Ecological and Economical Appraisal of Apple based Agroforestry Systems in Kullu Valley of Himachal Pradesh

Thesis

by

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(NF-2020-05-M)

submitted to

Dr. YASHWANT SINGH PARMAR UNIVERSITY OF HORTICULTURE AND FORESTRY

SOLAN (NAUNI) HP -173 230 INDIA

in

partial fulfilment of the requirements for the degree of

MASTER OF SCIENCE (FORESTRY)

AGROFORESTRY

DEPARTMENT OF SILVICULTURE AND AGROFORESTRY
COLLEGE OF HORTICULTURE AND FORESTRY, NERI

2022

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CERTIFICATE-I

This is to certify that the thesis entitled, "**Ecological and Economical Appraisal of Apple based Agroforestry Systems in Kullu Valley of Himachal Pradesh**", submitted in partial fulfilment of the requirements for the award of degree of **Master of Science (Forestry)** in the discipline of **Agroforestry** to Dr. Yashwant Singh Parmar University of Horticulture and Forestry, (Nauni) Solan (HP) is a record of bonafide research work carried out by **Ms. Manvi Acharya (NF-2020-05-M)** daughter of Shri Bharat Bhushan Acharya under my guidance and supervision. No part of this thesis has been submitted for any other degree or diploma.

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

Place: Neri, Hamirpur

Dated: 23.12.22

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CERTIFICATE -II

This is to certify that the thesis entitled **"Ecological and Economical Appraisal of Apple based Agroforestry Systems in Kullu Valley of Himachal Pradesh"**, submitted by **Miss Manvi Acharya (NF-2020-05-M)** daughter of Shri Bharat Bhushan Acharya to the Dr. Yashwant Singh Parmar University of Horticulture & Forestry, (Nauni) Solan (HP)- 173 230 India in partial fulfillment of the requirements for the degree of **Master of Science (Forestry)** in the discipline of **Agroforestry** has been approved by the Advisory Committee after an oral examination of the student in collaboration with an External Examiner.

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This is to certify that all the mistakes and errors pointed out by the external examiner have been incorporated in the thesis entitled, **"Ecological and Economical Appraisal of Apple based Agroforestry systems in Kullu Valley of Himachal Pradesh"**, submitted to Dr. Yashwant Singh Parmar University Of Horticulture and Forestry, Nauni, Solan (HP) by **Ms. Manvi Acharya (NF-2020-05-M)** daughter of Shri Bharat Bhushan Acharya in partial fulfillment of the requirements for the award of degree of **Masters of Science (Forestry)** in the discipline of **Agroforestry**.

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ACKNOWLEDGEMENT

First and foremost, praises and thanks to the ***God****, the Almighty, for His showers of blessings throughout my research work. Every effort is motivated by ambition and all ambitions have an inspiration behind. I owe this place to my parents* ***Mr. Bharat Bhushan Acharya*** *and* ***Mrs. Somlata*** *and my elder sister* ***Pooja*** *who encouraged me to undergo higher studies.*

I wish to express my deep and sincere gratitude to my major Advisor Respected ***Dr. Kamal Sharma, Professor and Head, Department of Silviculture and Agroforestry*** *for his dedicated help, convincing guidance, inspiration, encouragement and continuous support. Without his persistent help, the goal of this study would not have been realized. I whole-heartedly appreciate that his great advice proved monumental towards the success of this study. His freehearted guidance, discreet approach, illative and appraise critique and perpetual encouragement have deeply inspired me. It was a great privilege and honor to work and study under his guidance.*

I express my in depth gratitude to the members of the Advisory Committee ***Dr. Richa Salwan (Assistant Professor, Microbiology), Dr. Som Dutt Sharma (Associate Professor, Agroforestry) and Dr. Anil Kumar (Senior Scientist, Soil Science)*** *for their precious suggestions given to me during the entire course of this study.*

My thanks are also due to all respected teachers, Dr. Uday, Dr. Navjot Singh Kaler and Dr. Dushyant Sharma for their ideological contribution and prized suggestions.

Unforgettable is the help from Mr. Dinanath and his family at Bhindi Bai village in Kullu, for facilitating their apple orchards for my experimentation, moreover, for standing with me throughout the field work.

I fully acknowledge the Laboratory and department staff members for their constant help and full cooperation during my research studies. I shall always be grateful for the affection they have shown towards me.

Friendship is a golden chain made stronger with each minute. Each link is forged of memories that make you still dearer. The thoughtful things you say and do become the links of gold that I will treasure through the years and in my heart will hold sweet memories of Ananya, Kritika, Nipun and Kartikay for being with me and helping in course of this research.

Needless to say Errors and Omissions are mine.

