soils under tree cover than grasses when other soil forming factors have been kept relatively constant. The amount of nutrients returned through litterfall varies depending upon the age and growth of trees,

quantity of litterfall addition and concentration of nutrients in litterfall (Singh *et al.* 2007).

5.3.6 Available potassium (kg ha^{-1}) in soil under prominent agroforestry systems

Potassium is an essential plant nutrient and is required in large amounts for proper growth and reproduction of plants. Soil organisms have a much lower requirement for potassium than plants do. As organic residues decompose, most of the potassium is quickly released. The available potassium level also varied in four agroforestry systems and the maximum potassium level was recorded in horti-silvi-pastoral system as $292.15 \text{ kg ha}^{-1}$ and minimum as 231.5 kg ha^{-1} in agri-silviculture (boundary plantation). It may be due to nutrient rich litter of trees which may have contributed to higher amount of potassium returned back to soil in form of litter and relative pumping of potassium from upper soil layer by grass species. Same observations have been reported by Puri *et al.* (1994); Saha *et al.* (1999) and Lin and Kao (2001). Also, high levels of K in soils under pasture have been mentioned by various authors like Tome, (1997 and Tornquist *et al.* (1999). According to Tome (1997), high levels of K may occur in acid soils under older pastures due to the capacity of many grass species to extract K from the upper soil and, through recycling, promote the availability of this nutrient in the soil. Ashoka (1998) reported that forest tree species recorded higher available nutrients such as potassium at surface and sub-surface soils, respectively. Bhusara (2014) reported similar work in available potassium content in *O. sativa* grown with *T. grandis*.

5.3.7 Nutrient status of crops and trees

Knowledge of cycling of nutrients is important to understand the way in which the fertility, which is lost due to removal of fodder, fuel, fruits and grains from agroforestry systems, is restored by biological process or by external inputs. The nutrient cycles consist of stores, flows within the system and gains and losses external to it. The nutrient stores are live plant parts, plant residues, soil organic

matter and the available nutrients in mineral form in the soil solution. The main internal flows are from the plant components to plant residues via soil fauna to soil humus, through the process of mineralization to mineral nutrients and return to the plants via root uptake. The objective in designing and managing agroforestry systems is to modify cycling in such a way as to make more efficient use of the nutrients, whether these originate from natural renewal processes or from inorganic fertilizers. It is however, desirable to reduce the ratio between inputs and outputs. If this ratio can be reduced, nutrients would be reused more often by plants before being lost from the system.

The mineral cycling consists of absorbing minerals, retaining them, in the tree components and returning them to the ground via litter. Although substantial amounts of nutrients are accumulated in biomass components, organic retention is generally lower than that returned to the soil by leaf drops plus those returned by litter (Tandon *et al.*, 1991). The nutrient content of trees was higher in case of high density due to increase in dry matter accumulation. Net uptake is the sum of amount of nutrients retranslocated from leaf litter plus those returned through litter. In our study total uptake of nutrients among the tree species of agroforestry systems was almost double in poplar and walnut than in salix and apple in all the agroforestry systems. Maximum N uptake 70.71 kg ha^{-1} was observed in walnut in Horti-agriculture (table 32), while minimum 18.44 kg ha^{-1} in apple tree in agri-horti-silviculture (homegardens) (table 32 -35). Maximum P uptake 22.83 kg ha^{-1} was recorded in case of poplar in horti-silvi-pasture (table 35), while minimum phosphorus 0.53 kg ha^{-1} was recorded in apple tree in agri-horti-silviculture (homegardens) (table 34). Maximum Potassium uptake 44.18 kg ha^{-1} was recorded in poplar in horti-silvi-pasture (table 35), while as minimum potassium 11.04 kg ha^{-1} was recorded in apple tree in agri-horti-silviculture (homegardens) (table 34). Similar results were reported by Das *et al.* (2015) who reported that net uptake of nutrients by *Acacia lenticularis* trees (after adjustment for retranslocation of nutrients from senescing leaves) varied between 51.1-73.1 kg

ha⁻¹ for N, 4.4-6.6 kg ha⁻¹ for P and 22.4-33.0 kg ha⁻¹ for K. Similarly, Tandon *et al.* (1991) who recorded annual uptake of 43.0 kg of N, 1.27 kg of P, 29.2 kg of K by the leaves of *Populus deltoids* at age of 9 years and recommended that uptake increases with increasing age. Furthermore, same results have been recorded by Dhyani (1997). He reported that pattern of uptake of nutrients in mandarin Systems was as follows: N > K > P as 51.1 kg ha⁻¹ and 4.5 kg ha⁻¹, 19.7 kg ha⁻¹. The lowest nutrient uptake of trees may be due to intrinsically low relative growth rate and absorption capacity. (Hunt and Burnett, 1973). Similarly, Bhat and Sujhata (2009) in their study on nutrient uptake pattern of Arecanut (*Areca catechu* L.) reported total nitrogen, phosphorus and potassium uptake by leaves, nuts and husk as 143 kg ha⁻¹, 15 kg ha⁻¹ and 46 kg ha⁻¹ respectively.

The maximum nitrogen, phosphorus and potassium uptake was recorded as 167.4 kg ha⁻¹, 35.1 kg ha⁻¹ and 166.05 kg ha⁻¹ respectively in maize in horti-agriculture system (Table 28). The maximum nitrogen uptake as 124.74 kg ha⁻¹ in paddy, phosphorus uptake as 14.97 kg ha⁻¹ in mustard and potassium uptake as 135.63 kg ha⁻¹ in paddy was recorded in agri-silviculture (boundary plantation) (Table 29). The maximum nitrogen, phosphorus and potassium uptake as 52.73 kg ha⁻¹, 15.14 kg ha⁻¹ and 45.44 kg ha⁻¹ respectively was recorded in kale in agri-horti-silviculture (homegarden) (Table 30). The nitrogen uptake as 86.01 kg ha⁻¹, phosphorus uptake as 3.78 kg ha⁻¹ and potassium uptake as 6.49 kg ha⁻¹ was recorded in perennial grasses in horti-silvi-pasture (Table 31).

Nutrient uptake by crop depends primarily on dry matter accumulation and on nutrient content. The increased dry matter production and nutrient content in plants are the indicative and correspond to higher uptake. The increased yield of succeeding residual crop is due to better nutrient status of soil as evident from the uptake of nutrients by the crop. This increased nutrient uptake might have stimulated various physiological processes in plant leading to increased growth and yield attributing characteristics and subsequent cumulative effect resulting in enhanced productivity of cropping system and yield of individual crops. Also,

uptake of nutrients depends on number, surface area both laterally localized supply of nutrients with the result that the growth of understorey species may be inhibited by the competitions for nutrients. Similar trend of results was reported by Sharma *et al.* (2012) who analysed that nitrogen uptake in wheat ranged between 92.4 and 90.8 kg ha⁻¹ and 114.7 to 116.9 kg ha⁻¹ under boundary plantation. They also reported phosphorus uptake as 16.0 to 13.6 kg ha⁻¹ and 14.0 kg ha⁻¹ to 12 kg ha⁻¹ under three- and four-year-old poplar plantations respectively. Also, Pallavi *et al.* (2016) studied straw of finger-millet and find higher nutrient content as (0.77%, 0.15%, 2.64%) and uptake (32.8, 7.16, 125.33 kg ha⁻¹) respectively in agri-silviculture system. Similarly, Choudhary *et al.* (2011) in their research on fenugreek-pearl millet cropping sequence, reported total nitrogen and phosphorus uptake as 35.5 kg ha⁻¹ and 3.9 kg ha⁻¹ respectively. Also, Nighat (2019) reported nitrogen, phosphorus and potassium uptake in two varieties of garden pea (Block Nishat-1, Block SCH-2), where total nitrogen uptake was 40.19 kg ha⁻¹ and 43.50 kg ha⁻¹, phosphorus uptake was 12.20 kg ha⁻¹ and 14.47 kg ha⁻¹, potassium uptake was 45.38 kg ha⁻¹ and 48.23 kg ha⁻¹ as reported in two varieties of garden pea (Block Nishat-1, Block SCH-2) respectively.

