

**STUDIES ON NUTRIENT STATUS AND CARBON
SEQUESTRATION POTENTIAL OF IMPORTANT
MULTIPURPOSE TREES IN SUB-TROPICAL
REGION OF HIMACHAL PRADESH**

Thesis

by

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(F-2017-08-M)**

submitted to



**Dr. YASHWANT SINGH PARMAR UNIVERSITY
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CERTIFICATE-I

This is to certify that the thesis entitled, **“Studies on nutrient status and carbon sequestration potential of important multipurpose trees in sub-tropical region of Himachal Pradesh”** submitted in partial fulfillment of the requirements for the award of degree of **Master of Science (FORESTRY)** in the discipline of **Agroforestry** of Dr Yashwant Singh Parmar University of Horticulture and Forestry, (Nauni) Solan (HP)- 173230 is a record of bonafide research work carried out by **Mr. Abhijeet Singh (F-2017-08-M)** under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

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

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CERTIFICATE-II

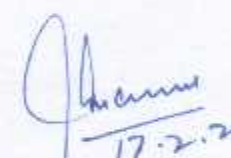
This is to certify that the thesis entitled, "Studies on nutrient status and carbon sequestration potential of important multipurpose trees in sub-tropical region of Himachal Pradesh" submitted by **Mr. Abhijeet Singh (F-2017-08-M)** son of Shri. Hitesh Kumar to Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni-Solan (HP) – 173230 India in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE in (FORESTRY) Agroforestry** has been approved by the Advisory Committee after an oral examination of the student in collaboration with the External Examiner.

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LIST OF ABBREVIATIONS

%	:	per cent
a.s.l	:	above sea level
C	:	Carbon
°C	:	degree Celsius
CD	:	Critical difference
Cm	:	Centimeter
Conc	:	Concentration
D	:	Depth
Df	:	Degree of freedom
Fig.	:	Figure
g or gm	:	Grams
Ha	:	hectare
K	:	Potassium
Kg	:	Kilogram
M	:	Meter
Mg	:	milligram
MPT	:	Multipurpose tree
N	:	Nitrogen
P	:	Phosphorous
SE	:	Standard error
SOC	:	Soil organic carbon
T	:	Treatment
TOC	:	Total organic carbon
TN	:	Total Nitrogen
AGTB	:	Above ground tree biomass
PF	:	Pine forest
IA	:	Irrigated agriculture

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Chapter-1

INTRODUCTION

The Himalaya is one of the well-defined phytogeographical regions of the Indian sub-continent. It includes an important ecological zone on which depends the prosperity of not only the people living in this zone but also of those living in the Indo-Gangetic plains. The uncontrolled exploitation of forests under the influx of ever increasing population pressure and resulted in the disappearance of many climax forests. Mounting population pressure in the inhabited hill regions multiplied as fast or faster than the population of plains (Moddie, 1981). The removal of vegetation cover in the Himalayas has resulted in the serious problems of soil erosion, depletion of the soil fertility, regeneration of the vegetation in the area. The aftermath of this havoc results in floods year after year in the Northern plains. Further, increased run off at the cost of infiltrated water during monsoons leads to lean flow of water in the rivers during winter and summer months which causes drought and affects the power generation and irrigation adversely.

The loss of plant resources in the Himalaya can be repaired only by large scale afforestation both under commercial and social forestry programmes. The urgent need is to develop a compatible system of land use, bringing a symbiosis of agriculture and forestry without disturbing the ecosystem. It is thus necessary to reassess the present land practices and to conserve the natural resources through proper management of agroforestry systems as to maximise the production while maintaining the ecological balance. The adoption of agroforestry system such as agrisilviculture, silvi-pastoral, agrisilvi-pastoral, etc shall meet out the diversified needs of the farmers and also helps in the conservation of the ecosystem.

Agroforestry is defined as “a sustainable land management system which increases the yield of the land, combines the production of crops (including tree crops) and forest plants and/or animals simultaneously and sequentially, on the same unit of land, and applies management practices that are compatible with the cultural practices of local population. (Bene *et al.*, 1977 and King and Chandler 1978). It is indeed the best land management system which brings harmony between forestry and agriculture for meeting the rural requirements of timber, food, fuel, fodder, etc, without disturbing the ecosystem.

The physiography of Himachal Pradesh is highly terrain and acute slopy which leads to high amount of soil erosion and area without tree cover on hilly slope is vulnerable to erosion and reduced fertility. Plantation of Multipurpose tree species in such areas can be one of the viable land-use management practices which can check land degradation. Major attributes of MPTs may sustain following criteria such as rapid juvenile growth, efficient dry matter production in terms of water and nutrient inputs, crown characteristics to maximise interception of solar radiation and ease of regeneration by coppicing (Fege, 1981). Multipurpose Trees provides timber and other non-timber forest products such as fruits, seeds, bulbs, bark, fibres, roots, leaves, small wooden logs, firewood, etc. Multipurpose tree species (MPTs) have always been an integral part of agriculture of the state. Trees like *Grewia optiva*, *Melia composita*, *Acacia mollissima*, *Toona ciliata*, etc are commonly found in the farm areas of small and marginal farmers.

In the present study *Albizia chinensis*, *Albizia lebbeck*, *Acacia mollissima*, *Dalbergia sissoo*, *Ulmus villosa*, *Toona ciliata* and *Melia composita* were selected to find out their impact on physico-chemical properties of soil and other parameters.

Albizia chinensis (Osbeck) Merr. commonly known as The Sau tree, is a large deciduous tree about 18-30 m in height and 1.8-3.0 m in girth with a clear bole and spreading flat-topped crown. Bark is dark grey with leaves paripinnate in shape and flowers with yellowish-white in colour. It is found throughout the sub-Himalayan tract and the Himalayan valleys from Kangra eastwards through Uttar Pradesh, northern West Bengal to hill states of eastern India. Like other *Albizias* it loves to grow near streams and ravine beds. It belongs to family Mimosaceae. The tree is evergreen in some parts of the country while it is leafless for a short period during winter in northern India where the old leaves fall in January-February and new ones appear in March-April. The flowers, which are inodorous and yellowish-white in colour, appear from April to June (Brandis, 1906), when the tree is laden with rich green new foliage. The pods are soon formed, develop rapidly and attain full size by about September. The young pods are pale reddish green and turn light brown on ripening. The ripe pods are about 8-15 cm long and 1.2-2.0 cm broad, flat, glabrous and often wrinkled over the seeds. The seed is long, flat, ovate or elliptical, greenish brown and smooth (Troup, 1921) It is mainly used for packing cases, box making, tea boxes, planking, etc. It is suitable for furniture of suitable quality. The tree is loped for fodder during winter season.

Albizia lebbbeck Benth. commonly known as Siris, is a moderate to large deciduous tree with 20-30 m in height and 2-3 m in girth with a single bole and broad crown. Bark is dark grey with leaves bipinnate in shape and flowers with whitish in colour. It occurs naturally in the sub-Himalayan tract from the Indus eastwards to the Khasi hills, West Bengal, throughout the Indian Peninsula and the Andamans. It is also found both in dry and as well as moist forests of Gujarat, Maharashtra and Karnataka. It belongs to family Fabaceae. Under North Indian climate, leaf shedding takes place in October-November, but some trees, particularly those having sufficient moisture supply, may continue shedding their leaves till January. The new leaves appear in March-April. Flowering takes place in April-May (Brandis, 1906) and the trees are covered with masses of yellowish-white flowers. The pods remain green up to October and start turning yellow in November. They ripen from December to February in North India and about a month earlier in South India. The ripe pods are flat, thin, linear-oblong and are about 20-30 cm long and 3-5 cm broad (Brandis, 1906). Each pod has about 6 to 12 seeds. The seeds are light brown, smooth, obovate or oblong, compressed, about 0.70-1.20 cm by 0.60-0.90 cm and have a hard testa (Troup, 1921). The timber is used for high class furniture, cabinet work, interior decoration, etc. It is also suitable for building purposes, agricultural implements, flooring, paneling and railway carriages.

Acacia mollissima Willd. commonly known as Black wattle, is a medium sized tree with usually smooth dark brown bark attaining height upto 25 m and 45 cm in diameter. It is a fast growing , medium sized evergreen tree native to Australia. The species was introduced to India in 1959 and cultivated extensively in even aged short rotation plantations in Nilgiri and Palni hills of Tamilnadu, Meghalaya, Nagaland and southern Rajasthan. Plantations of this species are also coming on massive scale in mid hills of Himachal Pradesh. Leaves are 8-12 cm long, fern like with green leaflets. The inflorescences are arranged in a much branched panicle. Flowering begins when the trees are about two years old, but significant seed production does not start before the fifth or sixth year. This species have a potential for fast growth, having great economic importance and provide a wide variety of useful products. Its bark is most prized for tannin extraction and its wood pulp serves as a raw material for manufacturing paper, viscose rayon, nitrocellulose, etc.

Ulmus villosa Brandis, commonly known as Marinoos, is a medium-to-large deciduous tree attaining height upto 25 m. Leaves are acute in shape with bark smooth in shape with distinctive horizontal bands of lenticels. It is found in the north-western sub-Himalayas at an

elevation of 1200 to 2500m. It is endemic to the valley of Kashmir but has become increasingly rare owing to its popularity as fodder. The tree is rather highly and pendulously branched, the bark is smooth with distinctive horizontal bands of lenticels, although it eventually becomes very coarsely furrowed. The oblong, elliptic and acute leaves are less than 10 cm long and 5 cm broad. The flowers appear in spring and are partially densely clustered. Stamens 3-4. Ovary and style densely villous. The samaras are elliptic and up to 12 mm long, densely hairy on both sides. The species is fast growing with considerable longevity and highly valued for its multipurpose uses i.e. timber, fuelwood, fodder, etc.

Dalbergia sissoo Roxb. Ex DC. commonly known as Shisham, is a medium to a large sized deciduous tree having thick, rough grey bark with tree attaining height upto 30 m and 2.4 m in girth. Leaves imparipinnate in shape and flowers yellowish-white in colour. It is found throughout the sub-Himalayan tract and outer Himalayan valleys from the Indus to Assam, usually upto 900m, but occasionally ascending to 1500m. It has been extensively planted along roads and canals especially in Punjab and Uttar Pradesh. The leaf fall begins in November-December depending upon the climatic conditions. The trees remain leafless up to the end of January or the middle of February when new leaves appear. The flower buds appear with the new leaves and the yellowish flowers open in March or April (Troup, 1921). The pods develop rapidly and attain full size by about July. They start turning brown in November and ripen in December-January. Full grown pods are about 5 to 8 cm long, pale brown, flat, one to three-seeded and indehiscent. Based on strength characteristics, the timber of Uttar Pradesh has been grouped as first choice for permanent structures. It is one of the most preferred species for door and window shutters and frames in Northern India. It is suitable for wooden flooring and paneling etc. It is a preferred species for building railway coaches, truck and lorry bodies.

Toona ciliata M. Roem. commonly known as Toon or Red Cedar, is a large deciduous tree attaining height of 20-30 m and a girth of 2-3 m. Bark dark grey with leaves imparipinnate in shape and flowers yellowish-white in colour. It is found throughout the sub-Himalayan tract and the valleys of the outer-Himalayas from Jammu eastwards, throughout the plains of Bihar, Assam, West Bengal, Khasi hills and the valleys of Eastern Ghats in the moist localities. It is cultivated to a fairly large scale in the plains, along roads in Himachal Pradesh, Uttar Pradesh and house compounds in Manipur. Small white flowers appear in March-April under North Indian conditions soon after the new flush of leaves in January-

February (Troup, 1921). The time of the shedding of old leaves differs according to the climatic conditions and moisture availability in a locality, in dry places the leaves are shed earlier than in moist places. The fruits ripen in May-June under North Indian climate and the seed is dispersed in June-July. The seeds are light brown and have a membranous wing at either end. The tree usually seeds abundantly every year (Troup, 1921). It is used for fodder, fuelwood, timber and for making musical instruments. It is suitable for making plywood, match-boxes and for low cost grade pencils. It is one of the woods found suitable for making racquets.

Melia composita Willd. commonly known as Darek, is a moderate-sized deciduous tree with a short trunk and spreading crown, reaching a height of 10-20 m in height and 1-1.5 m in girth. Bark is dark grey with leaves tripinnate in shape. It occurs mostly in tropical moist deciduous forest of the Sikkim, Himalayas, North Bengal and Upper Assam, Khasi hills, North Circle, Deccan and the Western Ghats at an altitude of 1200 to 1800m. The old leaves are shed in November-December and the new leaves appear in March-April depending upon the climatic conditions of the locality. The panicles of flowers appear from March to May. The fruits are soon formed in clusters and are of dark green colour. The fruits ripen during winter but remain on the tree till April-May. The fruit is a drupe, nearly globose, yellow when ripe, smooth at first and wrinkled afterwards. The fruit has a long and very hard endocarp. It is favoured where strength and hardness is required. It is used for piles, bridges, underground props in the tunnels, electric poles, pencil, match-boxes and plyboards. It can also be used for cabinet work.

The MPT's are able to maintain or improve soil health. The process by which trees improve soil fertility is photosynthesis, fixation of carbon and it's transfer to the soil via litter and root decay. Nitrogen fixation by leguminous trees, improve nutrient retrieval by tree roots and erosion control by a combination of ground cover and barrier effects, efficient uptake of nutrient from soil. Soils found under trees have a favourable structure and water holding capacity through organic matter stabilization and root action and exudation of growth promoting substances.

Trees reduce soil erosion as well as improve the location by supplementing of nutrients and organic matter by decaying of plant parts like leaf litter (Nair, 1992). Due to the tree shade there is an enhancement of growth and mineral nutrition for the grass species.

Shading enhances the accessibility of nutrients in the soil, and also improves the biological action of the soil.

The organic matter received through mineralisation is converted into soil organic carbon (SOC). The soil organic carbon that is stored for a long term in the form of humic substances (Kononova, 1996). Tree species influences the soil properties including the quality and quantity of soil organic carbon by the complex of the climate, soil type and management (Lal, 2005).

Tree exert a major effect on soil by influencing microclimate, soil properties, primarily by the amount and composition of litter deposited and by nutrient uptake and accumulation. Multipurpose tree species producing high quality litter may enhance soil nutrient availability and crop yield through mineralisation of soil organic matter and green manure (Kimaro, 2008).

High biomass production obviously is an important consideration in all tropical tree planting programmes. Biomass productivity of the MPTs, however, differs enormously with species, site characteristics and stand management practices. Nonetheless, it is useful to know the stocks of carbon as biomass per unit area, not only to facilitate choice of species but also to assess the impact of deforestation and re-growth rates on the global carbon cycle (Deans *et al.*, 1996).

The fundamental process of ecosystem is the decomposition of leaf litter which is basically associated to supplementation of nutrient for growth and development of the plant. Soils are generally found barren in lower western Himalayas and mid hills of western Himalayas, which unable to give sustainable production without the use of external inputs. Combination of trees with this kind of soil resulted the falling of leaf which helps to supply nutrients as well as improves the physico-chemical properties of the soil. Decomposition of leaf litter is totally dependent of the external climatic factors and structural composition. The decomposition of litter leads manipulates soil fertility and plant growth.

Carbon sequestration potential depends upon the biological productivity, which in turns depends upon interaction between species, climate, topography and management practices imposed. Thus carbon density and sequestration potential varies from place to place, which need to worked out on region to region and species to species basis. Establishment of

large scale short rotation woody crop plantation has been advocated as an effective method of sequestration CO₂ and mitigating increased atmospheric CO₂ levels (House *et al.*, 2002), through increasing long term C in woody biomass (Sejdo, 1989) and in the soil.