Place: Neri, Hamirpur

Dated: **(Manvi Acharya)**

CONTENTS

ABBREVIATIONS USED

et al.	:	et alia (co-worker)
viz.,	:	videlicet
i.e.	:	id est
m	:	meter
q/ha	:	quintal per hectare
ha	:	hectare
cm	:	centimeter
pH	:	potential of hydrogen
EC	:	electrical conductivity
OM	:	organic matter
OC	:	organic carbon
N	:	nitrogen
P	:	phosphorus
K	:	potassium
NS	:	non-significant
dS/m	:	deci Siemens per metre
kg/ha	:	kilogram per hectare
t/ha	:	ton per hectare
mg/kg	:	milligram per kilogram
mg/kg/year	:	milligram per kilogram per year
Cmic	:	microbial carbon
Nmic	:	microbial nitrogen
Pmic	:	microbial phosphorus
µg/g dry soil/hour	:	microgram per gram dry soil per hour
mg KMnO4/g dry soil	:	milligram potassium per magnate per gram dry soil
Rs.	:	rupees
kg	:	kilogram
g	:	gram

B:C Ratio	:	benefit-cost ratio
°C	:	degree Celsius
g/cm^3	:	gram per cubic centimetre
%	:	per cent
CD	:	critical difference
MD	:	mandays

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Chapter-1

INTRODUCTION

Agroforestry practice is an important management system for sustainable agriculture in the world. Over the last six decades, the quality of agriculture food is compromised because of the increased global environmental issues and the negative effects imposed by the excessive use of artificial fertilizers, weedicides, insecticides, and pesticides (Carvalho, 2017). Today, food is mostly available to tribal and for rural people around the world. However, increased deforestation in these areas has resulted in severe biodiversity loss. To overcome such issues, agroforestry has been recognized as a sustainable system to reconcile agricultural production and environmental protection (Noordwijk *et al.*, 2014; Catacutan *et al*., 2017,). Area under agroforestry has been estimated as one billion ha whereas 1.6 billion ha land worldwide has the potential to be put under agroforestry in near future (Nair and Garrity, 2012). In fact, agroforestry is substantially assisting in meeting the United Nations Millennium Development Goals (MDG) such as eradication of poverty and hunger, better health, nutrition and education to people, gender equality and environmental sustainability particularly in developing countries (Garrity, 2004 and Garrity, 2006). Agroforestry is an integrated land management system that helps in bridging the gap between the need for conservation and meeting people’s demand at the same time. According to Sanchez (1995), agroforestry centers around four factors *viz;* competition, complexity, sustainability and profitability however, there should be a balance among all these factors to get fruitful results.

Agroforestry provides one of the best alternatives for planting trees outside forests. Incorporation of the trees under agroforestry systems offer benefits even under low input sustainable agriculture. In fact, it is an age-old practice revived in the recent past with a renewed scientific interest to maintain the sustainability of agroecosystems, to meet the growing demands of increasing population, to compensate forests in the wake of fast increasing rate of deforestation and soil degradation both in the tropics and temperate regions of the world, and to conserve biodiversity (Noble and Dirzo, 1997). As an integrated farming system, agroforestry can generate diverse economic, ecological, and social benefits beyond those provided by sole-crop farming systems (Nair *et al.*, 2010; Catacutan *et al.*, 2017). Agroforestry is one of the best options to manage issues identified with land-use and worldwide temperature alteration (Li *et al*., 2012). Some agroforestry frameworks have received extended consideration because of their ability to capture comparatively more atmospheric carbon dioxide and accumulate carbon in soil and vegetation (Nair and Garrity, 2012).

In tree-crop combinations, both ecological and economical interactions exist between different components. Ecological interactions involve the impact of one species on germination, growth and yield of other and vice versa. Generally, neutral or supplementary, positive or complementary, and negative or competitive interactions are found between trees and crops depending upon the resource (Rao *et al*., 1998; Noordwijk and Hairiah, 2000). Neutral interactions are very rare and happen only when the niches are wide apart. Positive interactions include improvement of soil fertility through addition of tree litter, natural weed and pest management through allelochemicals of trees or through chemical signaling, modification of microclimate, environmental mitigation and phytoremediation, conservation of soil, moisture, and biodiversity through the protective roles of trees. Predominant negative interactions such as competition and allelopathy involve shading effect, harboring of the enemies of the crops and invasive potential of some of the introduced tree species.