Retranslocation has been characterized as one of the most important strategies used by trees to conserve nutrients, which consequently influences competition, nutrient uptake and productivity (Killingbeck, 1996). Nutrient resorption from senescing leaves has important implications for element cycling at the ecosystem level. The nutrients which are resorbed during senescence are directly available for further plant growth, which makes a species less dependent on current nutrient uptake. Nutrients which are not resorbed, however, will be circulated through litterfall. The litter must be decomposed and the nutrients contained in that litter must be remineralized to become once again available for plant uptake. As these processes can take several years (Staaf and Berg, 1982; Berg, 1986) the nutrients contained in litterfall must be, in the short term,

considered as losses to the plant population. This shows that nutrient resorption is an important nutrient conservation mechanism and about half of the N and P contained in mature leaves are resorbed during senescence. The retranslocation and transfer of nutrients from older leaves to a tree stem each year is an important process in the dynamics of nutrients in most ecosystems especially in broadleaved ecosystem community (Niinemets and Kull, 2003; Kllingbeck, 1996; Duchesne *et al.*, 2001). Foliar nutrient concentrations vary widely amongst different species and individuals of the same species within same community (Niinemets and Kull, 2003).

The percentage of nutrients (NPK) retranslocated in tree species in horti-agriculture system, was in the order of (N>P>K) and (P>N>K) in apple and walnut trees respectively, whereas in agri-silviculture (boundary plantation) (Table 32-33), poplar and salix follows (P>K>N) and (N>P>K) trend. In agri-horti-silviculture (homegardens) (Table 34) trend was in the order of (P>K>N) (N>P>K) and (N>P>K) in poplar, salix and apple respectively. In horti-silvi-pasture system (Table 35) poplar, salix and apple follows (P>K>N) (N>P>K) and (N>K>P) trend respectively. This is consistent with findings of Salehi *et al.*, 2013 who reported the percentage of retranslocation of nutrients (NPK) was in the order P>K>N in *Populus caspica* as (N=18.93, P=39.63, K=24.02) planted in Safrabasteh poplar research station in Guilan province about 20 years ago in the north of Iran as endemic and endangered poplar species. Also, Hashemi *et al.* (2012) and Rostamabadi *et al.* (2010) reported high P retranslocation in different tree species in northern Iran. The degree by which an element can be retranslocated is determined by its physical properties, as well as plant's nutrient requirements. Similar observations were recorded by Fife *et al.* (2008).

The maximum nitrogen retranslocation 68.75 % was observed in salix in agri-silviculture (boundary plantation) (Table 33) and minimum 47.85 % in poplar under horti-silvi-pasture system (Table 35). However maximum phosphorus retranslocation (71.64 %) was reported in poplar under agri-silviculture (boundary

plantation) (Table 33) and minimum (31.52%) in apple trees under horti-silvi-pasture (Table 35). The highest potassium retranslocation 66.67 % has been found in poplar under agri-silviculture (boundary plantation) (Table 33) and minimum 33.29 % in apple under horti-silvi-pasture system.

High nutrient reabsorption is an adaptive strategy to tolerate nutrient stress with plant species often exhibiting the highest nutrient use efficiency to tolerate low levels of soil fertility. The results are in agreement with (Pastor *et al.*, 1984) who estimated that nutrient reabsorption of eight tree species by using the inverse of nutrient concentration in litter fall. They found that red pine had a highest nutrient reabsorption on sites with lowest nutrient availability. Similar study was carried out by Abid (2008) and reported that 35 percent of nitrogen, 51 percent of phosphorus, 38 percent of potassium and 42 percent of magnesium was retranslocated from senescing leaves of *Ulmus wallichiana* species and 28 percent of nitrogen, 45 percent of phosphorus, 20 percent of potassium and 10 percent of magnesium was retranslocated in case of *Populus deltoides*.

According to the results, the high retranslocation of N, P, K under agri-silviculture (boundary plantation) (table 33) are the characteristics of trees under element poor conditions. Also, the different responses of nutrient retranslocation of same tree species in different agroforestry systems are according to their nutritional requirements and site characteristics. Das and Chaturvedi (2006) suggested that the elements in short supply for plants were efficiently redistributed before senescence of leaves. This type of conservative behaviour leads to certain independence from the soil as a nutrient medium but it also means a reduced transfer to litters, a factor which favours an even nutrient availability and a tight circulation in the ecosystem. Liu *et al.* (2004) reported that high nitrogen element retranslocation and low growth rate are the characteristics of plants in poor element conditions; soils under horti-silvi-culture and agri-horti-silviculture (homegardens) are relatively nutrient rich, as efficiently as in other agroforestry systems. Lower rate of nutrient retranslocation in apple tree in horti-

silvi-pasture and horti-agriculture systems suggested that trees are less nutrient conservative and nutrients are being recycled in the soil. Similar results were reported by Dar *et al.* (2019).

Various researchers have clearly reported that tree species differ in their retranslocation potential (Hagen-Thorn *et al.*, 2006; Rouhi -Moghaddan *et al.*, (2008) and Hashemi *et al.*, 2012). Sharma and Sharma (2004) suggested that different retranslocation of nutrients depends upon many factors such as plant growth, species and stature associated with age and site characteristics. Same findings were also observed by Cuevas and Lugo (1998) who reported that tree species differ in N and P retranslocation and these differences are in response to eco-physiological reaction of each tree species to site conditions. Wright and Westoby (2003) stated that retranslocation proficiency is a much more accurate indicator of site fertility

Nutrient returns through litter fall under different tree species are important to understand the dynamics of soil fertility and the rates of forest litter falls and their decomposition contribute to the regulation of nutrient cycling and the maintenance of soil fertility in forest ecosystems (Onyekwelu *et al.*, 2006). The amount of nutrient added to the soil through decomposition of leaf litter depends on climatic conditions, litter quality and other site conditions such as topographic factors (Morrison, 2003). Generally, litter with high lignin and low N concentration has a slower decomposition rate and immobilizes more N than litter with low lignin and high N content. Cornwell *et al.* (2008) and Berg *et al.* (2010) observed that decomposition depends on the type of humus and on the N and P content of the leaves. Tree species can play an important role in nutrient cycling through different properties, such as the amount of litter produced, nutrients release and chemical composition of the litter (Rahajoe, 2003). Different tree species involve different nutrient release patterns, which are related to litter quality and seasonal environmental factors (Khiewtam and Ramakrishnan, 1993). Tracking nutrient returns through litter fall under different tree species is

important to understand the dynamics of soil fertility. Soil and old leaf nutrient retranslocation, are the primary sources of nutrients in the leaves (Binkley and Sollins (1995) and Piatek and Lee Allen (2000) and litter fall nutrient abundance is related to intensity of retranslocation processes in autumn (Parzych *et al.* 2008).

The nutrient returned to the soil via senescent leaves in apple and walnut trees in case of horti-agriculture system follows the trend (K>P>N) and (K>N>P), respectively, whereas in agri-silviculture (boundary plantation), the nutrient returned to the soil by poplar and salix are in the order of (N>K>P) and (K>P>N) (Table 32-33). In agri-horti-silviculture (home gardens), poplar, salix and apple tree follows (N>K>P) (K>P>N) and (K>P>N) trend in nutrient return to soil, whereas in horti-silvi-pasture system, the nutrient returned to the soil in poplar, salix and apple are in the order of (N>K>P) (K>P>N) and (P>K>N) (Table 34-35).