A key issue is nutrient availability. Many research results suggest that leaf litters offer considerable potentials of improving soil productivity and increasing crop yield. A generalized reporting of the potential benefits and advantages are worth mentioning. However, the scenarios are different for every tree species. The availability of these nutrients through decomposition depends on several inherent and ecological factors. Leaf litter decomposition is the fundamental process of ecosystem functioning which is closely related to nutrient supply for plant growth.

The chief aspect in forest ecosystem of nutrient cycling and energy transfer is Litter dynamics (Maguire, 1994). This plays major role in Agroforestry system in cultivated, lands. Litter fall is a main principle path for provide back nutrients to the soil from the plants parts decomposition. The important processes of litter fall which lead to provide nutrient enrichment to the soil *i.e.* decomposition and mineralization (Mugendi and Nair, 1997). The different process are involved in which microorganism plays an important role and by their action the organic material get converted into inorganic form like nitrate or ammonia which are easily uptake by trees and crops. The decomposition of litter fall adds organic and inorganic elements in the soil. (Mudrick *et al.*, 1994).

The incorporation of leaf biomass of tree species was found to be successful and hence widely adapted for improving the soil nutrient status without much deleterious effect on the physico-chemical composition of the soil. Tree species vary widely in their leaf biomass decomposition rate and nutrient release pattern which is primarily a function of the chemical quality and prevailing weather conditions. Through experience, the incorporation of tree leaf biomass in to the soils has received wider recognition primarily in view of their capacity to retain long term fertility and aggregate stability of the soil (Kumar *et al.*, 2001).

Keeping in mind the aforesaid facts the potential of Multipurpose trees to optimize biomass productivity and store the carbon and protection functions like reducing soil erosion, improving soil physico-chemical properties etc. in the present work entitled, “Studies on nutrient status and carbon sequestration potential of important multipurpose trees in sub-tropical region of Himachal Pradesh” was carried out with following objectives:

- i) To determine the effect of MPTs on soil properties and nutrients
- ii) Carbon sequestration potential of different MPTs
- iii) Leaf litter accumulation and decomposition rate of different MPTs

Chapter-2

REVIEW OF LITERATURE

Agroforestry trees commonly referred as “Multipurpose Trees” form an integral component of different agroforestry interventions and models. The MPT’s not only provides the multiple outputs like fuel, fodder, timber and other miscellaneous products but helps in improvement of microclimate and ecological conditions. A common hypothesis is strongly implied to the MPT’s in agroforestry is that MPT’s increases the overall productivity and improves the physical and chemical properties of the soil. MPT’s in agroforestry also holds the good promise to enhance plant-soil carbon pools by sequestering carbon from the atmospheric carbon dioxide. However, to elucidate the potential of MPT’s to enhance the soil physical and chemical properties, biomass productivity and store the carbon sequestered for the long time either in biomass or soil, needs scientific evidences. The available literature from the sources accessible have been reviewed under the following heads:

2.1 Effect of MPTs on soil properties and nutrients.

2.2 Carbon sequestration potential of different MPTs

2.3 Leaf litter accumulation and decomposition rate of different MPT

2.1 EFFECT OF MPTS ON VARIOUS SOIL PROPERTIES AND NUTRIENTS

Tree species influences the soil properties including the quality and quantity of soil organic carbon by the complex interaction of climate, soil type and management. Trees not only reduce the soil erosion but also ameliorate the site by adding nutrients and organic matter in the form of leaf litter.

Yadav (1967) reported that available N content of Himachal Pradesh soils ranged from 120-230 ppm with average value of 180 ppm. He reported that available N content falls in the range between 118-242 Kg ha⁻¹ in some parts of Kinnaur district.

Evans and Rombold (1984) observed that *Melia azedarach* have a potential to improve soil by adding organic-C and nitrogen if clear felled after 10 years age. Besides improving soil aeration its root retrieve the nutrients leached below the root zone of annual crops. It was observed that humus layer was rebuilt and the soil structure had become less compact and more porous where woodlots were planted.

Deans *et al.* (1999) assessed the amount of biomass, soil pH, organic carbon and N, P and K contents in soil and plant tissue, using regression techniques in widely spaced (5m × 8 m), 3-18 year old *Acacia senegal* plantations on degraded soil in northern Senegal, in order to provide quantitative information on the rate of nutrient enrichment in tree fallows. They reported that by 18 years, the average tree had accumulated 945, 38 and 420 g of N, P and K, respectively. The soil organic matter, N, P, K concentrations were always greatest in surface horizons. While studying the correlation between soil organic matter and N, P and K contents in soil and plant tissue they reported that correlation between soil organic matter and N, P and K contents in soil and plant tissue were significantly higher in surface horizons only.

Dhyani *et al.* (1990) studied the effect of five tree species viz. *Bauhinia purpurea*, *Grewia optiva*, *Eucalyptus tereticornis*, *Leucaena leucocephala* and *Ougeinia oojeinensis* on the nutrient status in (0 – 15cm) soil depth and concluded that the total N, available P₂O₅, available K₂O, exchangeable Ca and Mg were higher in the soil under the tree species in comparison to area without tree plantation.

Kushalapa (1991) observed an enrichment of soil through leaf litter and increase of soil pH from 4.98 to 5.37 over the period of 8 years under *Acacia auriculiformis* plantation. In another experiment, Pakrashi (1991) studied the effect of leaf fall of *Albizia lebbeck*, *Acacia nilotica*, *Leucaena leucocephala*, *Acacia auriculiformis* and some non-legumes on soil properties and observed that there is a significant increase of all major nutrients in soil (N,P, K,C and Mg) with addition of leaf litter.

Bhola (1995) studied the soil enrichment potential of seven nitrogen fixing trees species and observed considerable improvement in soil chemical properties under all species in comparison to adjoining unplanted area. However, overall enrichment was recorded as 15.52-39.52, 8.59-17.98, 15.36 to 39.52 98.91, 2.09-14.0 and 1.93-9.54 percent for organic carbon, available nitrogen, available phosphorus, available potassium, exchangeable calcium and exchangeable magnesium, respectively.

Mongia *et al.* (1998) studied the ameliorating effect of forest trees on highly sodic soil in Haryana. They found that by growing *Acacia nilotica* for more than three years the pH, electrical conductivity of the soil and CaCO₃ content were lowered while organic matter, Fe and Mn content increased.

Patel and Singh (2000) tested the effectiveness of Ten multipurpose tree species in ameliorating marginal farmland at Junagarh in the semiarid South Saurashtra region of Gujarat and measured soil nutrient status under the canopy at (0-20cm) and (20-40cm) depth after 1 and 2 years of planting. They recorded highest increase in available N, P₂O₅ and K₂O as well as percent organic matter at 0-20cm soil depth under the canopy of *Albizia lebbeck* followed by *Cordia dichotoma*. However, they did not notice any significant change in soil pH under the canopy of the various tree species.

Maikhuri *et al.* (2000) evaluated Ten multipurpose tree species viz., *Albizia lebbeck*, *Alnus nepalensis*, *Celtis australis*, *Dalbergia sissoo*, *Ficus glomerata*, *Grewia optiva*, *Prunus cerasoides*, *Pyrus pashia*, and *Sapium sebiferum* which were established as mixed plantations on a degraded community forest land and an abandoned agricultural land and found that all the soil physico-chemical characteristics has shown a significant improvement at both sites.

Chandra (2010) studied the potentialities of twelve different species (*Eucalyptus hybrid*, *Eucalyptus camaldulensis*, *Eucalyptus citrodora*, *Hardwickia binnata*, *Tectona grandis*, *Dalbergia sissoo*, *Albizia lebbeck*, *Albizia procera*, *Terminalia bellirica*, *Cassia siamia*, *Pongamia pinnata* and *Bambusa aurandinacea*) planted by the State Forest Research Institute at Jabalpur, Madhya Pradesh in degraded oxisols for almost two decades. Results showed a marked improvement in bio-chemical characteristics of soil by increasing the water holding capacity, porosity and organic matter. Soil nitrogen was improved by 39.8%, Phosphorous 42.1%, Potassium 37% and Calcium 52% under tree plantations of 19-23 years age compared to the unplanted soil. Soil microbial activity was enhanced up to 2.9 fold due to accumulation of humus through organic matter.

A 26 years old agroforestry plantation consisting of four multipurpose tree species (MPTs) (*Michelia oblonga* Wall, *Parkia roxburghii* G. Don, *Alnus nepalensis* D. Don, and *Pinus kesiya* Royle ex-Gordon) maintained at ICAR Research Complex, Umiam, Meghalaya, India were compared with a control plot (without tree plantation) for soil fertility status and CO₂ efflux. The presence of trees improved all the physico-chemical and microbial biomass parameters studied in this experiment. Relative to control, soils under MPTs showed significant increases. However, these parameters significantly differed among the tree species. Ramesh *et al.* (2013).

Ramesh *et al.* (2015) studied the effect of four multipurpose trees (*Michelia oblonga* Wall, *Parkia roxburghii* G. Don, *Alnus nepalensis* D. Don, and *Pinus kesiya* Royle ex Gordon) and assessed the soil organic carbon stocks, microbial biomass carbon, readily oxidizable carbon, , non-labile carbon, particulate organic carbon and carbon management index. The TOC, POC, ROC, CNL and MBC in soils of agroforestry land use, on average, increased significantly by 26.3, 60.1, 27.1, 46.4 and 34 per cent, respectively in relative to control plot. However, the agroforestry systems consisting *A. nepalensis* recorded the highest mean SOC stocks (60.2 Mg ha⁻¹), TOC (3.60 g 100 g⁻¹), POC (5.42 g kg⁻¹), ROC (10.16 g kg⁻¹) and MBC (548 mg kg⁻¹) than other agroforestry systems.

Das *et al.* (2014) conducted an experiment to evaluate the performance and characterize plant growth behaviour, light profile and soil fertility status of seventeen different trees (12 years old). The study indicated higher bio-mass production potential of *Gmelina arborea*, *Dalbergia sissoo* and *Leucaena leucocephala*. Higher photosynthetically active radiation value below tree canopy indicates compatibility of trees with a majority of agricultural crops. In the present study, a significant increase in pH and decrease in EC of trees were observed. The significant reduction in nutrients in different trees indicated a need for replenishment of nutrients in soil for maintaining soil fertility in agro-forestry systems on long-term basis.

Chaudhary and Saxena (2015) conducted a study to quantify the Soil Organic Carbon (SOC), Total Nitrogen (TN) and Above Ground Tree Biomass (AGTB) in five prominent land uses - land cover of a village landscape in Garhwal Himalaya for two seasons. The forest land in Himalaya has been converted into various land uses like Pine Forest (PF), Oak Plantation (OP), Irrigated Agriculture (IA), Rainfed Agriculture (RA) and Abandoned Agriculture land (AA). In autumn, SOC (Mg ha) for 1m soil depth, varied from (37.99±6.96) in PF to 1 (51.53±4.16) in RA. In spring, the SOC content of complete profile (1m) varied from (20± 6.3) in PF to (36.38±6.9 Mg/ha) in OP. In autumn, TN content (Mg ha) up to 1 m varied from 1.082± 0.35 (PF) to 2.30±0.18 (AA). In spring, the TN in complete profile varied from (2.19±0.4) PF to (3.5± 0.23) RA. The highest value of tree density was found in PF (913.33±145.7) and it was significantly higher ($P > 0.05$) as compared to other land uses and land cover type. The AA (11.87±2.12) had basal area (BA) much lower than PF (115.68 ± 30.4) and OP (35.04 ± 8.71). The AGTB (kg ha) was found in PF (6426.8± 506.8) and minimum for IA (91.25±11.72).

Dalvi *et al.* (2015) studied the effect of different nitrogen fixing tree species on soil chemical properties and primary nutrients in lateritic soil of ten different species. The study revealed that there was no variation for pH and EC among the ten species. However, some of the tree species showed higher organic carbon, organic matter, available nitrogen, phosphorous, potassium as compared to control.

Kumar *et al.* (2017) investigated the effect of multipurpose tree species viz. *Prosopis cineraria*, *Acacia senegal* and *Tecomella undulata* on the physical and chemical properties of soils. The amount of nutrients returned to the soils through litter fall followed the order of $\text{Ca} > \text{K} > \text{Mg} > \text{P} > \text{Fe} > \text{Mn} > \text{Zn} > \text{Cu}$ under tree species and variation in the amount of nutrient returned to the soils among the different tree species and field without plantation explained by the quantity of litter production and its chemical composition. The present study also indicated that these available nutrients had significant and positive correlation with organic carbon content across the land uses.

Patel *et al.* (2018) studied the Thirty years old agroforestry tree plantation consisted of four multipurpose tree species (MPTs) viz., *Azadirachta indica*, *Prosopis cineraria*, *Prosopis juliflora* and *Acacia tortolis*. Relative to open field, soils under MPTs noted significantly increased WHC (26.50 per cent) and soil porosity (40.67 per cent) under *Prosopis cineraria* tree and *Azadirachta indica* tree species respectively while the lower values of BD (5.25 per cent) and minimum soil temperature (29.12°C) was noted under *Acacia tortolis* and lower values of maximum soil temperature (35.25°C) was under *Azadirachta indica* amongst all tree species. The pH and EC value decreased while organic carbon, available nitrogen, available phosphorus and available potash value in soil was increased under all tree species at different soil depth compared to open field. Reduced mean soil pH (3.97 per cent) and EC (75.45 per cent) was noted under the tree species of *Acacia tortolis* and *Prosopis juliflora*, respectively over control whereas mean maximum OC (0.63 per cent) and Available N (167.25 kg/ha) noted under *Acacia tortolis* tree species which was 320 per cent and 88.24 per cent higher over open field. Mean maximum available P_2O_5 (34.20 kg/ha) and available K_2O (419.45 kg/ha) noted under *Prosopis cineraria* and *Azadirachta indica* tree species respectively which was 38.57 per cent and 64.26 per cent higher over control.

2.2 CARBON SEQUESTRATION POTENTIAL OF MPTs

Houghton *et al.* (1987) reported that deforestation in the tropics is responsible for an annual net release of carbon to the atmosphere, estimated in 1980 at $0.5\text{-}4.2 \times 10^{15}$ g.

Comparative carbon release from fossil fuel combustion in 1980 was 5.2×10^{15} g. The wide range of estimates for the tropical biota and soils has been primarily caused by different estimates of the rate of deforestation.

Beer *et al.* (1990) gave a detailed breakdown of biomass production over 10 years in two tree combinations in Costa Rica: Cacao (*Theobroma cacao*), laurel (*Cordia alladora*) and Cacao – Poro (*Erythrina poeppigiana*). Based on these data, whole system carbon stocks were calculated by averaging the annual biomass production in the two periods and multiplying the output by 0.5 (Kurstsen and Burschel 1993). Thus, 11 Mg C ha⁻¹ yr⁻¹ was stored over 10 years in the system including 6 Mg C ha⁻¹ yr⁻¹ could be stored if rice fields were transformed into homegardens.

Katagiri *et al.* (1992) reported that dry weight of dead organic matter including dead standing trees was 4.1 to 16.8 per cent of the total above ground biomass in Sanbe forest, Shimane Japan. *Quercus serrata* and *Casfancca crenato* comprised the principal broad leaf species. Forest show the best mitigation potential followed by agroforestry, plantations and agriculture. Conversion of natural forests to agriculture in the humid tropics lead to a reduction, in ecosystem carbon storage due to removal of above ground biomass and a gradual subsequent reduction in soil organic carbon. Whereas forest conversion to well managed grasslands may lead to increased soil carbon storage, after an initial decline (Van *et al.*, 1997).