Unlike monoculture, agroforestry fosters an agro-ecosystem that is like a natural system which improves the productivity and fertility of the agricultural land (Zerihun *et al*., 2014). Intercropping trees and crops complement each other in terms of root distributions, with tree roots exploiting subsoil and crop roots exploiting topsoil. Though intercropping has been shown to increase the productivity of agro-ecosystems, but the belowground mechanisms such as enzymes produced by soil microbial community for degrading plant residues have not been well elucidated (Do *et al.*, 2020). The logic underpinning agroforestry systems is that trees grown in mixtures with crops should either have a beneficial influence, whereby crop performance is enhanced or should exert minimal competitive effect on associated crops (Ong *et al*., 2006). One of the promising agroforestry technologies is integration of fruit trees into farmlands. Promoting fruit-based agroforestry will shift the conventional agroforestry system towards market-led 'trees for cash'. Fruit-tree-based systems appreciate high ubiquity among resource constraints around the world in view of high market value and dietary needs (Bellow, 2004). But limited studies are available on intercropping of fruit trees with remunerative crops particularly vegetables which could generate higher income to farmers (Gao *et al*., 2013).

The Himalayas has a long convention of agroforestry, considering person's needs and site-unequivocal uniqueness (Yadav *et al.*, 2017). In Kullu valley of Himachal Pradesh, the farmers grow fruit trees like apple, pomegranate, plum, peach, apricot etc. spaced at specific distances. Among all these fruits, apple is the most widely grown and represented as the most important fruit crop commercially. Area under cultivation of apple is 18,524 hectares with annual fruit production of 80,000 to 90,000 metric tons. This represents about 9,000 truckloads of apples every year. The district also has a niche or comparative advantage for the production of vegetables, pulses, temperate fruits and medicinal plants. Vegetables like peas, tomato, beans, capsicum, cucumber and cash crops are grown as the edaphic conditions of district Kullu are highly salubrious for season and off-season vegetable production. To a limited extent, the space in between trees is utilized for growing cereals and vegetables by the farmers. However, systematic studies have not been conducted on different tree-crop combinations which quantify the economic and ecological benefits from these systems.

The present study, therefore, has been planned to assess the potential of apple-based agroforestry systems integrated with black gram, capsicum, tomato and brinjal besides their effect on soil physico-chemical properties and microbial driven processes i.e., soil microbial biomass, nutrient flux and enzyme activities with the following objectives:

i. To assess the productivity of apple-based agroforestry systems *vis-a-vis* sole agricultural crops.
ii. To evaluate carbon sequestration potential, economic returns and soil physico-chemical as well as biological properties under different land use systems.

Chapter- 2

REVIEW OF LITERATURE

Agroforestry systems, integrating annuals and perennial fruit and forest trees are biologically more diverse and hence complex than other land use systems. Horticulture based agroforestry is playing a vital role in agricultural production to realize nutritional security besides protection of the environment through carbon sequestration to mitigate ongoing climate change problem for better well-being of mankind. The recommendation is to use compatible tree crop combinations, thereby limiting competition for resources and maximizing synergies (Pardon *et al.*, 2018). An agri-horticulture system is designed to raise short-term arable crops in the interspaces next to fruit trees which can promote seasonal profits. The horticulture-based system can be considered as a humanizing approach to production, economic, food and service opportunities. The present investigation on "**Ecological and Economical Appraisal of Apple based Agroforestry Systems in Kullu Valley of Himachal Pradesh**" has been undertaken to work out the economic and ecological feasibility of selected tree and under crops grown in association. Therefore, the study was designed to observe the effect of trees on the growth and yield of the field crops and *vice versa* for productivity, soil health, and ultimately the economics of the agroforestry systems. The relevant literature has been reviewed under the following headings:

2.1 Effect of agroforestry systems on growth and yield of field crops

2.2 Effect of agroforestry systems on soil physico-chemical properties of soil

2.3 Effect of agroforestry systems on soil microbial biomass and flux of C, N, P

2.4 Effect of agroforestry systems on soil enzymatic properties

2.5 Economic evaluation of fruit-tree based agroforestry system

2.1 Effect of agroforestry systems on growth and yield of field crops

Kumar (1999) investigated tree-crop interactions of mulberry, plum and pomegranate with soybean and reported negative influence on the growth and yield of soybean grown under trees as compared to the sole crop. The growth and yield of soybean among all tree- crop combinations was highest in pomegranate-soybean combination followed by plum-soybean, mulberry-soybean, pomegranate-mulberry-soybean, plum-mulberry-soybean andplum-mulberry-pomegranate-soybean.