The results are in line with the findings of Salehi *et al.* (2013) reported that nutrient returned to the soil through senescent leaves was in the order of N>K>P in *Populus caspica* planted in Safrabasteh poplar research station in Guilan province about 20 years ago in the north of Iran as endemic and endangered poplar species. Pattern of nutrient concentration in senescent leaves varied according to the species. Similarly, Singh *et al.* (1989) and Lodhiyal and Lodhiyal (1997) reported the returned nutrient content by leaf litter in the order of N>K>P in *Populus deltoides* plantations in moist plain area in the north of India. However, Mahmood *et al.* (2009) and Mahmood *et al.* (2011) reported nutrient release from leaf litter of three tree species *Azadarachta indica*, *Dalbergia sissoo* and *Melia azadarach* in Bangladesh follows the order of K>N>P. Pawar (2013) also reported that the total return of the nutrients was in the order of N>K>P in *Albizia chinensis*. In a high-density plantation, nutrients returned to the floor was higher due to the increase in total litter production in relation to the low density of trees and the order of nutrients returned to the soil was N>K>P. The overall maximum 58.11 percent of N return was recorded in horti-agriculture, while maximum 68.55 percent phosphorus and 66.70 percent potassium was recorded in horti-silvipasture.

Chapter-6

SUMMARY AND CONCLUSION

The present investigation entitled, “**Biomass, carbon sequestration and nutrient status of prominent agroforestry systems of district Anantnag of Jammu and Kashmir**” was conducted in district Anantnag of Kashmir valley during the year 2018-2019 with following objectives:

- Identification of prevalent agroforestry systems
- Biomass production and carbon sequestration of prominent agroforestry systems
- Nutrient status of prominent agroforestry system

The first phase of the research included the collection of information regarding land use management and prevalent agroforestry systems in the said district based on the pre-tested questionnaire (Annexure-I) The second phase of the study was to further evaluate the biomass production and carbon sequestration of prominent agroforestry systems into account and their nutrient status.

From the investigation, it was appraised that six agroforestry systems were prevalent in district Anantnag, but four of them were found to be practised mostly by the farmers. The data were recorded on number of tree species, their height, diameter and biomass of all agroforestry systems by using 20×20m plot size in each agroforestry system.

The results revealed that different agroforestry systems have produced different biomass by each component such as stem, branch, leaf, canopy, aboveground, belowground, rabi crop and kharif crop as well as total biomass, carbon stocks and carbon mitigation potential by above mentioned categories.

Identification of prevalent agroforestry systems

Out of the total surveyed farmers, 70.83% belonged to marginal category,

followed by small (20.41%), medium (7.08 %) and large (1.67%) farmers. Six agroforestry systems were prevalent in district Anantnag viz., hortiagriculture, agri-silviculture (boundary plantation), agri-horti-silviculture (homegarden), horti-silvipasture, horti-pasture and silvi-pasture, but four of them viz., hortiagriculture, agri-silviculture (boundary plantation), agri-horti-silviculture (homegarden), horti-silvipasture, were found to be practiced mostly by majority of farmers. Almost 91.25% of surveyed farmers were practising Hortiagriculture system followed by boundary plantation (47.5 %), homegarden (27.08 %), horti-silvipastoral (17.91 %), hortipastoral (15.81 %) and silvi-pasture (9.58 %). Poplar and willow were common trees found in all the agroforestry systems. Apple tree dominated in fruit-based agroforestry systems. The commonly cultivated crops among different agroforestry systems were kale, chilli, beans, knol-khol and paddy in kharif season and radish, turnip, mustard and oats in rabi season.

A total of 4 genera, 6 species of 3 families and 4 genera, 5 species of 2 families were recorded, respectively in broad leaved and fruit tree species. Also, 1 genera having 2 species belonging to 1 family were of shrub layer and herbage represented 33 genera belonging to 38 plant species and 21 families.

Biomass production of prominent agroforestry systems

Horti-agriculture system was having four tree crop combinations C₁ (Apple+radish-kale), C₂ (Apple+kale-chilli), C₃ (Apple+kale-beans) and C₄ (Walnut+oats-maize). Maximum biomass was recorded as 41.63 t ha⁻¹ in combination C₃, whereas minimum biomass was recorded as 26.16 t ha⁻¹ in combination C₄.

Similarly, agri-silviculture system (boundary plantation) revealed two tree crop combinations C₁ (Poplar+salix+oats-paddy) and C₂ (Poplar+mustard-paddy). Maximum biomass was recorded as 37.51 t ha⁻¹ in combination C₂, whereas minimum biomass was recorded as 32.26 t ha⁻¹ in combination C₁.

Likewise, agri-horti-silviculture system (homegarden) was having three

tree crop combinations C_1 (Poplar+apple+kale-beans), C_2 (Poplar+apple+kale-chilli), C_3 (Poplar+apple+turnip-kale). Maximum biomass was recorded as 53.09 t ha^{-1} in combination C_3 , whereas minimum biomass was recorded as 48.2 t ha^{-1} was recorded in combination C_1 .

Also, horti-silvi-pasture was having two tree crop combinations C_1 (Apple+poplar+grasses) and C_2 (Apple+poplar+salix+grasses). Maximum biomass was recorded as 73.86 t ha^{-1} in combination C_1 , whereas minimum biomass was recorded as 59.3 t ha^{-1} in combination C_2 .

In horti-agriculture, fruit trees contributes 23.7 t ha^{-1} and crop components 12.52 t ha^{-1} of biomass. In boundary plantation, forest tree contributed 19.3 t ha^{-1} and crop component contributed 15.54 t ha^{-1} . In homegardens, forest trees, fruit trees and crop components contributed 31.04 t ha^{-1} , 7.91 t ha^{-1} and 11.15 t ha^{-1} of biomass respectively, whereas in horti-silvipasture, forest tree contributed 25.18 t ha^{-1} , fruit trees 19.29 t ha^{-1} and crop components 10.82 t ha^{-1} of biomass. The total biomass of four systems was in the order of horti-silvipasture (63.24 t ha^{-1}) > agri-horti-silviculture (homegardens) (50.18 t ha^{-1}) > horti-agriculture (36.22 t ha^{-1}) > boundary plantation (34.87 t ha^{-1}).

Carbon stock and carbon mitigation of prominent agroforestry systems

In horti-agriculture, fruit trees carbon stock was 10.66 t ha^{-1} and crop carbon stock was 5.62 t ha^{-1} . In boundary plantation, forest tree carbon stock contributed 8.68 t ha^{-1} and crop carbon stock contributed 6.99 t ha^{-1} . In homegardens, forest trees, fruit trees and crop carbon stock contributed 13.97 t ha^{-1} , 3.56 t ha^{-1} and 5.02 t ha^{-1} respectively, while as in horti-silvipasture forest tree carbon stock was 13.74 t ha^{-1} , fruit trees carbon stock was 11.33 t ha^{-1} and crop carbon stock was 4.87 t ha^{-1} . The carbon stock of four systems follows the trend as horti-silvipasture (28.46 t ha^{-1}) > homegardens (22.56 t ha^{-1}) > horti-agriculture (16.30 t ha^{-1}) > boundary plantation (15.69 t ha^{-1}). Similarly, maximum carbon mitigation potential was recorded in horti-silvipasture (104.4 t ha^{-1}) followed by

82.8 t ha⁻¹ in homegardens, 59.83t ha⁻¹ in horti-agriculture and minimum 57.58 t ha⁻¹ in boundary plantation.

Nutrient status of prominent agroforestry system

Soil nitrogen, phosphorus, potassium and organic carbon decreased with increase in soil depth. Maximum available nitrogen (313.6 kg ha⁻¹), available phosphorus (39.6 kg ha⁻¹) and available potassium (292.15 kg ha⁻¹) were recorded under horti-silvi-pasture, while minimum available nitrogen (281.4 kg ha⁻¹), available phosphorus (22.1 kg ha⁻¹) and available potassium (231.5 kg ha⁻¹) were recorded under boundary plantation. Maximum organic carbon 1.55 % was recorded in horti-silvipasture, while minimum 0.93 % was recorded under boundary plantation. Soil reaction (pH) increased with soil depth in all four agroforestry systems. Maximum value 7.05 was recorded in boundary plantation and minimum 6.76 in horti-silvi-pasture. Soil electrical conductivity (EC dSm⁻¹) shows a decreasing trend as we move downwards along soil profile. Maximum electrical conductivity (0.32 dSm⁻¹) was recorded in horti-silvipasture and minimum (0.26 dSm⁻¹) in boundary plantation.