Singh *et al.* (2000) identified three alternative to slash and burn agriculture and evaluated them in terms of carbon sequestration. The alternatives were commercial cassava cultivation, improved forest conversion and stratified agroforestry. These alternative landuse to reduce the potential of carbon losses over slash and burn practices by 10,55 and 75 Mg C ha⁻¹ yr⁻¹, respectively and also differs greatly in potential to alleviate rural poverty, protect biodiversity and reduce deforestation. Farm forestry is the major instrument for increasing carbon sequestration while supplying wood and non- wood products to meet both domestic and market requirements.

The amount of carbon sequestered largely depends on the system put in the place, the structure and function of which are to a great extent determined by environmental and socio-economic factors. Other factors influencing carbon storage in agroforestry systems include tree species and system management (Albrecht and Kandji 2003). Planting trees in fallow for

12 – 22 months in West Kenya resulted in carbon inputs ranging from 135 – 165 Mg ha⁻¹ in the soil.

Raizada *et al.* (2003) estimated the rate of C flux in selected short rotation tree species and reported that regular leaf shedding patterns have more capacity for C sequestering in litter which decomposes more rapidly than species with annual or bimodal leaf shedding patterns, fast growing conifers may produce slow decomposing litter leading to accumulation on forest floor, hence, risk for fire damage and decline in ground flora diversity and productivity, mixed planted forests of exotic and native species could be more efficient in sequestering C than monocultures, and fast growing hardy species like Eucalyptus would be ideal choice for wastelands afforestation / reforestation.

Upadhyay *et al.* (2005) studied on the land-use changes and degradation of forests and soils in the Hindu Kush Himalayan region have important implications for CO₂ emissions and global climatic change that calls for an interdisciplinary research to analyse the complexity of the problem. The main objective of this study was to document knowledge on C sequestration as affected by land-use changes and forest/soil degradation. Estimates of land-use changes, loss of soil due to erosion and soil organic carbon contents by dominant land-use categories have been documented from the available studies in the region. Some evidence exists to show that the land-use changes and forest/soil degradation affect C pools significantly. Finally, an analytical framework is presented for investigating the dynamics of C sequestration. On the basis of review of past studies, there appeared to be a high potential for enhancing the C sequestration in the vegetation and soils of the Himalayan region through improved management of degraded lands. It is suggested that the complexity of dynamics of C sequestration caused by diverse bio-physical and socio-economic factors in the region needs ideally be analysed by following systems approach in the future research endeavours.

Ravindranath *et al.* (2006), made an assessment of the impact of projected climate change on forest ecosystems in India, based on climate projections of regional climate model of Hadley centre (HadRM3), using the A₂ and B₂ scenarios of the special report on emissions scenarios (SRES) and the BIOME 4 vegetation response. The study found that under the climate projection for the year 2085, 77 and 68% of the forested grids in India, respectively, are likely to experience shift in forest under A₂ and B₂ GHG scenario. The north eastern region may experience a shift towards drier forest types in the absence of human interference. Increasing atmospheric CO₂ concentration and climate warming could also result in doubling

of net primary productivity under A₂ scenario and a nearly 70% under B₂ scenario. The NPP under tropical evergreen forests is projected to increase by 1.5 times under the GHG scenarios. The projected rate of increase in NPP is lower for cool conifer forest, cold mixed forest and temperate deciduous forest. Generally the rate of increase is higher for warmer vegetation types. However, the BIOME 4 model does not take into consideration nutrient limitations, particularly those of nitrogen and soils.

Kaul *et al.* (2010) studied a dynamic growth model (CO₂FIX) that was used for estimating the carbon sequestration potential of sal (*Shorea robusta* Gaertn. f.), Eucalyptus (*Eucalyptus tereticornis* Sm.), poplar (*Populus deltoides* Marsh), and teak (*Tectona grandis* Linn. f.) forests in India. The results indicate that long-term total carbon storage ranges from 101 to 156 Mg C ha⁻¹, with the largest carbon stock in the living biomass of long rotation sal forests (82 Mg C ha⁻¹). The net annual carbon sequestration rates were achieved for fast growing short rotation poplar (8 Mg C ha⁻¹ yr⁻¹) and Eucalyptus (6 Mg C ha⁻¹ yr⁻¹) plantations followed by moderate growing teak forests (2 Mg C ha⁻¹ yr⁻¹) and slow growing long rotation sal forests (1 Mg C ha⁻¹ yr⁻¹). They also used this model to evaluate the effect of changing rotation length and thinning regime on carbon stocks of forest ecosystem (trees + soil) and wood products, respectively for sal and teak forests. Extending rotation length from the recommended 120 to 150 years increased the average carbon stock of forest ecosystem (trees + soil) by 12%. Goal of maximum carbon storage and production of more valuable saw logs can be achieved from longer rotation lengths. Extended rotation lengths and reduced thinning intensity could enhance the long-term capacity of forest ecosystems to sequester carbon.

Devi *et al.* (2013) studied and estimated biomass production and carbon sequestration potential of different plantation ecosystems in north western Himalaya in India under different plantation forest ecosystems comprising of eight different tree species: *Quercus leucotrichophora*, *Pinus roxburghii*, *Acacia catechu*, *Acacia mollissima*, *Albizia procera*, *Alnus nitida*, *Eucalyptus tereticornis* and *Ulmus villosa*. Above (185.57±48.99 tha⁻¹) and below ground (42.47±10.38 tha⁻¹) biomass was maximum in *Ulmus villosa*. Soil carbon density was maximum (219.86±10.34 tha⁻¹) in *Alnus nitida*, and minimum (170.83±20.60 tha⁻¹) in *Pinus roxburghii*. Decomposition was higher in *Pinus roxburghii* (6.79±2.0 tha⁻¹). Carbon sequestration (7.91±3.4 tha⁻¹) and CO₂ mitigation potential (29.09±12.78 tha⁻¹) was maximum in *Ulmus villosa*.

Goswami *et al.* (2013) studied agroforestry land use systems existing on arable and non-arable lands in the Kwalkhad Watershed of middle Himalayan region of Himachal Pradesh, India. The agroforestry land use systems were evaluated for C sequestration and C credits. In total, eight land use systems existed in the watershed. Agrisilvihorticulture (ASH) system (14.78 Mg ha^{-1}) and agrihortisilviculture (AHS) system (14.45 Mg ha^{-1}) sequestered a high amount of C than silvipasture (SP), pure agriculture or grassland and abandoned land, though not significantly more than agrisilviculture (AS) or agrihorticulture. Total C pool in abandoned soils (0–40 cm) was highest followed by SP and ASH system. C stocks in soil (0–40 cm) exceeded C stocks in plants by a factor of 15.81 for AHS system. SP, ASH and AS systems, with their higher C mitigation potential of 1.71, 1.52 and 1.43, respectively, were more suitable land use systems for C mitigation in the region. The ASH system produced the most (21.49) C credits on a per-hectare basis.

Ranot and Sharma (2013) conducted the study with a purpose to compare above-ground biomass production and thereby the carbon sequestration potential of important thirteen tree species (20–30 years age) planted at 3m x 3m spacing in the Nauni campus of Dr .Y. S. Parmar University of Horticulture and Forestry, Nauni, Solan. The study concluded that above-ground volume mean annual increment per tree basis was maximum in *Acrocarpus fraxinifolius* (0.028 m) followed by *Eucalyptus tereticornis* (0.026 m), *Populus deltoides* (0.021 m), *Pinus roxburghii* (0.020 m), *Salix alba* (0.019 m), *Albizia lebbeck* (0.008 m), *Ulmus villosa* (0.008 m), *Melia composita* (0.008 m), *Grewia optiva* (0.007 m), *Acacia mollissima* (0.007 m), *Quercus leucotrichophora* (0.006 m), *Acacia catechu* (0.003 m) and *Punica granatum* (0.0003 m), whereas aboveground carbon mean annual increment among these tree species was maximum in *Acrocarpus fraxinifolius* (10.72 kg) followed by *Eucalyptus tereticornis* (8.60 kg), *Melia composita* (5.09 kg), *Pinus roxburghii* (5.08 kg), *Populus deltoides* (4.06 kg), *Ulmus villosa* (3.84 kg), *Salix alba* (3.65 kg), *Albizia lebbeck* (2.44 kg), *Acacia mollissima* (2.40 kg), *Quercus leucotrichophora* (2.43 kg), *Grewia optiva* (2.32), *Acacia catechu* (1.02 kg), and *Punica granatum* (0.13 kg).

Kanime *et al.* (2013) studied and assessed the biomass, carbon storage and carbon dioxide mitigation potential of plantations of *Populus deltoides*, *Eucalyptus tereticornis*, *Dalbergia sissoo*, *Mangifera indica*, *Litchi chinensis* and *Prunus salicina*. It was observed that the maximum total biomass (94.8 Mg ha^{-1}) was in a 10-year-old *D. sissoo* monoculture plantation, followed by an 8-year-old *Populus deltoides* block plantation (63.0 Mg ha^{-1}).

They also estimated the carbon sequestration rate for *Populus deltoides* block and boundary plantations which was found to be 2.75 and 0.43 Mg C ha⁻¹, respectively. Eucalyptus boundary plantation sequestered 0.84 Mg C ha⁻¹ while *Dalbergia sissoo* plantation sequestered 2.73 Mg C ha⁻¹.

Arora and Chaudhary (2014) conducted a study on the plantations of *Eucalyptus tereticornes*, *Tectona grandis*, *Syzygium cumini* were selected in the Kurukshetra University Campus for determining their potential to sequester carbon in vegetation and soil. The plant biomass was 169.44 Mg ha⁻¹ in *Eucalyptus tereticornes*, 153.31 Mg ha⁻¹ in *Tectona grandis* and 132.59 Mg ha⁻¹ in *Syzygium cumini* accounting for maximum carbon allocation in *Eucalyptus tereticornes* (81.33 Mg C ha⁻¹). The vegetation carbon pool *Tectona grandis* and *Syzygium cumini* was 73.58 Mg C ha⁻¹ and 63.64 Mg C ha⁻¹ respectively. Total Soil organic carbon stock (SOC) down to 100 cm depth was maximum in *Syzygium cumini* (77.72 Mg C ha⁻¹) followed by *Eucalyptus tereticornes* (74.69 Mg C ha⁻¹) and *Tectona grandis* (55.46 Mg C ha⁻¹). Microaggregates contributed highest to the per cent weight distribution of soil aggregate size fraction in all the depths and study sites whereas percent organic carbon content was higher in macroaggregates.

Ajit *et al.* (2016) estimated the carbon sequestration potential of existing agroforestry systems for simulation period of 30 years in twenty six districts from ten selected states of India. They reported that the biomass in the tree component varied from 0.58 to 48.50 Mg DM ha⁻¹, whereas, the total biomass (tree and crop) ranged from 4.96 to 58.96 Mg DM ha⁻¹. The soil organic carbon ranged from 4.28 to 24.13 Mg C ha⁻¹. The average estimated carbon sequestration potential of the AFS, representing varying edapho climatic conditions, on farmers field at country level was 0.21 Mg C ha⁻¹yr⁻¹. At national level, existing AFS are estimated to mitigate 109.34 million tons CO₂ annually, which may offsets one-third (33 %) of the total GHG emissions from agriculture sector.

Chaturvedi *et al.* (2016) studied the biomass production through agroforestry. In different vegetation systems, the bole/ stem biomass contributed 28 to 86 per cent of total aboveground biomass. The percentage contributions of bole, branch and leaf were 65-76, 14-19, 3-12 for fast growing tree species. In case of other tree based systems stem contributed about 76 to 80%, branch 11 to 29% and leaves 3 to 14% of aboveground biomass. A tree allocates on an average 81.89% to above ground biomass (stem, branch, leaves and litter) and 18.11% to below ground biomass (roots). The available estimates of carbon stored in tree

based systems ranged from 0.29 to 15.21 Mg C ha¹year⁻¹ in above ground and 30-300 Mg C ha⁻¹ upto 1 m depth in the soil. Soil carbon storage potential in agroforestry systems differed from system to system and highest storage potential was observed in homegardens where it stored 119.3 t SOC per hectare.

Sharma *et al.* (2016) carried out study on twenty four old plantation of five multipurpose tree species viz, *Acacia nilotica* (L.) Delile, *Albizia lebbeck* (L.) Benth., *Dalbergia sissoo* D.C., *Eucalyptus tereticornis* Sm. and *Terminalia arjuna* (Roxb. ex. DC.) Wight & Arn. with an objective to estimate above ground biomass and carbon sequestration potential at Mohand range, Dehradun Forest Division, during 2011-2012. Aboveground biomass production was observed to be maximum in *Eucalyptus tereticornis* (827.12 kg /tree) and the minimum was in *Terminalia arjuna* (450.80 kg/tree). Results of fixed carbon percentage showed *Albizia lebbeck* and *Dalbergia sissoo* as the most suitable multipurpose tree species.

Roshanzada *et al.* (2018) studied the growth, biomass, carbon storage and allometric relations for estimating stem volume and aboveground biomass on the basis of DBH and Height of tree and growth pattern curve, carbon storage and developed various allometric equations on selected Agroforestry trees. Total seven species including 210 trees were marked selected in this present study. The maximum adjust R² found in; *Albizia chinensis* where quadratic function showed the highest adj R² (0.993) on the basis of DBH and according to the height of tree (H), the bestfit was also quadratic, which showed adj R² in the value of (0.695), on the other hand for six species trees, power function was the best significant equation which modified the highest adj R² for the following specieses, that are *Albizia lebbeck* (0.964), *Acacia mollissima* (0.992), *Melia composita* (0.990), *Dalbergia sissoo* (0.992), *Toona ciliata* (0.888) and *Ulmus villosa* (0.990) recorded on the basis of DBH, however, to the height of tree as an independent variable, the best equation was sigmoid which showed the adj R² value in *Albizia lebbeck* (0.480), *Acacia mollissima* (0.530), *Melia composita* (0.598), *Dalbergia sissoo* (0.551), *Toona ciliata* (0.645) and *Ulmus villosa* (0.597). The total biomass (AGB + BGB) was calculated using specific gravity and root-shoot ratio. Branch and leaves biomass of each species was estimated using biomass expansion factor (BEF) of trees as per the guidelines of IPCC (2003). All biomass values were converted to tree biomass carbon by multiplying factor of 0.5. However, in this research, equation selection was based on adjust R² and minimum standard error.

2.3 LEAF LITTER ACCUMULATION AND DECOMPOSITION RATES OF DIFFERENT MPTs

One of the major recognized avenues of soil fertility improvement in forestry/agroforestry system is recycling of nutrients through decomposition of tree biomass – mainly leaf litter. The extent of benefits derived will, of course depend on the nutrient content of the biomass added and the rate of decomposition.

Hopmans *et al.* (1980) found that the ammonification was higher in soils under eucalyptus than pine irrespective of soil moisture content and incubation period. Tree species vary in their nutrient uptake rates and recycling capacity. Nutrients in litter fall are more slowly released into the soil from organic matter. Rapid decomposition of plant litter at the onset of the rainy season, however, usually enhances major increases in nutrient accumulation over a relatively short period (Swift *et al.*, 1979).

Sharma and Ambasht (1987) made a comparison over 2 years in stands aged 7, 17, 30, 46 and 56 years in the Kalimpong forest division, Darjeeling, West Bengal. It was reported that seasonal decomposition rates with the highest rates in the 3 months of the warm, rainy season. Decomposition rate was highest in the 30 year old stand, i.e. at the time of canopy closure.

Litter production is a major process in the transfer of organic matter and nutrients from above – ground tree parts to the soil. The addition of tree leaves and branches as mulches to soils has been shown to improve site micro – environmental conditions (Budelman, 1989).

The nutrient content (especially N and P) and the lignin and polyphenolic concentrations of litter strong influence its rate of decomposition and nutrient release into the soil (Szott *et al.*, 1991).

Tian *et al.* (1992) reported that the decrease in decomposition rate of litter was of the order: Gliricidia prunings > Leucaena prunings > Rice straw > Maize stover > Acacia prunings. Negative correlations were observed between decomposition rate constants and C : N ratio, per cent lignin and polyphenol content of plant residues. The results indicated that both the chemical composition of plant residues and nature of the decomposer played an important role in plant residue decomposition.

Liu *et al.* (2000) reported that fast initial litter decomposition was followed by lower rates. The decomposition rates of canopy species and bamboo leaf litter appeared to be controlled by the initial concentration of lignin, nitrogen (N) and phosphorus (P) more than by morphological feature of the leaves.

Kumar *et al.* (2001) conducted a study to determine the effect of leaf litters of *Acacia mangium* on soil nutrient, decomposition pattern and soil improvement. The leaf litter decomposed completely within 10 months.

Swamy and Puri (2005) conducted a study to determine biomass production, C-sequestration and nitrogen allocation in *Gmelina arborea* planted as sole and agri-silviculture system on abandoned agricultural land. At 5 years, total stand biomass in agri-silviculture system was 14.1 Mg ha⁻¹. Plantations had 35% higher biomass than agri-silviculture system. Over the 5 years of study, trees had 3.5 Mg ha⁻¹ more C and 36 kg ha⁻¹ more N in plantation than agri-silviculture system. Biomass and C storage followed differential allocation. Relatively more C was allocated in above ground components in plantations compared to agri-silviculture system. After 5 years, soil organic C increased by 51.2 and 15.1% and N by 38.4 and 9.3% in plantation and agri-silviculture system, respectively. Total C storage in abandoned agricultural land before planting was 26.3 Mg ha⁻¹, which increased to 33.7 and 45.8 Mg ha⁻¹ after 5 years in plantation and agri-silviculture system, respectively. Net C storage (soil + tree) was 7.4 Mg ha⁻¹ in agri-silviculture system compared to 19.5 Mg ha⁻¹ in *Gmelina arborea* monoculture stands. The studies suggest that competitive interactions played a significant role in agri-silviculture system. Plantations were more efficient in accreting C than agri-silviculture system on abandoned agricultural land.

Tripathi *et al.* (2009) conducted the study under 3 developed agroforestry systems that is, Khasi mandarin (*Citrus reticulata*), Alder (*Alnus nepalensis*) and Khasi pine (*Pinus kesiya*) in the state of Meghalaya, northeast India to study the litter dynamics and physico-chemical properties of soil. The findings of our investigation revealed that the soil texture in 3 systems varied from sandy to loamy sand and water holding capacity varied significantly ($P < 0.05$) between plots and depths. Soil was acidic in all the plots. Soil organic carbon as well as organic matter content was high in Khasi mandarin-based system than the other systems. Total Kjeldahl nitrogen concentration was low in all the soils. It was lowest in Khasi pine based system and a similar trend was observed in concentrations of available phosphorus and potassium. Monthly variation in litter mass varied markedly between different agroforestry

systems. The rate of weight loss of Alder leaf litter was much faster than other 2 species. Litter decomposition was fast during rainy season and slow during winter season. Rate of release of nitrogen and phosphorus from the decaying leaf litter of Alder occurred at much faster rate compared to Khasi mandarin and Khasi pine, however, potassium release was faster from Khasi mandarin. Total input of N, P and K through litter was higher in Khasi than other 2 species due to greater litter production.

Das and Das (2010) conducted a study in the village Dargakona, Barak Valley, northeast India to understand the pattern of litter production and litter decomposition in the traditional homegardens. Annual litter production was 6.27 Mg ha^{-1} with a bimodal distribution pattern and the nitrogen input through litterfall accounted for $48.17 \text{ kg ha}^{-1} \text{ year}^{-1}$. Litter decomposition studies for ten multipurpose trees revealed *Sapium baccatum* and *Toona ciliata* to be the most labile litter species and the decay rate coefficients varied among the species with differing rates of nutrient release pattern. Such studies can provide information regarding the litter quality of indigenous tree species and help validate farmers planting and management of multiple species which allows for efficient nutrient cycling of the system.

Partey *et al.* (2011) studied the decomposition pattern of *Tithonia diversifolia*, *Acacia auriculiformis*, *Leucaena leucocephala*, *Senna spectabilis* and *Gliricidia sepium* at the Agroforestry Research Station of the Kumasi Ghana. The highest dry weight loss occurred in *Tithonia diversifolia* and lowest in *Acacia auriculiformis*. From the results it was evident that substrate quality influences decomposition of plant materials. The initial N concentration and C/N ratio influences the degradability of organic residues added to the soil (Melillo and Aber, 1993).

Triadiati *et al.* (2011) studied litterfall production by using litter trap and decomposition of leaf litter by nylon net bag technique. The result showed that NF had the higher annual litter fall (13.67 t/ha/year) than that of cacao agroforestry. Natural forest had the highest coefficient of decomposition and or the fastest rate of decomposition, whereas cacao agroforestry under CF_2 had the lowest one. Carbon released was higher in the NF than that of cacao agroforestry. Nitrogen released was higher in the NF than that of cacao agroforestry in the first period.

Kaushal *et al.* (2012) studied the leaf litter decomposition and nutrient dynamics of four important agroforestry tree species viz., *Grewia optiva*, *Morus alba*, *Toona ciliata* and *Popular deltoides* by placing the leaf litter in surface and sub surface layer for one year at the experimental farm of the Department of Silviculture and Agroforestry, Dr Y S Parmar University of Horticulture and Forestry, Nauni Solan in Himachal Pradesh. Decomposition rate was highest in *M. alba* followed by *G. optiva*, *T. ciliata* and *P. deltoides* for both the placement. Rate of decomposition was influenced significantly by combined effect of rainfall and temperature. Faster decomposition in *Grewia optiva* and *Morus alba* was attributed to high N concentration in leaf litter as compared to *T. ciliata* and *P. deltoides*..

Bargali *et al.* (2015) conducted a study in a tropical dry deciduous forest at Barnawapara wildlife sanctuary, Raipur, Chhattisgarh, India. Leaf litter decomposition and nutrient release were studied in four tree species viz., *Shorea robusta* C.F. Gaertn.f., *Madhuca indica* J.F. Gmel., *Diospyros melanoxylon* Roxb. and *Schleichera oleosa* (Lour.) Oken. The objectives of the study were to determine the weight loss and nutrient mineralization pattern of leaf litter of these four major species. The weight loss was fastest in *S. robusta* and slowest in *M. indica*. Monthly weight loss was positively related ($P < 0.05$) with the climatic factors (rainfall, temperature and relative humidity) except for *M. indica* for which the relationship was not significant. Weight remaining was inversely related ($P < 0.01$) to N and P concentrations, but was positively related to K concentration. The nutrient content in the residual litter decreased continuously with time for all species, except in the case of P for *S. robusta* and *D. melanoxylon*. We conclude that *S. robusta* decomposed at faster rate followed by *D. melanoxylon*, *S. oleosa* and *M. indica*. The former species also released the two important nutrients (N and P) at a faster rate as compared to the other species. *M. indica* showed the slowest decomposition rate and nutrient release.

Chauhan *et al.* (2015) conducted a study on six years poplar plantations that were assessed for productivity, carbon storage and economics in comparison to sole cropping. Wheat grain yield was significantly higher in control plots (4.55 t/ha) than boundary plantation (3.28 t/ha) and block plantation (2.03 t/ha). Similar trend was recorded for straw yield (6.61 t/ha in control plots, 4.83 t/ha in boundary plantation and 3.5 t/ha in block plantation). The boundary plantation produced higher DBH (24.23 cm) than the block plantation (19.71 cm). However, the total tree biomass was higher with block plantation (96.31 t/ha) than boundary plantation (30.14 t/ha) but per tree biomass was more in boundary

plantation than block plantation. The total carbon storage was higher in block planting method (55.43 t/ha) than in boundary plantation (32.70 t/ha) and lowest total carbon storage in sole cropping system (31.20 t/ha). Agro forestry systems likely had a greater capacity to sequester C in the long-term than the annual cropping systems because of their diverse configurations. Adoption of on farm poplar plantations will develop new opportunities for enhanced income in addition to employment and environmental amelioration.

Tangjang *et al.* (2015) investigated litter production, litter decomposition and nutrient dynamics from three traditional agroforestry systems in Harmutty (Assam) and Nirjuli and Doimukh (Arunachal Pradesh) in northeast India. Litter production was studied by using litter traps and decomposition of leaf litter by nylon net bag technique. Overall, leaf litterfall was greater during winter in Harmutty and Doimukh sites and during autumn in Nirjuli site. This is attributed to species characteristics. Decay rate was highest for *Colocasia esculenta* (8.61) and lowest in *Livistona jenkinsiana* (0.68). The initial N content was greater in *Ageratum conyzoides* and lower in *Musa* sp. During the early period of decomposition nutrients decreased whereas the concentration of nitrogen increased. The residue quality could contribute to the nutrient cycling processes that facilitates the production and productivity of agroforestry systems.

Nutrient potentials of leaf litters of three commonly cultivated multipurpose trees - *Dacryodes edulis* (G. Don, H. J. Lam), *Chrysophyllum albidum*, (G. Don) and *Irvingia gabonensis* (O' Rorke) Baill were investigated in Akwa Ibom State. Ebe *et al* (2016) the leaf litters were composted in open soil pits covered with netting materials in the Forestry Department Experimental Farm. The experimental design was the completely randomised design in three replicates. The litters were allowed to decompose and cure by aerobic process for a period of 9 months. The cured manure were analysed for soil nutrients using Association of Official Analytical Chemist (AOAC) methods. In all, *I. gabonensis* yielded the highest significant ($P= 0.05$) macro and micro nutrients to the soil, the highest organic carbon, but the least moisture content. This was followed by *D. edulis* which yielded a significant organic carbon with *C. albidum* yielding the least significant ($P= 0.05$) nutrients to the soil. It is concluded that these multi-purpose trees have great potentials for adding substantial amount of nutrients to the soil for planting in agroforestry farms and thus sustains crop production in the state.

Gaisie *et al.* (2016) Decomposition and pattern of nutrients in the residual leaf material is important in assessing suitability of MPTs species to provide nutrients for growing crop. The rate of decomposition of organic matter, mineralization and release of nitrogen, phosphorus, potassium, calcium, magnesium of fresh leaf litter of five multipurpose trees (MPTs) were measured using litter bags for 12 weeks at the CSIR-Crops Research Institute's field at Kwadaso-Kumasi. Nitrogen concentration in leaf biomass sample of the MPTs ranged from 3.08 to 4.76% in the order *Albizia lebbbeck* > *Leucaena leucocephala* > *Senna spectabilis* > *Gliricidia sepium* > *Senna siamea*. Potassium contents ranged from 0.43 to 0.68%. The decomposition process was slow in *S. siamea* and *A. lebbbeck* which lost 45.2% and 43.3% respectively. Decomposition was highest in the 6th week, *S. spectabilis* and *L. leucocephala* losing 50.9% and 59.2% respectively. By the end of the 12th week *S. spectabilis*, *L. leucocephala* and *G. sepium* lost 75.8%, 75.9% and 79.1% respectively, representing 189.6g, 189.8g and 197.8g of leaves respectively. N release is considerably faster in the first six to eight weeks. On the basis of the results obtained from this study *Leucaena leucocephala* and *Gliricidia sepium* showed promise as materials that could be applied for the release of nutrient to growing crop especially nitrogen, phosphorus, potassium and calcium.

Litter decomposition is mainly carried out by fungi and, to a minor extent, by bacteria (Baldrian *et al.*, 2016). These latter have been poorly investigated compared to fungi, probably due to their limited ability in decomposing wood and leaf polymers and to colonize plant tissues. In recent years, it has been shown that also bacteria are able to degrade lignin and catabolize side products deriving from its incomplete degradation by fungi (Bugg *et al.*, 2011).

Kooch *et al.* (2017) studied the effects of different tree species on litter quality and soil properties in a plain forest stand. He had studied the effect of *Carpinus betulus* (CB), *Acer velutinum* (AV), *Pterocarya fraxinifolia* (PF), *Quercus castaneifolia* (QC) species on litter and topsoil physical, chemical and biological features was considered in northern Iran. The highest total nitrogen (N) concentration (1.88%) and lowest organic carbon (C) (41.18%) was under *Carpinus betulus*. The bulk density and sand content were highest under CB (1.66 g cm⁻³ and 44.70%, respectively) with the least silt content (28%). Soil pH (7.10), EC (0.29 ds/m), total N (0.35%), available P (21.85 mg kg⁻¹), K (316.66 mg kg⁻¹), Ca (254.50 mg kg⁻¹), Mg (58.50 mg kg⁻¹), earthworm density/biomass (2.50 n m⁻² and 29.59 mg m⁻² ,

respectively) with more share of epigeic, total nematode (443.90 in 100 g soil) and microbial respiration ($0.47 \text{ mg CO}_2\text{-C gsoil}^{-1} \text{ day}^{-1}$) were significantly higher beneath CB trees.

Bani *et al.* (2018) studied the effects of changed litter inputs on soil labile carbon and nitrogen pools in a eucalyptus-dominated forest. Leaf litter and deadwood have important roles in the forest ecosystems, ie fungi produced the specific enzyme which help to increase nutrient uptake of the plant. The microbial community along with environment determines the quality of substrates. Nitrogen content is influenced by the uptake of exogenous N by decomposers to meet their metabolic requirements.

Angst *et al.* (2019) studied the effects of different tree species (alder, spruce, oak, and willow) exert on litter decomposition by comparing decomposition patterns and microbial measures of both tree and understory litter exposed at the respective tree species stands of a common garden experiment. The results indicate that microbial organism help to decompose litter on understory litter which help to change the chemical properties of the soil

Wang *et al.* (2019) reported influence of litter inputs on soil labile carbon and nitrogen pools in a eucalyptus-dominated forest of southeast Queensland, Australia. He resulted that the litter input rates had no significant effects on litter decomposition at both sites ($P > 0.05$). After 15-month of decomposition, mean litter mass loss was 46.3% and 31.2% at the HQ and LQ sites, respectively.

Chapter-3

MATERIALS AND METHODS

The present study entitled **“Studies on nutrient status and carbon sequestration potential of important MPTs in sub-tropical region of Himachal Pradesh”** was conducted at the Experimental farm of the Department of Silviculture and Agroforestry, Dr Y. S. Parmar University of Horticulture and Forestry, Nauni, Solan-173230, Himachal Pradesh during 2017-2018. A detail account of the site characteristics, experimental material used and methodology adopted during the course of investigations has been presented under the following subheads:

3.1 Experimental site

3.2 Experimental methodology

3.1 EXPERIMENTAL SITE

3.1.1 Location and physiography

The site is located at an elevation of 1000-1300 m above mean sea level in the mid-Himalayan zone. It lies between 30°50'30'' to 30°52'0'' N latitude and 77°11'30'' E latitude (Survey of Indian Topo sheet Number 53F/1). The areas falls in the mid-hill zones of Himachal Pradesh. The soil is well drained and of silty loamy type. The terrain is undulating, hilly and marked with elevation and depressions and has a gentle slope towards the south-eastern aspect.