In horti-agriculture, the maximum nitrogen, phosphorus and potassium content was recorded as 1.24%, 0.26% and 1.23% and their uptake as 167.4 kg ha⁻¹, 35.1 kg ha⁻¹ and 166.05 kg ha⁻¹ respectively in maize. In case of tree species, maximum nitrogen and phosphorus content was recorded in walnut as 2.20% and 0.27% respectively and 1.19% potassium content in apple trees. Maximum nitrogen, phosphorus and potassium uptake was recorded as 70.71 kg ha⁻¹, 8.67 kg ha⁻¹ and 27.32 kg ha⁻¹ respectively in walnut. Maximum retranslocation of 58.60% nitrogen and 37.88% potassium in apple trees and 63.61% phosphorus in walnut and maximum return of 55.01% nitrogen and 63.91% potassium in walnut and 62.06% phosphorus in apple trees.

In boundary plantation, maximum nitrogen, phosphorus and potassium content in crop component was recorded as 1.39%, 0.25% and 2.12% respectively

in mustard. Maximum nitrogen and potassium uptake was recorded in paddy as $124.74 \text{ kg ha}^{-1}$ and $135.63 \text{ kg ha}^{-1}$ respectively and maximum phosphorus uptake was recorded as 14.97 kg ha^{-1} in mustard. In case of tree species, maximum 1.75% nitrogen and 0.51% phosphorus were recorded in poplar and 0.95% potassium in salix trees. Maximum uptake of nitrogen (56.35%), phosphorus (16.42%) and potassium (28.65%) was recorded in poplar. Maximum retranslocation 68.75% nitrogen in salix, 7.64 % phosphorus and 66.67% potassium in poplar and maximum return of 41.18% nitrogen in poplar, 37.31% phosphorus and 46.65% potassium in in Salix.

In homegardens, the maximum nitrogen, phosphorus and potassium content was recorded as 0.94%, 0.27% and 0.81% and their uptake as 52.73 kg ha^{-1} , 15.14 kg ha^{-1} and 45.44 kg ha^{-1} respectively in kale. In case of trees, maximum nitrogen and potassium content in tree component was recorded as 1.82% and 1.09% respectively in apple trees and phosphorus as 0.57% in poplar. Maximum potassium uptake was recorded as 66.09 kg ha^{-1} in onion. In case of trees, maximum nitrogen, phosphorus and potassium uptake was recorded in poplar as 35.54 kg ha^{-1} , 11.99 kg ha^{-1} and 20.19 kg ha^{-1} respectively. Maximum retranslocation 62.52% nitrogen in apple tree, 58.52% phosphorus and 54.13% potassium in poplar and maximum return of 50.05 % nitrogen in poplar, 46.76% phosphorus in apple tree and 58.82% potassium in salix.

In horti-silvipasture, in case of perennial grasses, nitrogen, phosphorus and potassium content was 1.59 kg ha^{-1} , 0.07 kg ha^{-1} and 0.12 kg ha^{-1} and its uptake was 86.01 kg ha^{-1} , 3.78 kg ha^{-1} and 6.49 kg ha^{-1} respectively. In case of tree species, maximum nitrogen and potassium was recorded in apple trees as 1.91% and 1.36% respectively and 0.61% phosphorus in poplar trees. Maximum uptake of nitrogen (68.51%), phosphorus (22.83 %) and potassium (44.18%) was recorded in poplar. Maximum retranslocation 59.08 % nitrogen in salix, 53.85 % phosphorus and 51.79% potassium in poplar and maximum return of 52.15% nitrogen in poplar, 68.55% phosphorus and 66.70% potassium in apple trees.

CONCLUSION

- The marginal farmers (70.83%) dominated the farming community of Anantnag district.
- Six agroforestry systems were identified viz; hortiagriculture, agri-silviculture (boundary plantation), agri-horti-silviculture (homegardens), horti-silvi-pasture, horti-pasture, silvi-pasture but four of them viz., hortiagriculture, agri-silviculture (boundary plantation), agri-horti-silviculture (homegardens), horti-silvi-pasture, were found to be practiced mostly by majority of farmers.
- In terms of biomass production, carbon stock and carbon sequestration, horti-silvi-pasture was the best agroforestry system with best tree crop combination as C₁ (Apple+poplar+grasses) having values 73.86 t ha⁻¹, 30.67 t ha⁻¹ and 122.0 t ha⁻¹ respectively
- Horti-silvi-pasture was having maximum biomass, carbon stock and carbon sequestration potential as 63.24 t ha⁻¹, 28.46 t ha⁻¹ and 104.4 t ha⁻¹ respectively.
- Maximum available nitrogen (313.6 kg ha⁻¹), available phosphorus (39.6 kg ha⁻¹) and available potassium (292.15 kg ha⁻¹) were recorded under horti-silvipasture, while minimum 281.4 kg ha⁻¹ available nitrogen, 22.1 kg ha⁻¹ available phosphorus and 231.5 kg ha⁻¹ available potassium were recorded under boundary plantation.
- Maximum organic carbon 1.55 % was recorded in horti-silvipasture, while minimum 0.93 % was recorded under boundary plantation.
- Maximum soil reaction (pH) was recorded in boundary plantation (7.05) and minimum in horti-silvipasture (6.76).

- Maximum soil electrical conductivity (EC dSm^{-1}) (0.32 dSm^{-1} was recorded in horti-silvipasture and minimum (0.26 dSm^{-1}) in boundary plantation.
- In crop component, maximum nitrogen, phosphorus, potassium uptake was recorded in maize as 167.4 kg ha^{-1} , 35.1 kg ha^{-1} and $166.05 \text{ kg ha}^{-1}$ respectively under horti-agriculture system.
- In boundary plantation, maximum nitrogen and potassium uptake was recorded in paddy as $124.74 \text{ kg ha}^{-1}$ and $135.63 \text{ kg ha}^{-1}$ respectively and maximum phosphorus uptake was recorded as 14.97 kg ha^{-1} in mustard.
- In homegardens, maximum nitrogen, phosphorus and potassium uptake was recorded as 0.94%, 0.27% and 0.81% and their uptake as 52.73 kg ha^{-1} , 15.14 kg ha^{-1} and 45.44 kg ha^{-1} respectively in kale.
- In hort-silvi-pasture, the nitrogen, phosphorus and potassium uptake was 86.01 kg ha^{-1} , 3.78 kg ha^{-1} and 6.49 kg ha^{-1} respectively by perennial grasses.
- In tree component, maximum nitrogen uptake was recorded as 70.71 kg ha^{-1} in walnut in horti-agriculture system, 22.83 kg ha^{-1} phosphorus uptake and 44.18 kg ha^{-1} potassium uptake in poplar in horti-silvi-pasture respectively.
- Maximum nitrogen, phosphorus, potassium retranslocation was recorded under boundary plantation as (68.75% N in salix) (71.64 % P in poplar) and (66.67 % K in poplar), respectively.
- Maximum return was recorded under horti-agriculture system as 55.01 kg ha^{-1} Nitrogen in walnut, 68.55 kg ha^{-1} Phosphorus and 66.70 kg ha^{-1} Potassium in apple in horti-silvi-pasture respectively.

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APPENDIX-I

QUESTIONNAIRE

Serial No..... Date:

A. General information

1. Name of decision maker.....
2. Name of village.....
3. Block/District.....
4. Total land.....leased-in leased-out.....