Climatically, the site lies in the sub- tropical belt but is slightly skewed towards the temperate climate. The area experiences a wide range of temperature with a minimum of 1°C in winter to a maximum of 37°C during hot summer and mean annual temperature being 19.8°C with May and June as the hottest months whereas December and January are the coldest months. Winters are accompanied by a fair amount of frost which kills large amount of regeneration in the area but snowfall is witnessed rarely. The area receives an annual rainfall of 1150mm with maximum downpour during the monsoon season (July and August).

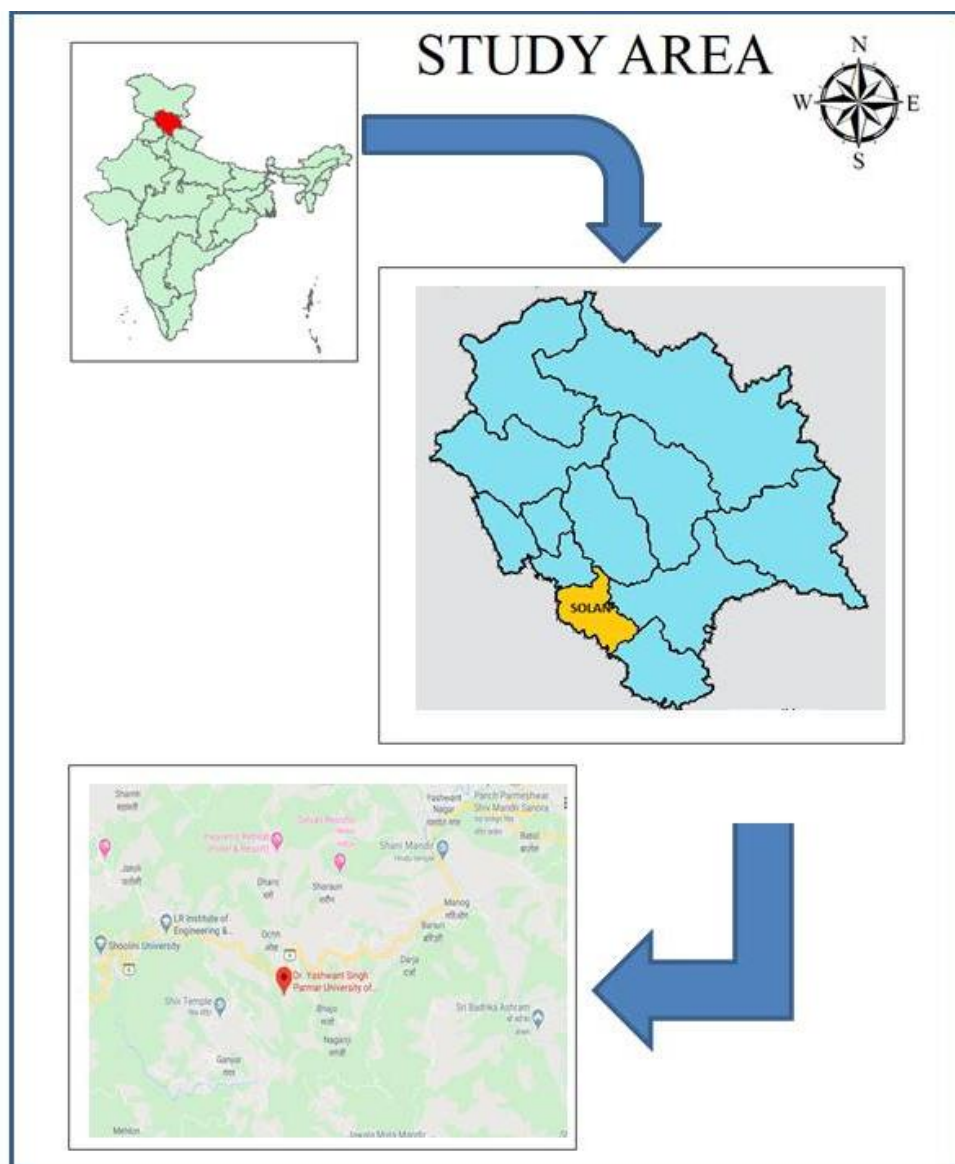


Fig. 1 Map showing studying area

3.1.2 Description of the sites

The natural and plantation stand of *Albizia chinensis*, *Albizia lebbeck*, *Acacia mollissima*, *Dalbergia sissoo*, *Ulmus villosa*, *Toona ciliata* and *Melia composita* were selected for the study. Among these multipurpose tree species, *Albizia lebbeck*, *Acacia mollissima*, *Ulmus villosa* and *Melia composita* are man-made plantation whereas *Albizia chinensis*, *Dalbergia sissoo* and *Toona ciliata* are growing naturally. For the selection of MPTs a plot size of 33m×33m was prepared. The study sites were selected from different locations in main campus of this university. The description of the different selected sites is given in (Table 3.1).

Table 3.1 Locality factors of the study area

Latitude	30°50'30'' to 30 52''0 N
Longitude	77°8'30'' to 77°11'30''E
Altitude	1000-1300 m a.s.l
Climate Type	Sub-tropical Temperate
Mean annual temperature	19.8°C
(Survey of India Toposheet No, 53/1) according to survey of India	

3.2 EXPERIMENTAL METHODOLOGY

The study was carried out by three different experiments. The methodologies applied are as under:

Experiment 1: To study soil properties and nutrients status under different multipurpose trees

A) MPTs (Multipurpose tree species)

T₁	=	<i>Albizia chinensis</i>
T₂	=	<i>Albizia lebbeck</i>
T₃	=	<i>Acacia mollissima</i>
T₄	=	<i>Dalbergia sissoo</i>
T₅	=	<i>Ulmus villosa</i>
T₆	=	<i>Toona ciliata</i>
T₇	=	<i>Melia composita</i>

B) Soil depth: D₁ (0-15 cm), D₂ (15-30 cm)

Number of treatments	=	14 (7×2)
Number of replications	=	3
Experimental design	=	RBD
Sample plot size	=	33 m×33m (0.1 ha)

Observations recorded on various soil parameters:

The following observations were recorded during the present study; Soil pH, Electrical conductivity, Soil bulk density, Soil organic carbon, Available Nitrogen, Available Phosphorous and Available Potassium.

Experiment 2: To study the carbon sequestration potential of different MPTs

A) MPTs (Multipurpose tree species)

T₁ = *Albizia chinensis*

T₂ = *Albizia lebbeck*

T₃ = *Acacia mollissima*

T₄ = *Dalbergia sissoo*

T₅ = *Ulmus villosa*

T₆ = *Toona ciliata*

T₇ = *Melia composita*

Number of treatments = 7

Number of replications = 3

Experimental design = RBD

Sample plot size = 33 m×33m (0.1 ha)

Observations recorded on various tree parameters:

During the present study, the following observations were recorded to quantify the above ground biomass (Stem biomass, Branch biomass, Leaf biomass), below ground biomass and Carbon inventory.

Experiment 3: To study leaf litter accumulation and decomposition rate of different multipurpose trees

Litter collection:

Litter collection was done at an interval of 30 days and the same has been put into decomposition study for the period of 6 months.

Moisture content in the soil:

Moisture content in the soil was recorded at an interval of 30 days and it was continued upto 6 months.

- Initial moisture content
- Moisture content after 120 days
- Moisture content after 150 days
- Moisture content after 180 days

Soil Analysis

Collection and preparation of samples

Soil samples were collected in the month of November from the plot. From each plot, nine samples were collected. The samples were mixed thoroughly to make composite sample. Soil samples from plot area were obtained by digging profiles upto 0-15 cm, 15-30 cm. Samples were air dried in shade, grinded with pestle, passed through 2 mm sieve and stored in cloth bags for further laboratory analysis.

Method employed for soil chemical analysis

The details of method employed for estimating different soil parameters are as follows:

Soil pH

Soil pH was recorded by digital pH meter, by making 1: 2: 5 soil water suspensions (Jackson, 1957).

Electrical conductivity (dS/m)

Electrical conductivity was recorded with the help of conductivity meter.

Soil organic carbon (%)

Organic carbon was determined by rapid titration method as given by Walkley and Black (1934).

Available Nitrogen (kg/ha)

Available nitrogen was estimated with the help of the method given by Alkaline potassium permanganate method of Subbiah and Asija (1956).

Available Potassium (kg/ha)

Available Potassium was determined with the help of Flame photometer method of Merwin and Peach (1951).

Available Phosphorous (kg/ha)

Available Phosphorous was determined with the help of Olsen method (1954).

Soil carbon pool inventory (Mg ha⁻¹)

Soil carbon pool inventory was calculated by Soil bulk density (g cm⁻³) × Soil depth (cm) × organic carbon (g kg⁻¹), which was expressed as Mg ha⁻¹.

Biomass production and carbon sequestration

Above ground biomass was calculated by non-destructive method for different plant parts.

Stem biomass

To estimate biomass all the tree falling in the plot of 0.1 hac were enumerated. The diameter at breast height (dbh) was measured with caliper and height with Ravi's multimeter, form height was calculated using Spiegel relaskope to find out the tree volume using the formula given by Pressler's (1865) and Bitlerlich (1984).

$$f = 2h_1/3h$$

Where,

$$F = \text{form factor}$$

$$h_1 = \text{height at which diameter is half of dbh}$$

$$h = \text{total height}$$

Volume was calculated by Pressler's formula (1865)

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

Where,

$$V = \text{volume}$$

$$f = \text{form factor}$$

$$h = \text{total height}$$

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

Where, r = radius, dbh - diameter at breast height

Specific gravity

Specific gravity was determined from the available literature. Where, the specific gravity values were not available in that case the stem cores were taken to find out specific gravity which was used further to determine the biomass of volume

Mn = Weight of saturated volume sample

Mo = Weight of oven- dried sample

Gso = Average density of wood substances equal to 1.53

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

Mass = Average specific gravity of stem wood x volume

3.4.2 Branch Biomass of forest trees

Total numbers of branches irrespective of size were counted on each of the sample tree, then these were categorized on the basis of basal diameter into three groups, viz., < 6cm, 6-10cm, and >10 cm. Fresh weight of two sampled branches from each group was recorded separately. The formula (Chidumayo, 1990) was used to determine the dry weight of branches.

$$Bdwi = Btwi/1 + Mcbdi$$

Where,

Bdwi = oven dry weight of branch

Btwi = Fresh/green weight of branches

Mcbdi = Moisture content of branch on dry weight basis

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

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

Where,

Bbt - Branch biomass (fresh/dry) per tree

Ni - Number of branches in the ith branch group

Bwi - average weight of branch of ith group

I - 1, 2, 3,----- refers to branch group

3.4.3 Leaf biomass

Leaves from the branches were removed, weighed and oven dried separately to a constant weight at $80 \pm 5^{\circ}\text{C}$.

3.3.4 Tree biomass

The total tree biomass was the sum of stem biomass, branch biomass and leaf biomass. The tree biomass was converted into carbon fraction by a factor of 0.5 (IPCC default value).

3.3.5 Surface litter

Surface litter was collected in five quadrates of 1 x 1 m². Samples were weighed, sub-sampled and oven dried at 65 + 5°C to a constant weight ground and ashes. Corrected ash dry was assumed to contain 45 per cent of carbon.

3.3.6 Below ground biomass

Below ground biomass of trees (Broad leaved) was calculated by multiplying aboveground biomass of tree with the factor 0.26 (IPCC, 2003).

3.4 LEAF LITTER ACCUMULATION AND DECOMPOSITION RATE

3.4.1 Leaf litter accumulation

To determine the natural litter fall of MPTs, litter traps (1m² iron frame with fine mesh iron gauge) were placed 25cm above the ground level under each tree in East, West, North and South directions. The litter collection was made in October – November months. Litter samples were oven dried at 65+2°C and weighed to know the quantity of litter produced. The average of four collecting traps per tree was computed to find out the litter produced m⁻² tree⁻¹, which was multiplied with ground area covered by the crown to estimate litter production tree⁻¹ and was expressed in kg ha⁻¹ after multiplying with number of trees ha⁻¹.

Ground area covered by the tree crown was determined by the formula:

$$A = \pi r^2$$

Where,

A = Ground area covered by the tree crown in meter square.

r = Crown radius

r = r₁ + r₂ + r₃ + r₄ are the crown radii along East, West, North, South directions, respectively.

3.4.2 Litter decomposition

Leaf litter decomposition was studied following Heuvelink et al., (1988) procedure. Fresh leaves of tree species were collected and samples are air dried until the weight of dry matter became constant. 10g of air dried leaves of each of the tree species were placed in

nylon bag of 30 × 30cm size and of 1 mm mesh containing 10gm of leaves were exposed on the soil in the experimental field. Three litter bags of each species were recovered at one month interval. In the laboratory, the residual litter was separated from the bags and carefully cleaned to remove the attached soil particles. This material was then oven dried at 65±2°C to constant Weight to calculate the decomposition loss as follows;

$$\begin{aligned} \text{Dry weight of remaining} &= \frac{\text{Dry wt. at subsequent intervals} \times 100 \text{ samples (\%)}}{\text{Dry weight at 1st day}} \\ \text{Decomposition} &= \frac{\text{Per cent dry weight of - Per cent dry weight loss(\%)}}{\text{samples at 1st day remaining samples at subsequent interval}} \end{aligned}$$

3.5 STATISTICAL ANALYSIS

The data obtained were subjected to statistically analysis using RBD of experimentation as per the procedure suggested by Gomez and Gomez (1984). Wherever, the effects exhibited significance at 5% level of popularity, Critical difference (CD) was calculated.

Chapter-4

RESULTS AND DISCUSSION

The present investigation entitled “**Studies on nutrient status and carbon sequestration potential of important multipurpose trees in sub-tropical region of Himachal Pradesh**” was conducted in the Experimental farm of the Department of Silviculture and Agroforestry, Dr Y. S. Parmar University of Horticulture and Forestry, Nauni, Solan-173230, Himachal Pradesh during 2017-2018. The experimental results thus obtained through different experiments during the present study are described under the following heads:

- 4.1 Effect of multipurpose tree species on soil physico-chemical properties and nutrients**
- 4.2 Carbon sequestration potential of different MPTs**
- 4.3 Leaf litter accumulation and Decomposition rate of different MPTs**

4.1 SOIL PHYSICO-CHEMICAL PROPERTIES UNDER MPTS – AGROFORESTRY SPECIES

4.1.1 Effect of MPTs on Soil pH

The data pertaining to effect of MPTs on soil pH has been recorded and presented in Table 1. The contents of the data presented in Table 1 revealed that all the MPTs had a significant effect on Soil pH (Table 1). Higher pH value (7.68) was recorded under T₄ (*Dalbergia sissoo*) followed by T₇ (*Melia composita*) (7.91) and lower pH value was recorded in T₅ (*Ulmus villosa*) (6.55). Among the two soil depths D₂ (15 – 30 cm) registered higher pH value (7.42) and D₁ (7.10) respectively. The cumulative effect of treatment and soil depth (T × D) had register significant effect on soil pH. It was statistically significant maximum under T₇D₂ (7.91), whereas minimum found in T₅D₁ (6.55).

A critical appraisal of the data (Table 1) indicates that soil pH under different treatments varied between 6.70 –7.68. The soil pH increases with depth which may be attribute to lower content of organic matter and weathering soil conditions at lower depths. It may also because upper horizon receive maximum leaching and rainfall and by dissolved carbonic acid and organic acid which remove metal cations and replace with the hydrogen

ions where as lower horizon are not so strongly leached. Similar results were also reported by Raina (1988); Sharma (1991); Raina and Kumar (2000). In general soil reaction was neutral which is ideal for the availability of most of the available nutrients from the soil, as well as from those applied through fertilizers.

Table 1. Influence of different multipurpose trees on soil pH

Treatments(T)	Depth(cm)		Mean
	D ₁ (0-15)	D ₂ (15-30)	
T ₁ (<i>Albizia chinensis</i>)	7.17	7.79	7.48
T ₂ (<i>Albizia lebbeck</i>)	7.11	7.21	7.16
T ₃ (<i>Acacia mollissima</i>)	6.86	6.92	6.89
T ₄ (<i>Dalbergia sissoo</i>)	7.55	7.81	7.68
T ₅ (<i>Ulmus villosa</i>)	6.55	6.84	6.70
T ₆ (<i>Toona ciliata</i>)	7.20	7.43	7.32
T ₇ (<i>Melia composita</i>)	7.24	7.91	7.58
Mean	7.10	7.42	

T(Treatments) 0.05
D(Depths) 0.03
T×D 0.07

4.1.2 Electrical conductivity (dS/m)

The data pertaining to influence of MPTs on soil electrical conductivity (EC) has been recorded and presented in Table 2. The contents of the data presented in Table 2 showed that treatment, soil depth and interaction between soil depth and treatments, significantly influenced the EC (Table 2). Higher EC value was found under (*Albizia lebbeck*) T₂ (0.34 dS/m) where as minimum under (*Toona ciliata*) T₆ (0.22 dS/m) which was statistically at par with (*Melia composita*) T₇ (0.22 dS/m). The value of EC was found significant among two soil depths.

The cumulative effect of treatment and depth was found statistically significant. The maximum electrical conductivity was (0.37 dS/m) found in T₅D₁, whereas minimum (0.19 dS/m) under T₆D₂.

EC in soil under different treatments varies from 0.22 – 0.34 dS/m, suggesting the low amount of soluble salts. Therefore the soil under study were in safe limits of EC i.e. < 0.8 dS/m. and evidence significant variation under species (Table 2). The results indicate that EC under tree canopies increased considerably as compared to the area devoid of vegetation.

Raina and kumar (2000) and Verma (2003) have also reported average EC value in the range of 0.370 - 3.80 dS/m in the soils of forest of Rajgarh and Solan Division.

Table 2. Influence of different multipurpose trees on Electrical conductivity (dS/m)

Treatments(T)	Depth(cm)		Mean
	D ₁ (0-15)	D ₂ (15-30)	
T ₁ (<i>Albizia chinensis</i>)	0.31	0.29	0.30
T ₂ (<i>Albizia lebbbeck</i>)	0.36	0.32	0.34
T ₃ (<i>Acacia mollissima</i>)	0.26	0.22	0.24
T ₄ (<i>Dalbergia sissoo</i>)	0.31	0.27	0.29
T ₅ (<i>Ulmus villosa</i>)	0.37	0.24	0.30
T ₆ (<i>Toona ciliata</i>)	0.24	0.19	0.22
T ₇ (<i>Melia composita</i>)	0.25	0.19	0.22
Mean	0.30	0.24	

T (Treatments) 0.01
D (Depths) 0.00
T×D 0.01

4.1.3 Organic carbon (%)

The content of (Table 3) shows that treatment, soil depth and interaction between them significantly influenced the Organic-C content. Maximum organic carbon significantly higher under T₅ (*Ulmus villosa*) (2.54%) which was statistically at par with T₇ (*Melia composita*) and T₃ (*Acacia mollissima*). Organic carbon under T₁ (*Albiza chinensis*) (2.11%) was found to have minimum.

Among two soil depths, the organic C was found significantly higher in soil depth D₁ (2.43%) as compared to soil depth D₂ (2.31%). The interaction (T×D) effect of treatments and depth was found significant. It was recorded higher in T₇D₁ (2.63%), whereas it was recorded minimum in T₁D₂ (2.06%).

The results of the present investigation (Table 3) showed variation under treatments value ranging from 2.54-2.11%. It was improved markedly under *Ulmus villosa*, followed by *Acacia mollissima*, *Melia composita*, *Albizia lebbbeck*, *Toona ciliata*, *Dalbergia sissoo* and *Albizia chinensis*. Organic carbon was found high under all tree species. This is because, the area covered by broad deciduous tree species all around, thus heavy litter fall and its subsequent decomposition may have contributed to high organic carbon. The results reveals that the (Table 3) organic carbon decrease with increase in depth which may be due to the addition of more litter fall on the surface soils.

As regard the efficiency of individual species in improving the Organic carbon it can be related to the amount of litter production and rate of decomposition. The higher accumulation under *Ulmus villosa* may be attributed to more production of litter and lower rate of organic matter decomposition. Conversely the lowest Organic -C accumulation under *Albizia chinensis* may be ascribed to low litter production and faster rate of decomposition.

The increase in organic-C under tree is well in consonance with the findings of other researchers (Hazra and Tripathi, 1986; Hussain *et al.*, 1987; Sharma and Gupta, 1989).

Table 3. Influence of different multipurpose trees on organic carbon (%)

Treatments(T)	Depth(cm)		Mean
	D ₁ (0-15)	D ₂ (15-30)	
T ₁ (<i>Albizia chinensis</i>)	2.15	2.06	2.11
T ₂ (<i>Albizia lebbek</i>)	2.61	2.46	2.53
T ₃ (<i>Acacia mollissima</i>)	2.58	2.50	2.54
T ₄ (<i>Dalbergia sissoo</i>)	2.20	2.08	2.14
T ₅ (<i>Ulmus villosa</i>)	2.57	2.51	2.54
T ₆ (<i>Toona ciliata</i>)	2.28	2.10	2.19
T ₇ (<i>Melia composita</i>)	2.63	2.45	2.54
Mean	2.43	2.31	

T (Treatments) 0.01
D (Depths) 0.01
T×D 0.02

4.1.4 Available nitrogen (kg/ha)

A perusal of data presented in (Table 4) shows that the tree species, soil depth and their interaction exercised significant influence on available nitrogen. The data presented in (Table 4) shows that available N under treatment varied markedly among the different species ranging 238.43 – 375.47 kg/ha. It was followed the trend T₂(375.47 kg/ha), T₃(362.58 kg/ha), T₁(359.88 kg/ha), T₄(358.53 kg/ha), T₅(334.13 kg/ha), T₇(242.33 kg/ha) and T₆ (238.43 kg/ha), respectively in descending order. Available nitrogen, as expected was found significantly more in the soil under N fixing tree species . The average effect of depth on available N found significant under the tree. Among two soil depths, depth D₁ (0-15) was recorded higher with available nitrogen (331.47 kg/ha) and it was recorded minimum in D₂ (317.50 kg/ha).

Interaction between treatment and soil depth registered significant effect on available nitrogen. Higher available nitrogen was recorded under treatment combination T₂D₁ (384.97

kg/ha) whereas it was recorded minimum (232.30 kg/ha) under treatment combination T₆D₂ which was statistically at par with T₇D₂.

Table 4 showed the significant variation under tree species from 238.43 kg/ha to 375.47 kg/ha under *Albizia lebbeck*. As expected the nitrogen fixing trees did prove relatively more efficient in increasing available N content compared to non- fixing trees. Similar results indicating an improvement in macronutrient status including N under tree covers have been also been reported by Laskar and Datta (1992). The similar findings have been reported by Sharma (1989) and Bhola and Mishra (1998).

The available N content in the soil showed a general diminishing trend as the depth of the soil increased. Patel and Singh (2000) made similar observations with *Albizia lebbeck* and *Cordia dichotoma*.

Table 4. Influence of different multipurpose trees on available nitrogen (kg/ha)

Treatments(T)	Depth(cm)		Mean
	D ₁ (0-15)	D ₂ (15-30)	
T ₁ (<i>Albizia chinensis</i>)	367.33	352.43	359.88
T ₂ (<i>Albizia lebbeck</i>)	384.97	365.97	375.47
T ₃ (<i>Acacia mollissima</i>)	368.70	356.47	362.58
T ₄ (<i>Dalbergia sissoo</i>)	361.33	355.73	358.53
T ₅ (<i>Ulmus villosa</i>)	244.57	232.30	238.43
T ₆ (<i>Toona ciliata</i>)	341.00	327.27	334.13
T ₇ (<i>Melia composita</i>)	252.37	232.30	242.33
Mean	331.47	317.50	

T (Treatments) 1.68
D (Depths) 0.90
T×D 2.38

4.1.5 Available phosphorus (kg/ha)

The contents of the data presented in the (Table 5) reveals that both treatments and soil depth have a significant effect on available phosphorus (kg/ha). Higher value of phosphorus (47.03 kg/ha) was recorded under T₂ (*Albizia lebbeck*) and minimum available phosphorus was recorded in T₅ with a value of (25.05 kg/ha). Among two soil depth, soil depth D₁ (0-15 cm) (37.10 kg/ha) registered higher value for phosphorus content as compared to soil depth D₂ (15-30cm) (29.12 kg/ha).

Interaction between treatment and depth also registered significant effect on available phosphorus. Higher phosphorus content was recorded in treatment combination T₂D₁ (59.37 kg/ha) and minimum was recorded in T₅D₂ (23.70 kg/ha).

It is evident from the data presented in (Table 5) that soil available P differed significantly under MPTs and demonstrated a discernible improvement under tree canopies. The available P improved remarkably under tree canopies in comparison to area devoid of vegetation which reinforces the earlier findings Aggarwal *et al.*(1993) reported that there was an increase of 43 % in available P under the *Prosopis cineraria* over the soils in adjacent open fields. Similar improvements in available P under tree canopies have also been observed by others like Palled *et al.* (1987); Sharma and Gupta (1989) and Bhola (1995).

As in the case of nitrogen, the top soil also showed higher Phosphorus content under all tree species. It is suggestive of the fact that mineralization of organic matter on the soil surface contributed to Phosphorus richness in the top soil.

Kimaro *et al.* (2008) reported that agroforestry tree species producing high quality litter may enhance past-fallow soil nutrient availability and crop yields through mineralization of soil organic matter and green manure due to the high soil N and P levels resulting from net release by high quality foliage. However, it is observed that the tree species vary with respect to their ability to supplement soil phosphorus. It is possible that the Phosphorus efficiency vary with plants, as it depends on various factors like soil characteristics.

Table 5. Influence of different multipurpose trees on available phosphorous (kg/ha)

Treatments(T)	Depth(cm)		Mean
	D ₁ (0-15)	D ₂ (15-30)	
T ₁ (<i>Albizia chinensis</i>)	37.73	34.40	36.06
T ₂ (<i>Albizia lebbbeck</i>)	59.38	34.73	47.06
T ₃ (<i>Acacia mollissima</i>)	39.00	31.58	35.29
T ₄ (<i>Dalbergia sissoo</i>)	35.17	29.14	32.16
T ₅ (<i>Ulmus villosa</i>)	26.36	23.69	25.03
T ₆ (<i>Toona ciliata</i>)	30.86	26.56	28.71
T ₇ (<i>Melia composita</i>)	31.23	23.74	27.49
Mean	37.10	29.12	

T (Treatments) 1.20
D (Depths) 0.64
T×D 1.70

4.1.6 Available potassium (kg/ha)

The data presented in (Table 6) reflects that all the treatments, soil depths and interactions had a significant effect on available potassium (kg/ha). Higher available potassium (351.97 kg/ha) was recorded in T₂ treatment, whereas it was recorded minimum in T₅ treatment. On the other hand depth (D₁) registered higher value for available potassium as compared to depth (D₂).

Interaction between treatment and soil depth also exhibit significant effect on available potassium (kg/ha). Higher potassium content was recorded in treatment combination T₂D₁ (360.57 kg/ha) and minimum was recorded in T₅D₂ (218.74 kg/ha).

The soil available K showed significant variation under different tree species as well as different depth of soil (Table 6). Dhyani *et al.* (1990) concluded that soil under *Bauhinia purpurea*, *Grewia optiva*, *Eucalyptus tereticornis*, *Leucaena leucocephala* contained more available K₂O in comparison to area which was without trees. Laskar and Datta (1992) observed an improvement of available nutrient status of soil under 3 years of tree cover of *Dalbergia sissoo*, *Leucaena leucocephala*, *Acacia auriculiformis* and *Albizia lebbeck*.

As regards the effect of individual tree species on soil chemical characteristics it may be attributed to differences in litter production and its rate of decomposition differential nutrient release capacity and recycling potential of the species. Parsad *et al.* (1985) also reported that the changes in soil chemical properties under different vegetation may be attributed to differential biocycling of nutrients by different species.

Table 6. Influence of different multipurpose trees on available potassium (kg/ha)

Treatments(T)	Depth(cm)		Mean
	D ₁ (0-15)	D ₂ (15-30)	
T ₁ (<i>Albizia chinensis</i>)	347.60	335.45	341.53
T ₂ (<i>Albizia lebbeck</i>)	360.57	343.36	351.97
T ₃ (<i>Acacia mollissima</i>)	354.65	338.48	346.56
T ₄ (<i>Dalbergia sissoo</i>)	328.50	316.57	322.53
T ₅ (<i>Ulmus villosa</i>)	226.51	218.74	222.63
T ₆ (<i>Toona ciliata</i>)	319.24	306.34	312.79
T ₇ (<i>Melia composita</i>)	285.56	248.64	267.10
Mean	317.52	301.08	

T (Treatments) 1.58
D (Depths) 0.84
T×D 2.23

4.1.7 Bulk density (g cm^{-3})

A critical examination of the data presented in (Table 7) inferred significant variations in bulk density (BD) values for different agroforestry tree species, soil depth and interaction between them. Mean value of bulk density under treatments was found significantly higher in T_2 (1.13 g cm^{-3}) which was significantly at par with T_4 and minimum was found in T_5 (1.09 g cm^{-3}). On the other hand among two soil depths, soil depth D_2 registered higher bulk density as compared to soil depth D_1 . Cumulative effect of both tree species and soil depth also influence bulk density significantly. It was recorded higher in treatment combination T_2D_2 with a value of (1.18 g cm^{-3}) whereas minimum bulk density was recorded in treatment combination T_5D_1 with a value of (1.02 g cm^{-3}).

The critical examination of the data presented in Table 7 inferred significant variations in the bulk density (BD) values for different agroforestry tree species. The bulk density values however, increased with soil depth. The increase in clay content and soil compaction with the increasing soil depth was accompanied by a decrease in organic carbon content and this may be responsible for the increasing bulk density values in the surface soils. The maximum value significantly higher in area devoid of vegetation in comparison to different MPTs. The results indicated that woody perennials in the forest decreased the bulk density of soils.