B. Land-use system

Land-use class	Area (Kanals)	Other components
Agriculture		
Horticulture		
Forestry		
Pasture		
Non-cultivable		
Homestead		
Other		
1		
2		

C. Components of Agroforestry systems identified

Name of system	Area (kanals)	Tree compone nt	Fruit tree compone nt	Agriculture crop component	
				Kharif	Rabi
Boundary plantation (paddy fields)					
Agri-silviculture (slopy lands)					
Agri-silviculture (plain lands)					
Horti-silviculture					
Horti-silvipasture					
Horti-silvi-agriculture					
Kitchen garden					
Compact block planting					
Other (specify)					

APPENDIX-II

Categorization of farmers

Category	Holding size (ha)	No. of farmers selected
Marginal	Upto 1.0 ha	170
Small	01- 02 ha	49
Medium	2.1-4.0 ha	17
Large	4.1 and above	4

Haque *et al.*, (2010)

APPENDIX-III**Standard monthly meteorological data for the year 2018 and 2019**

Standard met. months	Mean temperature (°C)		Total rainfall (mm)
	Maximum	Minimum	
2015			
January			
February			
March			
April			
May			
June			
July			
August			
September			
October			
November			
December			
2016			
January			
February			
March			
April			
May			
June			
July			
August			
September			
October			
November			
December			

Appendix IV

Average biomass production (t ha⁻¹) under Horti-agriculture system (for year 2018)

Tree crop combinations	Fruit trees					Crops		Total biomass
	Stem	Canopy	Aboveground	Belowground	Total	Rabi	Kharif	
C ₁	15.03	4.85	19.88	6.56	26.44	5.13	5.73	36.41
C ₂	14.65	4.78	19.43	6.41	25.84	5.56	4.96	36.20
C ₃	14.67	7.78	22.45	7.40	29.85	5.09	5.06	39.01
C ₄	1.87	3.07	4.94	1.63	6.57	5.01	13.6	23.17
Mean	11.91	5.31	17.22	5.68	22.90	4.80	6.71	34.42

Aboveground = stem + canopy; Total = aboveground + belowground

C₁ = Apple+radish-kale

C₂ = Apple+kale-chilli

C₃ = Apple+kale-beans

C₄ = Walnut+oats-maize

Appendix V

Average biomass production (t ha⁻¹) under Horti-agriculture system (for year 2019)

Tree crop combinations	Fruit trees					Crops		Total biomass
	Stem	Canopy	Aboveground	Belowground	Total	Rabi	Kharif	
C ₁	16.81	5.93	22.74	7.50	30.24	5.17	5.79	41.2
C ₂	15.63	6.02	21.65	7.14	28.79	5.60	4.94	39.33
C ₃	16.15	8.66	24.81	8.18	32.99	5.13	5.10	43.22
C ₄	2.79	3.79	6.58	2.17	8.75	4.97	13.4	27.12
Mean	12.49	5.89	18.38	6.06	24.44	5.21	7.30	37.71

Aboveground = stem + canopy; Total = aboveground + belowground

C₁ = Apple+radish-kale

C₂ = Apple+kale-chilli

C₃ = Apple+kale-beans

C₄ = Walnut+oats-maize

Appendix VI

Average biomass production (t ha^{-1}) under Agri-silviculture (boundary plantation) system (for year 2018)

Tree crop combination	Forest trees						Crops		Total biomass
	Stem	Branch	Leaf	Above ground	Below ground	Total	Rabi	Kharif	
C ₁	11.56	1.08	0.11	12.75	3.188	15.94	5.30	10.11	31.35
C ₂	14.37	1.88	0.23	16.48	4.12	20.6	5.94	9.89	36.43
Mean	12.97	1.48	0.17	14.62	3.654	18.27	5.47	10.0	33.89

Aboveground = stem + canopy; Total = aboveground + belowground

C₁ = Poplar+salix+oats-paddy

C₂ = Poplar+mustard-paddy

Appendix VII

Average biomass production (t ha^{-1}) under Agri-silviculture (boundary plantation) system (for year 2019)

Tree crop combination	Forest trees						Crops		Total biomass
	Stem	Branch	Leaf	Above ground	Below ground	Total	Rabi	Kharif	
C ₁	12.68	1.3	0.29	14.27	3.568	17.84	5.38	9.91	33.13
C ₂	15.81	2.12	0.33	18.26	4.565	22.83	6.04	9.71	38.58
Mean	14.25	1.71	0.31	16.27	4.066	20.33	5.85	9.81	35.85

Aboveground = stem + canopy; Total = aboveground + belowground

C₁ = Poplar+salix+oats-paddy

C₂ = Poplar+mustard-paddy

Appendix VIII

Average biomass production (t ha⁻¹) under Agri-horti-silviculture (homegardens) system (for year 2018)

Tree crop combin.	Forest trees						Fruit trees					Crops		Total biomass
	Stem	Branch	Leaf	Above ground	Below ground	Total	Stem	Canopy	Above ground	Below ground	Total	Rabi	Kharif	
C ₁	23.32	1.22	0.34	24.88	6.22	31.1	3.43	0.72	4.15	1.37	5.52	5.19	5.15	49.96
C ₂	22.1	0.92	0.27	23.29	5.823	29.11	4.34	1.14	5.48	1.808	7.28	5.49	5.11	46.99
C ₃	22.95	1.08	0.33	24.36	6.09	30.45	4.78	1.42	6.2	2.046	8.24	5.48	6.15	51.35
Mean	22.79	1.073	0.313	24.18	6.044	30.22	4.183	1.093	5.277	1.741	7.01	5.38	5.47	48.43

Aboveground(forest trees)=stem+branch+leaf; Aboveground(fruit trees)=stem+canopy; Total=aboveground+belowground

C₁ = Poplar+apple+kale-beans

C₂ = Poplar+apple+kale-chilli

C₃ = Poplar+apple+ turnip-kale

Appendix IX

Average biomass production (t ha⁻¹) under Agri-horti-silviculture (homegardens) system (for year 2019)

Tree crop combn.	Forest trees						Fruit trees					Crops		Total biomass
	Stem	Branch	Leaf	Above ground	Below ground	Total	Stem	Canopy	Above ground	Below ground	Total	Rabi	Kharif	
C ₁	23.56	1.58	0.36	48.7	12.18	31.88	4.51	0.94	5.45	1.799	7.249	5.17	5.11	49.41
C ₂	23.1	1.22	0.35	46.27	11.57	30.84	5.32	1.48	6.8	2.244	9.044	5.53	5.13	50.54
C ₃	24.61	1.32	0.47	48.52	12.13	33	5.99	1.66	7.68	2.534	10.17	5.50	6.13	54.8
Mean	23.76	1.373	0.393	47.83	11.96	31.9	5.273	1.36	6.643	2.192	8.822	5.4	5.45	51.58

Aboveground(forest trees)=stem+branch+leaf; Aboveground(fruit trees)=stem+canopy; Total=aboveground+belowground

C₁ = Poplar+apple+kale-beans

C₂ = Poplar+apple+kale-chilli

C₃ = Poplar+apple+ turnip-kale

Appendix X

Average biomass production (t ha⁻¹) under horti-silvi-pasture system (Pooled data for year 2018)

Tree crop combn.	Fruit trees					Forest trees						*Crops		Total biomass
	Stem	Canopy	Above ground	Below ground	Total	Stem	Branch	Leaf	Above ground	Below ground	Total	**1 st cut	***2 nd cut	
C ₁	15.88	6.46	22.34	7.37	29.71	21.62	1.45	0.42	23.49	5.87	29.36	7.49	4.09	70.65
C ₂	15.76	5.55	21.31	7.03	28.34	13.2	0.78	0.24	14.22	3.55	17.78	6.86	3.17	56.15
Mean	15.82	6	21.82	7.2	29.02	17.41	1.11	0.33	18.86	4.71	23.58	7.17	3.63	63.4

Aboveground(forest trees)=stem+branch+leaf; Aboveground(fruit trees)=stem+canopy; Total=aboveground+belowground