Table 7. Influence of different multipurpose trees on bulk density (g cm^{-3})

Treatments(T)	Depth(cm)		Mean
	D_1 (0-15)	D_2 (15-30)	
T_1 (<i>Albizia chinensis</i>)	1.06	1.13	1.10
T_2 (<i>Albizia lebbek</i>)	1.08	1.18	1.13
T_3 (<i>Acacia mollissima</i>)	1.07	1.13	1.10
T_4 (<i>Dalbergia sissoo</i>)	1.08	1.17	1.13
T_5 (<i>Ulmus villosa</i>)	1.02	1.16	1.09
T_6 (<i>Toona ciliata</i>)	1.05	1.17	1.11
T_7 (<i>Melia composita</i>)	1.05	1.14	1.10
Mean			

T (Treatments) **0.02**
D (Depths) **0.01**
T×D **0.03**

Variations in the BD of soil at different depths of soil profile shown significant differences in their values (Table 7). The data indicated that the bulk density of surface soils (0-15 cm) was the lowest (1.05 g cm^{-3}), which increased gradually with an increase in soil

depth and attained its maximum value of 1.18 g cm^{-3} at 15 - 30 cm. The results are supported by Sharma and Qahar (1989). Who reported that the lower values of bulk density are indicative of top soil rich in Organic matter. Similar results on forest soils have, also been reported by Kaushal (1992) and Malik (1992).

4. 1.8 Soil Carbon pool inventory (Mg ha^{-1})

Data presented in (Table 8) reveals that tree species, soil depths and their interaction had registered significant effect on soil carbon inventory (mg ha^{-1}). Among various treatments, treatment (T_2) registered higher (43.12 mg ha^{-1}) value for soil carbon pool inventory whereas it was recorded minimum in treatment T_1 (35.35 mg ha^{-1}). The interaction between treatments and soil depths also influence soil carbon pool inventory. Among different treatment combination, treatment combination T_2D_2 recorded higher value for carbon pool inventory.

The increase or decrease in the soil organic carbon pool was associated with bulk density and soil organic carbon content at a particular depth. The higher amount of soil organic carbon may be attributed to the reduced rate of decomposition of organic material. The soil organic carbon pool decreases with the increase in the soil depth. The greater accumulation of organic carbon in the surface is due to the incorporation of leaf litter and addition of decayed roots to the upper layer. The results are in the line with the findings of Joao Carlos *et al.* (2001), Nair and Chamuah (1988) and Minhas *et al.* (1997).

Table 8. Influence of different multipurpose trees on soil carbon pool inventory (Mg ha^{-1})

Treatments(T)	Depth(cm)		Mean
	D ₁ (0-15)	D ₂ (15-30)	
T ₁ (<i>Albizia chinensis</i>)	34.99	35.70	35.35
T ₂ (<i>Albizia lebbeck</i>)	42.12	44.12	43.12
T ₃ (<i>Acacia mollissima</i>)	41.86	42.50	42.18
T ₄ (<i>Dalbergia sissoo</i>)	35.64	36.86	36.25
T ₅ (<i>Ulmus villosa</i>)	39.78	43.50	41.64
T ₆ (<i>Toona ciliata</i>)	36.34	36.75	36.55
T ₇ (<i>Melia composita</i>)	41.35	42.30	41.83
Mean	38.87	40.25	

T (Treatments) 1.03
D (Depths) 0.55
T×D 1.46

4.2 BIOMASS PRODUCTION LEVELS OF DIFFERENT MPTs

Seven different MPTs have shown significant variations in their total biomass production levels. The biomass produced has been apportioned among different above and below ground parts for each tree species.

4.2.1 Aboveground biomass (kg/tree)

The data presented in Table 9 shows the aboveground and belowground biomass production levels of different tree species in term of stem, branch, leaf and whole tree as well as litter production. Stem biomass was found highest in *Albizia lebbeck* (630.51 kg/tree), which was statistically at par with *Albizia chinensis*. Branch biomass was found higher in *Toona ciliata* (6.30 kg/tree). Similar to branch biomass, leaf biomass was also significantly recorded higher in *Toona ciliata* (3.7 kg/tree).

Whole tree biomass was found higher in *Toona ciliata* (643.59Kg/tree), which was statistically at par with *Albizia chinensis* and *Albizia lebbeck*.

The total aboveground biomass followed the trend almost similar to the whole tree biomass among the different tree species. It was found higher in *Toona ciliata* (813.17 kg/tree) which was statistically at par with *Albizia lebbeck*.

The contribution of biomass is dependent upon different tree components such as stem, root, leaves and branches. In the present study, amongst the different species the stem wood of *A. lebbeck* had the maximum (630.51 kg) biomass followed by branches (6.30) and (3.70 kg) leaves biomass. Similarly, different species studied by Chauhan *et al.* (2009) maximum biomass accumulation was found in the stem. The results of present study are also in line with Swamy *et al.* (2003) they demonstrated that the stem wood contributed the maximum biomass followed by branch and foliage in all the species under study. In the present investigation, stem, branches and leaves contributed 630.51 kg, 5.36 kg, and 2.94, respectively to the total standing biomass (638.82) of *A. lebbeck*. Present investigation revealed that in *A. lebbeck* above ground biomass allocation was in the order of stem> branches> leaves. The variability in biomass in different agroforestry trees is indicative of the fact that the growth of trees is dependent upon many factors like locality, management practices followed, age of trees and its inherent ability (i.e. fast or slow growing tree species). Since, these species were in natural mixture the differences may be associated with increased

competition related to motility. Many studies based on long term experiments showed that mixed species can produce 10-30 per cent more biomass than monoculture containing N₂ fixing trees species can over-yield by 50 per cent (Liang *et al.* 2016). Roshanzada *et al.* (2018) and Kumar *et al.* (2012) made similar observations with *Toona cilata* and other multipurpose tree species.

Table 9. Influence of different multipurpose trees on total biomass ((kg/tree)

Species Components	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	T ₇	CD _(0.05)
Above ground								
Stem	624.25	630.51	318.92	562.80	202.11	533.59	283.88	77.40
Branch	4.47	5.36	2.39	3.43	2.13	6.30	3.15	1.37
Leaf	2.68	2.94	1.20	2.15	1.89	3.70	2.98	0.56
Whole tree	631.31	638.82	322.52	568.38	206.13	643.59	290.02	78.33
Litter	4.48	3.56	1.35	2.07	0.72	2.24	3.68	0.58
Total	634.79	642.38	323.87	570.45	203.85	645.83	293.70	78.32
Below ground	164.14	166.09	83.86	147.78	53.60	167.33	75.40	20.36
Grand total	793.93	808.49	407.73	718.24	260.45	813.17	369.11	98.69

4.2.2 Belowground biomass (kg/tree)

The below ground biomass observed highest in *Toona ciliata* (167.33 kg/tree), which was statistically at par with *Albizia chinensis* and *Albizia lebbeck*.

Total above and below ground biomass was highest in *Toona ciliata* having values of (813.17 kg/tree), statistically at par with *Albizia lebbeck* (808.49 kg/tree). On the other hand *Ulmus villosa* (T₅) recorded lowest total biomass with a value of (260.45 kg/ha).

In present study substantial differences existed among treatments. Table 9, showed that the below ground biomass per tree was maximum (167.33 kg) in *T. ciliata* followed by *A. lebbeck* (166.09 kg) and *A. chinensis* (164.14 kg). The whole tree biomass (above and below) was maximum (808.49 kg) in *A. lebbeck* followed by *A. chinensis* (793.93 kg) and *D. sissoo* (718.24 kg). The results of present study are in accordance with Swamy and Puri (2005) who studied biomass production of *Gmelina arborea* in plantation and agroforestry system. They pointed out that the Stem, leaves, branches and below ground biomass contributed 65.2%, 4.1%, 10%, and 20.7%, respectively to total standing biomass (17.9 Mg/ha). In present study the stem contributed maximum biomass followed by root, branches and leaves biomass of all the species under consideration. Similar results are also observed by Gawali *et al.* (2014) who reported that in total biomass production, stem component

contributed the highest (45.3-47.7%) followed by below ground root biomass (22.8-22.9%), branch (16.75-17.84%), pod (6.36-9.11%) and leaves (5.82-5.92%) components of *C. pentandra*. From present investigation it was found that biomass allocation in different tree species under study was in the order of stem > roots > branches > leaves (Table 9). The results are in the line with the findings of Roshanzada *et al.* (2018) and Kumar *et al.* (2012).

4.3 CARBON SEQUESTRATION POTENTIAL OF DIFFERENT MPTs

Carbon in plant biomass from different MPTs has been termed as current carbon stock. The table reveals the variability in carbon stocks, among the different MPTs. Carbon stock for total biomass was higher in *Toona ciliata* (406.59 Kg/tree), which was statistically at par with *Albizia lebbeck* and *Albizia chinensis*.

Carbon sequestration potential kg annum^{-1} was significantly higher in T_1 (30.93 Kg annum^{-1}) whereas it was recorded minimum in T_5 (9.38 Kg annum^{-1}).

The study concluded by Prasad *et al.* (2010) concluded that there is significant variation in different tree species and in the allocation of carbon content in different plant parts of different tree species. It can also be concluded that the significant variation in carbon content in selected species may be due to their genetic makeup, crown architecture and chemical and anatomical uniqueness of wood Lamtom and Savidge (2003) and Ford (1985). The variation in carbon allocation among tree components might be due to complex phenomena working between carbon source organs (leaves) and carbon sink viz; stem, branches, roots, etc of a tree Genard *et al.* (2008). The variations in carbon stock depend on several factors such as type of agroforestry system, site quality and previous land use systems. Similar results on carbon stock have also been reported by Kumar *et al.* (2012) and Roshanzada *et al.* (2018).

Table 10. Total biomass carbon and carbon sequestration potential of different agroforestry tree species (Kg/tree and Kg annum^{-1})

Species	Total biomass carbon (Kg / tree)	Carbon sequestration potential (Kg annum^{-1})
T_1 (<i>Albizia chinensis</i>)	399.46	30.93
T_2 (<i>Albizia lebbeck</i>)	404.24	26.40
T_3 (<i>Acacia mollissima</i>)	203.87	17.37
T_4 (<i>Dalbergia sissoo</i>)	359.12	25.04
T_5 (<i>Ulmus villosa</i>)	130.22	9.38
T_6 (<i>Toona ciliata</i>)	406.59	25.97
T_7 (<i>Melia composita</i>)	184.55	12.30
CD _{0.05}	49.34	4.24

4.4 LITTER ACCUMULATION AND LITTER DECOMPOSITION (%) UNDER DIFFERENT MPTs

4.4.1 Litter accumulation under different MPTs

The content of the data presented in Table 11 reveals that among seven multipurpose tree species, higher amount of litter was accumulated under *Albizia chinensis* which is closely followed by *Albizia lebbeck*. On the other hand, litter accumulated under *Ulmus villosa* was very less and it was in the tune of (0.72 kg/ha).

Litter accumulate (kg/tree) by *Albizia chinensis* was found higher and followed by *Albizia lebbeck*, which may be due to large size and crown development, *Ulmus villosa* produced least litter.

In previous study Gupta *et al.* (2010) also reported that leaves formed the major component of the total litter followed by petiole, fruit and bark. Leaves formed 67.7, 67.8, 69.7 and 70.4 per cent of the total litter under *Albizia procera* un-pruned + fallow, *Albizia procera* unpruned + cropping, *Albizia procera* pruned 50 per cent + cropping, and *Albizia procera* pruned 70 per cent + cropping, respectively. Annually, litter production under these systems varied between 6.32 – 26.0 kg tree⁻¹. It is observed that quantity of N, P and K addition through litter fall of MPTs depends on the nature of MPTs, amount of litter fall, season, nutrient composition, canopy structure/geometry and canopy positions underneath. In irrespective of *Albizia procera* based land uses and pruning regimes therein, maximum amounts of N, P and K addition in winter followed by summer and rainy season coincided with the amounts of litter fall in respective seasons.

Table 11. Litter accumulation under different MPTs

Species	Total litter production (kg/tree)
T ₁ (<i>Albizia chinensis</i>)	4.48
T ₂ (<i>Albizia lebbeck</i>)	3.56
T ₃ (<i>Acacia mollissima</i>)	1.35
T ₄ (<i>Dalbergia sissoo</i>)	2.07
T ₅ (<i>Ulmus villosa</i>)	0.72
T ₆ (<i>Toona ciliata</i>)	2.24
T ₇ (<i>Melia composita</i>)	3.69
CD _{0.05}	0.08

4.4.2 Litter decomposition rate of different MPTs

Litter decomposition rate of different agroforestry tree species was studied during August to January 2018. The data presented showed significant variation among different

species. The monthly weight loss for all the species were positively related with moisture content present in the soil. On 1st sampling date i.e. 1st August, the decomposition rate was maximum in *Albizia chinensis* followed by *Ulmus villosa*, *Toona ciliata*, *Acacia mollissima*, *Albizia lebbeck*, *Dalbergia sissoo* and *Melia composita*. On 1st September litter decomposition rate was also found maximum in *Albizia chinensis* and minimum in *Ulmus villosa*. On the last two sampling dates i.e. 1st December and 1st January the decomposition rate was followed the order *Acacia mollissima* > *Albizia chinensis* > *Albizia lebbeck* > *Dalbergia sissoo* > *Toona ciliata* > *Melia composita* > *Ulmus villosa*.

During the month of August, September and October, *Albizia chinensis*, *Ulmus villosa* and *Toona ciliata* showed highest per cent of decomposition rate as compared to other tree species. Thereafter, it decreased in January as compared to December which was more pronounced in *Albizia chinensis* and *Acacia mollissima*. At the termination of the experiment i.e. in the month of January decomposition rate declined.

Under all the tree species, in surface layer the soil moisture was maximum in September closely followed by October. Considering mean monthly soil moisture variation among the different tree species its maximum value under *Albizia chinensis* and minimum at *Acacia mollissima*. Initial slow decomposition rate till January to the low moisture content resulting into low activity of decomposers. From August, decomposition increased gradually this attributed to rising soil moisture.

Gupta *et al.* (2017) studied the litter decomposition and subsequent nutrient release (N, P, K) from litter fall under six-year old *Albizia procera* in agroforestry system. For 95 percent decay leaf, petiole and pod litter decomposed faster under *Albizia procera* + crop. Decomposition of *Albizia procera* litter is positively correlated with N, P and hemicellulose concentration of litter and negatively correlated with lignin, C/N ratio, and lignin/N ratio. The added nutrients may contribute to the sustainability of soil fertility, which is becoming an important phenomenon for agroforestry practices.