C₁ = Apple+poplar+grasses

C₂ = Apple+poplar+salix+grasses

*Crop biomass of perennial grasses

**1st cut- June

***2nd cut- September

Appendix XI

Average biomass production (t ha⁻¹) under horti-silvi-pasture system (Pooled data for year 2019)

Tree crop combn.	Fruit trees					Forest trees						*Crops		Total biomass
	Stem	Canopy	Above ground	Below ground	Total	Stem	Branch	Leaf	Above ground	Below ground	Total	**1 st cut	***2 nd cut	
C ₁	17.46	7.1	24.56	8.1	32.66	21.62	1.85	0.45	23.92	5.98	29.9	7.53	4.13	74.22
C ₂	17.5	6.11	23.61	7.79	31.4	13.2	1.16	0.271	14.63	3.65	18.28	6.92	3.23	59.83
Mean	17.48	6.605	24.08	7.94	32.03	17.41	1.505	0.36	19.27	4.81	24.09	7.22	3.68	67.02

Aboveground(forest trees)=stem+branch+leaf; Aboveground(fruit trees)=stem+canopy; Total=aboveground+belowground

C₁ = Apple+poplar+grasses

C₂ = Apple+poplar+salix+grasses

*Crop biomass of perennial grasses

**1st cut- June

***2nd cut- September

Appendix XII

Average carbon stock (t ha⁻¹) under Horti-agriculture system (for year 2018)

Tree crop combinations	Fruit trees					Crops		Total biomass
	Stem	Canopy	Aboveground	Belowground	Total	Rabi	Kharif	
C ₁	6.76	2.18	8.95	2.95	11.9	2.30	2.57	16.38
C ₂	6.59	2.15	8.74	2.89	11.6	2.50	2.23	16.29
C ₃	6.6	3.5	10.1	3.33	13.4	2.29	2.27	17.55
C ₄	0.84	1.38	2.22	0.73	2.96	2.25	6.12	10.42
Mean	5.36	2.39	7.75	2.56	10.3	2.16	3.02	15.48

Aboveground = stem + canopy; Total = aboveground + belowground

C₁ = Apple+radish-kale

C₂ = Apple+kale-chilli

C₃ = Apple+kale-beans

C₄ = Walnut+oats-maize

Appendix XIII

Average carbon stock (t ha⁻¹) under Horti-agriculture system (for year 2019)

Tree crop combinations	Fruit trees					Crops		Total biomass
	Stem	Canopy	Aboveground	Belowground	Total	Rabi	Kharif	
C ₁	7.56	2.67	10.2	3.38	13.6	2.32	2.60	18.54
C ₂	7.03	2.71	9.74	3.22	13	2.52	2.22	17.69
C ₃	7.27	3.9	11.2	3.68	14.8	2.30	2.29	19.44
C ₄	1.26	1.71	2.96	0.98	3.94	2.23	6.03	12.20
Mean	5.62	2.65	8.27	2.73	11	2.34	3.28	16.96

Aboveground = stem + canopy; Total = aboveground + belowground

C₁ = Apple+radish-kale

C₂ = Apple+kale-chilli

C₃ = Apple+kale-beans

C₄ = Walnut+oats-maize

Appendix XIV

Average carbon stock (t ha⁻¹) under Agri-silviculture (boundary plantation) system (for year 2018)

Tree crop combination	Forest trees						Crops		Total biomass
	Stem	Branch	Leaf	Above ground	Below ground	Total	Rabi	Kharif	
C ₁	5.2	0.49	0.05	5.74	1.43	7.17	2.38	4.54	14.1
C ₂	6.47	0.85	0.1	7.42	1.85	9.27	2.67	4.45	16.4
Mean	5.83	0.67	0.08	6.58	1.64	8.22	2.46	4.50	15.3

Aboveground = stem + canopy; Total = aboveground + belowground

C₁ = Poplar+salix+oats-paddy

C₂ = Poplar+mustard-paddy

Appendix XV

Average carbon stock (t ha⁻¹) under Agri-silviculture (boundary plantation) system (for year 2019)

Tree crop combination	Forest trees						Crops		Total biomass
	Stem	Branch	Leaf	Above ground	Below ground	Total	Rabi	Kharif	
C ₁	5.71	0.59	0.13	6.42	1.61	8.03	2.42	4.45	14.9
C ₂	7.11	0.95	0.15	8.22	2.05	10.3	2.71	4.36	17.4
Mean	6.41	0.77	0.14	7.32	1.83	9.15	2.63	4.41	16.1

Aboveground = stem + canopy; Total = aboveground + belowground

C₁ = Poplar+salix+oats-paddy

C₂ = Poplar+mustard-paddy

Appendix XVI

Average carbon stock (t ha^{-1}) under Agri-horti-silviculture (homegardens) system (for year 2018)

Tree crop combn.	Forest trees						Fruit trees					Crops		Total biomass
	Stem	Branch	Leaf	Above ground	Below ground	Total	Stem	Canopy	Above ground	Below ground	Total	Rabi	Kharif	
C ₁	10.5	0.55	0.15	11.2	2.8	14	1.54	0.32	1.87	0.62	2.48	2.33	2.31	21.13
C ₂	9.95	0.41	0.12	10.5	2.62	13.1	1.95	0.51	2.47	0.81	3.28	2.47	2.29	21.14
C ₃	10.3	0.49	0.15	11	2.74	13.7	2.15	0.64	2.79	0.92	3.71	2.46	2.76	23.10
Mean	10.3	0.48	0.14	10.9	2.72	13.6	1.88	0.49	2.37	0.78	3.16	2.42	2.46	21.78

Aboveground(forest trees)=stem+branch+leaf; Aboveground(fruit trees)=stem+canopy; Total=aboveground+belowground

C₁ = Poplar+apple+kale-beans

C₂ = Poplar+apple+kale-chilli

C₃ = Poplar+apple+ turnip-kale

Appendix XVII

Average carbon stock (t ha^{-1}) under Agri-horti-silviculture (homegardens) system (for year 2019)

Tree crop combn.	Forest trees						Fruit trees					Crops		Total biomass
	Stem	Branch	Leaf	Above ground	Below ground	Total	Stem	Canopy	Above ground	Below ground	Total	Rabi	Kharif	
C ₁	10.6	0.71	0.16	21.9	5.48	14.3	2.03	0.42	2.45	0.81	3.26	2.32	2.29	22.23
C ₂	10.4	0.55	0.16	20.8	5.21	13.9	2.39	0.67	3.06	1.01	4.07	2.48	2.30	22.74
C ₃	11.1	0.59	0.21	21.8	5.46	14.9	2.7	0.75	3.46	1.14	4.58	2.47	2.75	24.66
Mean	10.7	0.62	0.18	21.5	5.38	14.4	2.37	0.61	2.99	0.99	3.97	2.43	2.45	23.21

Aboveground(forest trees)=stem+branch+leaf; Aboveground(fruit trees)=stem+canopy; Total=aboveground+belowground

C₁ = Poplar+apple+kale-beans

C₂ = Poplar+apple+kale-chilli

C₃ = Poplar+apple+ turnip-kale

Appendix XVIII

Average carbon stock (t ha^{-1}) under horti-silvi-pasture system (Pooled data for year 2018)

Tree crop comb n.	Fruit trees					Forest trees						*Crops		Total biomass
	Stem	Canopy	Above ground	Below ground	Total	Stem	Branch	Leaf	Above ground	Below ground	Total	**1 st cut	***2 nd cut	
C ₁	7.15	2.91	10.1	3.32	13.4	9.73	0.65	0.19	10.6	2.64	13.2	3.37	1.84	31.79
C ₂	7.09	2.5	9.59	3.16	12.8	5.94	0.35	0.11	6.4	1.6	8	3.08	1.42	25.26
Mean	7.12	2.7	9.82	3.24	13.1	7.83	0.5	0.15	8.49	2.12	10.6	3.22	1.63	28.53

Aboveground(forest trees)=stem+branch+leaf; Aboveground(fruit trees)=stem+canopy; Total=aboveground+belowground