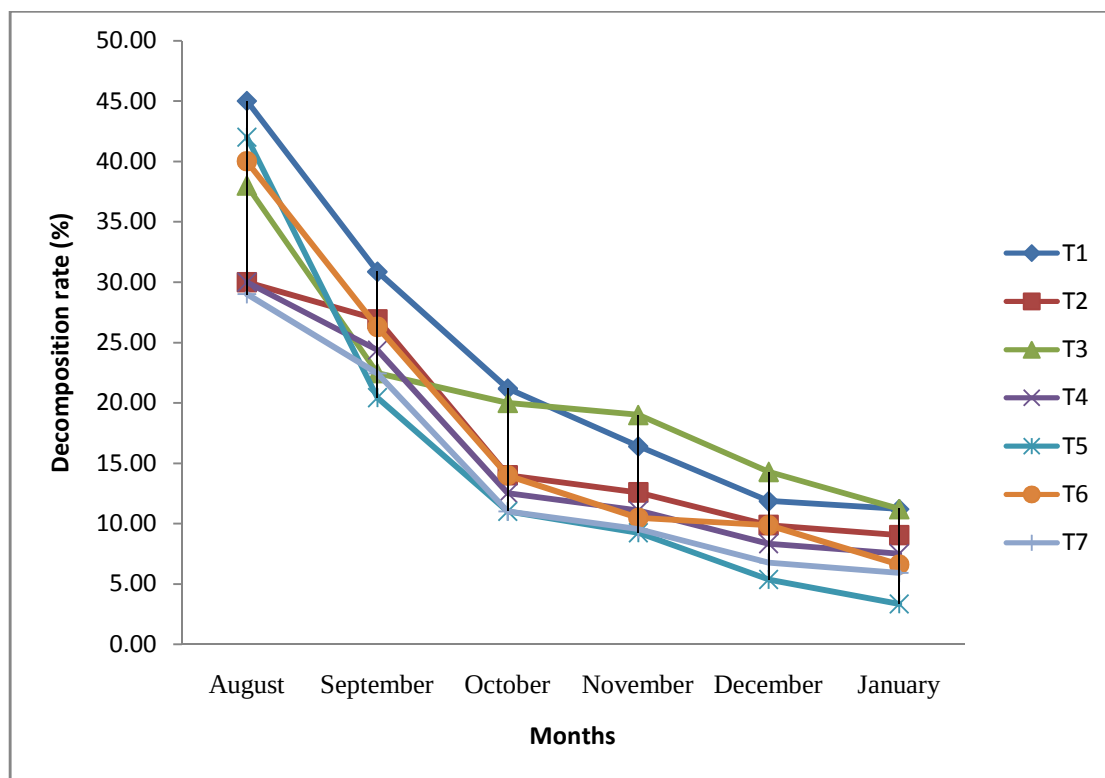


Fig. 1. Litter decomposition rate of important multipurpose trees

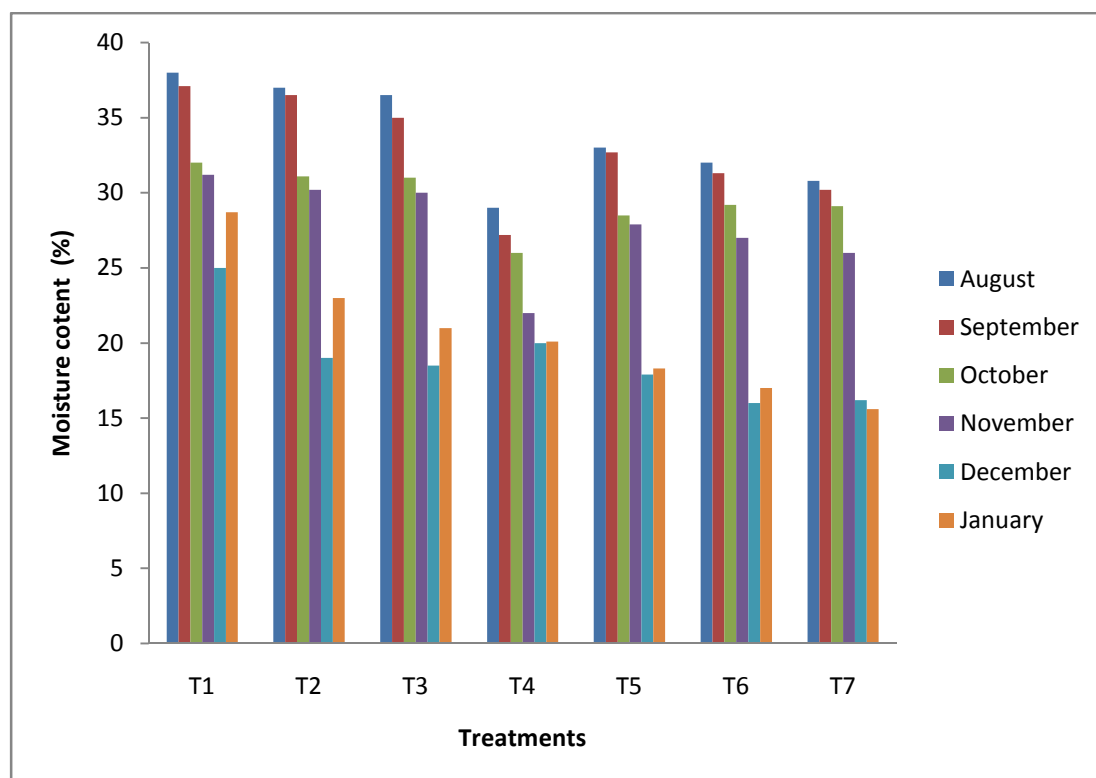


Fig. 2. Percent moisture content of important multipurpose trees

Chapter-5

SUMMARY AND CONCLUSION

The present investigation entitled “**Studies on nutrient status and carbon sequestration potential of important multipurpose tree species in sub-tropical region of Himachal Pradesh**” was conducted at the Experimental farm of the Department of Silviculture and Agroforestry, Dr Y. S. Parmar University of Horticulture and Forestry, Nauni, Solan-173230, Himachal Pradesh during 2017-2018. The results of the present investigation are summarized as under the following heading:

5.1 Soil physico- chemical properties under important multipurpose tree species

5.2 Carbon sequestration potential of important multipurpose trees

5.3 Decomposition rate of important multipurpose tree species

5.1 SOIL PHYSICO- CHEMICAL PROPERTIES UNDER IMPORTANT MULTIPURPOSE TREE SPECIES

The study was intended to explore the status of soil chemical characteristics under MPTs. The study revealed higher nutrient contents at surface layer D₁ (0– 15 cm) which decrease with the increase of soil depth. The soil under the MPTs showed pronounced changes. The pH were recorded maximum under *Melia composita* and lowest under *Ulmus villosa*. The EC were recorded maximum under *Albizia lebbeck* and minimum under *Melia composita* and *Toona ciliata*. The organic carbon varied significantly under MPTs and maximum Organic-C was observed under *Ulmus villosa* at both depths and minimum under *Albizia chinensis*. As regard to the available nutrients, i.e. available N, P and K were observed maximum under *Albizia lebbeck*, where as these were recorded minimum under *Ulmus villosa*. A comparison of soil chemical characteristics under MPTs and control revealed an improvement in soil EC, Organic carbon, available nutrients and microbial biomass.

The *Albizia lebbeck* and *Acacia mollissima* are excelled amongst all studied tree species for improving available soil nutrients. The soil bulk density was higher under *Dalbergia sissoo* and *Albizia lebbeck* and lowest in *Ulmus villosa*. The bulk density depicted an increasing trend with the increase in soil depth. Soil organic carbon pool inventory was

higher under *Albizia lebbeck* and minimum in *Albizia chinensis*. The Soil organic carbon pool inventory was maximum in surface soil (0–15cm) whereas minimum soil organic pool was recorded in sub- surface soil (15–30 cm).

5.2 CARBON SEQUESTRATION POTENTIAL OF IMPORTANT MPTs

5.2.1 Biomass production levels of different MPTs

The aboveground biomass of woody perennials was apportioned into stem, branch and leaf biomass by non – destructive method. All the species differ significantly with each other for their biomass production level. The total biomass (kg/tree) was found highest in *Toona ciliata* and *Albizia lebbeck* among all the seven multipurpose tree species studied during present investigation.

5.2.2 CARBON SEQUESTRATION POTENTIAL OF DIFFERENT MPTs

The result of present investigation indicates that *Albizia chinensis* and *Albizia lebbeck* sequestered more carbon as compared to other species, whereas low carbon was sequestered by *Ulmus villosa*, *Melia composita* and *Acacia mollissima*.

5.3 LITTER ACCUMULATION AND LITTER DECOMPOSITION RATE (%) OF DIFFERENT MPTs

Litter accumulation (kg/tree) was found higher under *Albizia chinensis* and minimum under *Ulmus villosa*. On the other hand, *Albizia chinensis* and *Ulmus villosa* recorded higher decomposition rate under available soil moisture condition. Initial slow decomposition rate at starting months (December – February) due to the low moisture content resulting into low activity of decomposers. From last incubation period of investigation(August- September) the rate of decomposition increased gradually, this attributed to rising soil moisture. The decomposition rate was followed the order *Acacia mollissima* > *Albizia chinensis* > *Albizia lebbeck* > *Dalbergia sissoo* > *Toona ciliata* > *Melia composita* > *Ulmus villosa*.

CONCLUSION

- MPTs have potential to improve the soil chemical properties i.e. soil pH, organic carbon, available N, P, K . The findings of the present study clearly indicate the positive effects of MPTs on soil properties and nutrients. Therefore these MPTs are used to rejuvenate the wasteland and in reforestation purposes.

- The high and improved amount of available nutrients (N, P K) and organic carbon was found at soil depth (0 – 15cm) which further decrease with the increase of soil depth.
- Carbon sequestration potential kg/tree was found highest in *Albizia chinensis* as compared to other multipurpose tree species. These species should be encouraged for plantation.
- The rate of decomposition of leaf litter is governed by moisture condition. Decomposition rate vary with the available moisture condition in the soil, it increases with more moisture in soil and was found highest in order of *Acacia mollissima* > *Albizia chinensis* > *Albizia lebbeck* > *Dalbergia sissoo* > *Toona ciliata* > *Melia composita* > *Ulmus villosa*. *Acacia mollissima* and *Albizia chinensis* due to high quality of leaf litter can be recommended to improve soil properties at faster rate.

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APPENDIX

APPENDIX-I: (Table 1) Effect of different multipurpose tree species on soil pH

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	0.007			
Factor T	6	4.754	0.792	514.624	0.00000
Factor D	1	1.061	1.061	689.353	0.00000
Interaction T X D	6	0.500	0.083	54.146	0.00000
Error	26	0.040	0.002		
Total	41	6.363			

APPENDIX- II : (Table 2) Effect of different multipurpose tree species on Electrical conductivity (dS/m)

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	0.000			
Factor T	6	0.077	0.013	315.035	0.00000
Factor D	1	0.033	0.033	814.944	0.00000
Interaction T X D	6	0.010	0.002	40.275	0.00000
Error	26	0.001	0.000		
Total	41	0.121			

APPENDIX- III : (Table 3) Effect of different multipurpose tree species on Organic carbon (%)

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	0.001			
Factor T	6	1.593	0.266	2,764.083	0.00000
Factor D	1	0.154	0.154	1,599.346	0.00000
Interaction T X D	6	0.022	0.004	38.694	0.00000
Error	26	0.002	0.000		
Total	41	1.773			

APPENDIX- IV: (Table 4) Effect of different multipurpose tree species on available nitrogen (kg/ha)

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	5.154			
Factor T	6	124,259.544	20,709.924	10,424.263	0.00000
Factor D	1	2,050.248	2,050.248	1,031.985	0.00000
Interaction T X D	6	208.377	34.729	17.481	0.00000
Error	26	51.654	1.987		
Total	41	126,574.977			

APPENDIX- V : (Table 5) Effect of different multipurpose tree species on available phosphorus (kg/ha)

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	1.783			
Factor T	6	1,942.872	323.812	319.664	0.00000
Factor D	1	668.010	668.010	659.454	0.00000
Interaction T X D	6	519.602	86.600	85.491	0.00000
Error	26	26.337	1.013		
Total	41	3,158.605			

APPENDIX- VI: (Table 6) Effect of different multipurpose tree species on available potassium (kg/ha)

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	6.006			
Factor T	6	82,360.245	13,726.707	7,881.189	0.00000
Factor D	1	2,837.823	2,837.823	1,629.336	0.00000
Interaction T X D	6	818.438	136.406	78.318	0.00000
Error	26	45.284	1.742		
Total	41	86,067.796			

APPENDIX – VII : (Table 7) Effect of different multipurpose tree species on Bulk density (g cm⁻³)

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	0.002			
Factor T	6	0.020	0.003	4.674	0.00238
Factor D	1	0.086	0.086	123.480	0.00000
Interaction T X D	6	0.036	0.006	8.551	0.00004
Error	26	0.018	0.001		
Total	41	0.161			

APPENDIX – VIII: (Table 8) Effect of different multipurpose tree species on Soil carbon pool inventory (Mg ha⁻¹)

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	0.152			
Factor T	6	399.850	66.642	583.105	0.00000
Factor D	1	12.436	12.436	108.816	0.00000
Interaction T X D	6	4.289	0.715	6.255	0.00037
Error	26	2.971	0.114		
Total	41	419.698			

APPENDIX –IX: (Table 9) Biomass production levels of different multipurpose tree species(Kg/tree)

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	2,822.308			
Treatment	6	658,341.394	109,723.566	57.860	0.00000
Error	12	22,756.363	1,896.364		
Total	20	683,920.065			

APPENDIX – X: (Table 10) Carbon sequestration potential of different multipurpose tree species(Kg annum⁻¹)

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	2	26.670			
Treatment	6	1,178.099	196.350	35.228	0.00000
Error	12	66.884	5.574		
Total	20	1,271.653			

APPENDIX – XI: (Table 11) Leaf litter accumulation of different MPTs (Kg / tree)

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Replication	3	0.228			
Treatment	6	44.593	7.432	48.894	0.00000
Error	18	2.736	0.152		
Total	27	47.557			

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Title of Thesis	Studies on Nutrient Status and Carbon Sequestration Potential of important Multipurpose trees in Sub-tropical region of Himachal Pradesh.
Name of the Student	Abhijeet Singh
Admission Number	F-2017-08-M
Major Advisor	Dr. K S Pant
Major Field	Forestry
Minor Field(s)	i. Agroforestry ii. Soil science
Degree Awarded	Master of Science (Forestry) Agroforestry
Year of Award Degree	2019
No of Pages in Thesis	62+iii
No of words in Abstract	297

ABSTRACT

The present investigation entitled “**Studies on nutrient status and carbon sequestration potential of important Multipurpose trees in Sub-tropical region of Himachal Pradesh**” was carried out in the experimental farm of Department of Silviculture and Agroforestry, Dr.Y.S. Parmar University of Horticulture and Forestry, Nauni, Solan (H.P.), during 2017-2018, with the objective to study the effect of MPTs on soil properties, nutrients, Carbon sequestration potential and leaf litter accumulation and decomposition rate of different MPTs . Experiment was laid out in RBD design with two soil depths (0-15cm and 15-30cm). Seven multipurpose tree species namely *Albizia chinensis*, *Albizia lebbeck*, *Acacia mollissima*, *Dalbergia sissoo*, *Ulmus villosa*, *Toona ciliata* and *Melia composita* were selected for the study.

The present study revealed that the nutrient contents were found higher at surface layer (0-15cm) which decrease with increase in soil depth. Among the different multipurpose tree species *Ulmus villosa* registered significantly higher amount of organic carbon (2.54 %). *Albizia lebbeck* registered significantly higher amount of available nitrogen (375.47 kg ha⁻¹), available potassium (351.97 kg ha⁻¹), and Soil carbon pool inventory (43.12 Mg ha⁻¹) at surface depth. Available potassium varied significantly under all tree species and found maximum under *Albizia lebbeck* (25.05 kg ha⁻¹). Irrespective of soil depths, electrical conductivity was found high under *Albizia lebbeck* (0.34 dS m⁻¹). Total biomass carbon stock was found maximum under *Toona ciliata* (406.59 kg tree⁻¹) and carbon sequestration potential of these species were evaluated, and was found maximum under *Albizia chinensis* (30.93 kg annum⁻¹). The decomposition rate of these species at the end of incubation period (six months) was in the order of *Acacia mollissima*> *Albizia chinensis*> *Albizia lebbeck*> *Dalbergia sissoo* > *Toona ciliata*> *Melia composita*> *Ulmus villosa*. The results clearly indicated the positive effect of soil moisture on rate of decomposition of different MPTs.

Signature of the Advisor

Signature of the Student

Countersigned

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