C₁ = Apple+poplar+grasses

C₂ = Apple+poplar+salix+grasses

*Crop biomass of perennial grasses

**1st cut- June

***2nd cut- September

Appendix XIX

Average carbon stock (t ha^{-1}) under horti-silvi-pasture system (Pooled data for year 2019)

Tree crop combn.	Fruit trees					Forest trees						*Crops		Total biomass
	Stem	Canopy	Aboveground	Below ground	Total	Stem	Branch	Leaf	Aboveground	Below ground	Total	** 1 st cut	***2 nd cut	
C ₁	7.86	3.2	11.1	3.65	14.7	9.73	0.83	0.2	10.8	2.69	13.5	3.38	1.85	33.39
C ₂	7.88	2.75	10.6	3.51	14.1	5.94	0.52	0.12	6.58	1.64	8.23	3.11	1.45	26.92
Mean	7.87	2.97	10.8	3.57	14.4	7.83	0.68	0.16	8.67	2.16	10.8	3.24	1.65	30.15

Aboveground(forest trees)=stem+branch+leaf; Aboveground(fruit trees)=stem+canopy; Total=aboveground+belowground

C₁ = Apple+poplar+grasses

C₂ = Apple+poplar+salix+grasses

*Crop biomass of perennial grasses

**1st cut- June

***2nd cut- September

Appendix XX

Average carbon sequestration (t ha⁻¹) under Horti-agriculture system (for year 2018)

Tree crop combinations	Fruit trees					Crops		Total biomass
	Stem	Canopy	Aboveground	Belowground	Total	Rabi	Kharif	
C ₁	24.82	8.01	32.83	10.83	43.67	8.47	9.46	60.13
C ₂	24.19	7.894	32.09	10.59	42.68	9.18	8.19	59.78
C ₃	24.23	12.85	37.08	12.24	49.31	8.40	8.35	64.42
C ₄	3.088	5.07	8.158	2.692	10.85	8.27	22.46	38.26
Mean	19.67	8.769	28.44	9.385	37.82	7.92	11.08	56.84

Aboveground = stem + canopy; Total = aboveground + belowground

C₁ = Apple+radish-kale

C₂ = Apple+kale-chilli

C₃ = Apple+kale-beans

C₄ = Walnut+oats-maize

Appendix XXI

Average carbon sequestration (t ha^{-1}) under Horti-agriculture system (for year 2019)

Tree crop combinations	Fruit trees					Crops		Total biomass
	Stem	Canopy	Aboveground	Belowground	Total	Rabi	Kharif	
C ₁	27.76	9.793	37.56	12.39	49.95	8.53	9.56	68.04
C ₂	25.81	9.942	35.75	11.8	47.55	9.24	8.15	64.95
C ₃	26.67	14.3	40.97	13.52	54.5	8.47	8.42	71.37
C ₄	4.608	6.259	10.87	3.586	14.45	8.20	22.13	44.78
Mean	20.63	9.727	30.35	10.02	40.37	8.60	12.05	62.27

Aboveground = stem + canopy; Total = aboveground + belowground

C₁ = Apple+radish-kale

C₂ = Apple+kale-chilli

C₃ = Apple+kale-beans

C₄ = Walnut+oats-maize

Appendix XXII

Average carbon sequestration (t ha^{-1}) under Agri-silviculture (boundary plantation) system (for year 2018)

Tree crop combination	Forest trees						Crops		Total biomass
	Stem	Branch	Leaf	Above ground	Below ground	Total	Rabi	Kharif	
C ₁	19.09	1.784	0.182	21.06	5.264	26.32	8.75	16.69	51.87
C ₂	23.73	3.105	0.38	27.22	6.804	34.02	9.80	16.33	60.13
Mean	21.41	2.444	0.281	24.14	6.034	30.17	9.04	16.51	56

Aboveground = stem + canopy; Total = aboveground + belowground

C₁ = Poplar+salix+oats-paddy

C₂ = Poplar+mustard-paddy

Appendix XXIII

Average carbon sequestration (t ha^{-1}) under Agri-silviculture (boundary plantation) system (for year 2019)

Tree crop combination	Forest trees						Crops		Total biomass
	Stem	Branch	Leaf	Above ground	Below ground	Total	Rabi	Kharif	
C ₁	20.94	2.147	0.479	23.57	5.892	29.46	8.88	16.36	54.61
C ₂	26.11	3.501	0.545	30.16	7.539	37.7	9.97	16.03	63.74
Mean	23.53	2.824	0.512	26.86	6.715	33.58	9.66	16.20	59.18

Aboveground = stem + canopy; Total = aboveground + belowground

C₁ = Poplar+salix+oats-paddy

C₂ = Poplar+mustard-paddy

Appendix XXIV

Average carbon sequestration (t ha^{-1}) under Agri-horti-silviculture (homegardens) system (for year 2018)

Tree crop combn.	Forest trees						Fruit trees					Crops		Total biomass
	Stem	Branch	Leaf	Above ground	Below ground	Total	Stem	Canopy	Above ground	Below ground	Total	Rabi	Kharif	
C ₁	38.51	2.015	0.562	41.09	10.27	51.36	5.665	1.189	6.854	2.262	9.115	8.57	8.50	77.55
C ₂	36.5	1.519	0.446	38.46	9.616	48.08	7.168	1.883	9.05	2.987	12.04	9.06	8.43	77.60
C ₃	37.9	1.784	0.545	40.23	10.06	50.29	7.894	2.345	10.24	3.379	13.62	9.04	10.15	84.80
Mean	37.64	1.773	0.517	39.93	9.982	49.91	6.909	1.806	8.714	2.876	11.59	8.88	9.03	79.94

Aboveground(forest trees)=stem+branch+leaf; Aboveground(fruit trees)=stem+canopy; Total=aboveground+belowground

C₁ = Poplar+apple+kale-beans

C₂ = Poplar+apple+kale-chilli

C₃ = Poplar+apple+ turnip-kale

Appendix XXV

Average carbon sequestration (t ha^{-1}) under Agri-horti-silviculture (homegardens) system (for year 2019)

Tree crop combn.	Forest trees						Fruit trees					Crops		Total biomass
	Stem	Branch	Leaf	Above ground	Below ground	Total	Stem	Canopy	Above ground	Below ground	Total	Rabi	Kharif	
C ₁	38.91	2.609	0.595	80.43	20.11	52.64	7.448	1.552	9.001	2.97	11.97	8.53	8.43	81.60
C ₂	38.15	2.015	0.578	76.41	19.1	50.93	8.786	2.444	11.23	3.706	14.94	9.13	8.47	83.46
C ₃	40.64	2.18	0.776	80.13	20.03	54.5	9.892	2.741	12.68	4.186	16.8	9.08	10.12	90.50
Mean	39.23	2.268	0.65	78.99	19.75	52.69	8.709	2.246	10.97	3.621	14.57	8.91	9.0	85.18

Aboveground(forest trees)=stem+branch+leaf; Aboveground(fruit trees)=stem+canopy; Total=aboveground+belowground

C₁ = Poplar+apple+kale-beans

C₂ = Poplar+apple+kale-chilli

C₃ = Poplar+apple+ turnip-kale

Appendix XXVI

Average carbon sequestration (t ha^{-1}) under horti-silvi-pasture system (Pooled data for year 2018)

Tree crop combn.	Fruit trees					Forest trees						*Crops		Total biomass
	Stem	Canopy	Above ground	Below ground	Total	Stem	Branch	Leaf	Above ground	Below ground	Total	**1 st cut	***2 nd cut	
C ₁	26.23	10.67	36.89	12.17	49.07	35.71	2.395	0.694	38.79	9.694	48.49	12.36	6.75	116.67
C ₂	26.03	9.166	35.19	11.61	46.8	21.8	1.288	0.396	23.48	5.863	29.36	11.32	5.23	92.73
Mean	26.13	9.909	36.04	11.89	47.93	28.75	1.833	0.545	31.15	7.779	38.94	11.84	5.99	104.70

Aboveground(forest trees)=stem+branch+leaf; Aboveground(fruit trees)=stem+canopy; Total=aboveground+belowground

C₁ = Apple+poplar+grasses

C₂ = Apple+poplar+salix+grasses

*Crop biomass of perennial grasses

**1st cut- June

***2nd cut- September

Appendix XXVII

Average carbon sequestration (t ha^{-1}) under horti-silvi-pasture system (Pooled data for year 2019)

Tree crop combination	Fruit trees					Forest trees						*Crops		Total biomass
	Stem	Canopy	Above ground	Below ground	Total	Stem	Branch	Leaf	Above ground	Below ground	Total	**1 st cut	***2 nd cut	
C ₁	28.84	11.73	40.56	13.38	53.94	35.71	3.055	0.743	39.5	9.876	49.38	12.43	6.82	122.57
C ₂	28.9	10.09	38.99	12.87	51.86	21.8	1.916	0.448	24.16	6.028	30.19	11.42	5.33	98.80
Mean	28.87	10.91	39.77	13.11	52.9	28.75	2.486	0.595	31.82	7.944	39.78	11.92	6.07	110.68

Aboveground(forest trees)=stem+branch+leaf; Aboveground(fruit trees)=stem+canopy; Total=aboveground+belowground

C₁ = Apple+poplar+grasses

C₂ = Apple+poplar+salix+grasses

*Crop biomass of perennial grasses

**1st cut- June

***2nd cut- September

Appendix XXVIII

Nitrogen, Phosphorus and Potassium content (%) in trees and their uptake, retranslocation, and return (kg ha⁻¹) under Horti-agriculture system (data for the year 2018)

Species	Parameter	N	P	K
Apple	Nutrient(%)	1.75	0.05	1.15
	Uptake	26.1	0.84	17.14
	Retranslocation	15.3	0.31	6.49
	Return	10.81	0.52	10.64
Walnut	Nutrient (%)	2.18	0.26	0.82
	Uptake	70.07	8.37	26.40
	Retranslocation	31.52	5.71	10.22
	Return	38.54	3.26	18.11

Appendix XXIX

Nitrogen, Phosphorus and Potassium content (%) in trees and their uptake, retranslocation, and return (kg ha⁻¹) under Horti-agriculture system (data for the year 2019)

Species	Parameter	N	P	K
Apple	Nutrient(%)	1.83	0.06	1.22
	Uptake	27.28	0.89	18.33
	Retranslocation	15.98	0.34	6.94
	Return	11.29	0.55	11.39
Walnut	Nutrient (%)	2.21	0.27	0.87
	Uptake	71.34	8.96	28.23
	Retranslocation	32.09	6.12	10.93
	Return	39.25	3.49	19.36

Appendix XXX

Nitrogen, Phosphorus and Potassium content (%) in trees and their uptake, retranslocation, and return (kg ha⁻¹) under Agri- silviculture system (boundary plantation) (data for the year 2018)

Species	Parameter	N	P	K
Poplar	Nutrient (%)	1.7	0.5	0.877
	Uptake	54.74	16.1	28.23
	Retranslocation	32.2	11.53	18.82
	Return	22.55	4.569	9.411
Salix	Nutrient (%)	1.137	0.058	0.935
	Uptake	25.96	1.314	21.35
	Retranslocation	17.85	0.824	11.39
	Return	8.112	0.49	9.961

Appendix XXXI

Nitrogen, Phosphorus and Potassium content (%) in trees and their uptake, retranslocation, and return (kg ha⁻¹) under Agri- silviculture system (boundary plantation) (data for the year 2019)

Species	Parameter	N	P	K
Poplar	Nutrient (%)	1.8	0.52	0.903
	Uptake	57.96	16.74	29.07
	Retranslocation	34.08	11.99	19.38
	Return	23.87	4.751	9.689
Salix	Nutrient (%)	1.203	0.06	0.965
	Uptake	27.48	1.366	22.03
	Retranslocation	18.89	0.856	11.75
	Return	8.588	0.51	10.28

Appendix XXXII

Nitrogen, Phosphorus and Potassium content (%) in trees and their uptake, retranslocation, and return (kg ha⁻¹) under Agri-horti-silviculture system (homegardens) (data for the year 2018)

Species	Parameter	Nitrogen	Phosphorus	Potassium
Poplar	Nutrient (%)	1.64	0.553	0.932
	Uptake	34.49	11.64	19.59
	Retranslocation	17.23	6.813	10.61
	Return	17.27	4.823	8.987
Salix	Nutrient (%)	1.08	0.068	1.041
	Uptake	18.7	1.08	16.54
	Retranslocation	11.48	0.584	6.811
	Return	7.22	0.496	9.73
Apple	Nutrient (%)	1.76	0.05	1.054
	Uptake	17.83	0.509	10.68
	Retranslocation	11.15	0.271	5.406
	Return	6.683	0.238	5.271

Appendix XXXIII

Nitrogen, Phosphorus and Potassium content (%) in trees and their uptake, retranslocation, and return (kg ha⁻¹) under Agri-horti-silviculture system (homegardens) (data for the year 2019)

Species	Parameter	Nitrogen	Phosphorus	Potassium
Poplar	Nutrient (%)	1.74	0.587	0.988
	Uptake	36.59	12.34	20.79
	Retranslocation	18.27	7.227	11.25
	Return	18.31	5.117	9.533
Salix	Nutrient (%)	1.14	0.072	1.099
	Uptake	19.74	1.14	17.46
	Retranslocation	12.12	0.616	7.189
	Return	7.62	0.524	10.27
Apple	Nutrient (%)	1.88	0.054	1.126
	Uptake	19.05	0.543	11.4
	Retranslocation	11.91	0.289	5.774
	Return	7.137	0.246	5.629

Appendix XXXIV

Nitrogen, Phosphorus and Potassium content (%) in trees and their uptake, retranslocation, and return (kg ha⁻¹) under Horti-silvi-pasture system (data for the year 2018)

Species	Parameter	N	P	K
Poplar	Nutrient (%)	1.769	0.59	1.14
	Uptake	66.21	22.06	42.7
	Retranslocation	31.68	11.88	22.11
	Return	34.53	10.19	20.58
Salix	Nutrient (%)	1.172	0.088	1.045
	Uptake	28.92	2.168	25.79
	Retranslocation	17.09	1.084	9.12
	Return	11.83	1.074	16.66
Apple	Nutrient (%)	1.856	0.059	1.321
	Uptake	31.64	1.01	22.53
	Retranslocation	17.29	0.318	7.5
	Return	14.35	0.693	15.03

Appendix XXXV

Nitrogen, Phosphorus and Potassium content (%) in trees and their uptake, retranslocation, and return (kg ha⁻¹) under Horti-silvi-pasture system (data for the year 2019)

Species	Parameter	N	P	K
Poplar	Nutrient (%)	1.891	0.63	1.22
	Uptake	70.81	23.6	45.66
	Retranslocation	33.88	12.7	23.65
	Return	36.93	10.89	22.02
Salix	Nutrient (%)	1.228	0.092	1.095
	Uptake	30.32	2.272	27.03
	Retranslocation	17.91	1.136	9.56
	Return	12.41	1.126	17.46
Apple	Nutrient (%)	1.964	0.063	1.399
	Uptake	33.5	1.07	23.85
	Retranslocation	18.31	0.336	7.94
	Return	15.19	0.733	15.91

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CERTIFICATE

Certified that all the corrections/amendments as suggested by External Examiner Dr. Punit Choudhary, Head, KVK, Jammu during Viva-Voce examination held on 23-09-2021 have been incorporated in the manuscript entitled **“Biomass, carbon sequestration and nutrient status of prominent agroforestry systems of district Anantnag of Jammu and Kashmir”** submitted by **Ms. Ishrat Saleem (Regd. No. 2017-722-D)**.

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