Anjulo (2009) conducted a field study on component interactions and their influence on the production of apple-based agroforestry system in wet temperate zone of Himalayas during 2007-08 and 2008-09. Five tree-crop combinations *viz.,* S_1 (Apple + Wheat-Tomato), S_2 (Apple + Pea-Tomato), S_3 (Apple + Wheat- Field bean), S_4 (Apple alone) and S_5 (annual crop controls) were tried. The values of different parameters of wheat and field bean *viz.*, grain yield, thousand grain weight, biological yield and harvest index were higher in open (control) than those under apple. Contrary to these, tomato had significantly higher plant height, number of fruits per plant and fruit yield per plant under the apple canopy over control. Though no significant difference was observed in apple canopy spread between intercropped and uncropped trees, yet fruit yield was significantly higher in pure apple.

Hanif *et al.* (2010) studied the performance of three okra varieties *viz.,* hybrid okra, BARI-1 and local okra under litchi-based agroforestry system along with the sole okra crops as control. The result of the experiment revealed highest yield (10.24 t ha^{-1}) in sole cropping of hybrid okra and the lowest (4.24 t ha^{-1}) in Litchi+Local okra combination. The findings of this study ensured higher returns and sustainability in litchi based agroforestry system over sole cropping.

Fadl and Sheikh (2010) investigated the effect of *Acacia senegal* on growth and yield of groundnut in agroforestry system in North Kordofan State, Sudan. The study revealed reduction in the growth and yield of groundnut by 35 per cent and 17 per cent in the first season and 37 per cent and 39 per cent the second season, respectively.

Vanlalngurzauva *et al.* (2010) conducted field experiments on kharif crops during 2005-06 to study the growth and productivity of rice, cowpea, groundnut and black gram intercrops under 14-years old *Gmelina arborea* (Gamhar) plantation at Regional Research Station (Red and Laterite Zone), Paschim Medinipur, West Bengal. The study revealed higher yields 1.97, 1.03, 0.69 and 0.46 t ha^{-1} of rice, cowpea, groundnut and black gram under Gamhar, respectively.

Arya *et al.* (2011) carried out a field experiment to investigate the performance of component crops in tree-crop farming system under arid region of Rajasthan. Variations in growth and yield performances of trees (aonla, ber and karonda) as well as annual crops, namely, cluster bean and moth bean were raised during kharif, while mustard and brinjal were raised during rabi season, were recorded. Results revealed increase in yield (86.52 q/ha) of ber under integrated model over sole cropping (56.32 q/ha). The authors also reported significant increase in plant height and yield of all component crops under tree-crop farming system as compared to the sole cropping.

Osman *et al*. (2011) studied the performance of cowpea and pearl millet intercropped with *Parkia biglobsa* in an agroforestry system. The observations revealed reduced flowering and yield of cowpea and pearl millet under the system. The reduction in yield was up to 21 per cent for cowpea and 67 per cent for pearl millet.

Chauhan *et al.* (2012) studied quantitative performance of wheat under 1-5 years old poplar plantations in irrigated agroecosystem to assess the biological yield of tree and crop components. Results revealed significant decrease in the growth and yield of wheat with increasing poplar age. The per cent reduction in net grain yield was 17 per cent under one year old poplar plantation, which increased to 52.15 per cent under five-year-old plantation.

Sirohi *et al.* (2012) evaluated growth and yield of wheat and paddy under four years old *Dalbergia sissoo* based agri-silviculture system on sodic soil in eastern Uttar Pradesh. The experiment involved three varieties *viz.,* NW-1067, NW-1014 and HD-2643 of wheat and three *viz.,* Sarjoo-52, Narendra Usar-2 and Narendra Usar-3 of paddy grown in factorial Randomized Block Design. The study reported maximum plant height (89.33 cm and 98.00 cm) and straw yield (1.15 t ha^{-1} and 1.59 t ha^{-1}) in wheat var. HD-2643 and paddy var. Narendra Usar-2 at 1.0 m distance away from *D. sissoo* tree base in the alley cropping. However, maximum number of ear/panicle and 1000 grain test weight was recorded for wheat var. NW-1067 and paddy var. Narendra Usar-2, respectively in open. Among different varieties, wheat (NW-1067) and paddy (Narendra Usar-2) were found the best for cultivation under *D. sissoo* based agri-silviculture system.

Gao *et al.* (2013) assessed photosynthesis, growth and yield of *Glycine max* (soybean) and *Arachis hypogaea* (peanut) in *Malus pumila* (apple) plantation spaced at 4 m × 5 m on the Loess Plateau of China. The results indicated suitability of peanut as intercrop under apple for higher economic benefits over soyabean. Deficiency in soil nutrients, moisture content and light also exerted a significant impact on crop yields.

Singh and Bishnoi (2013) carried out experiment on kharif bean crops *viz.*, cluster bean, moth bean and mung bean in combination with khejri trees in the arid regions of Haryana under rainfed conditions. Quadrats of 1 m^2 were laid at 1 m distance in all directions of the tree using transect line approach. All bean crops revealed better vegetative growth and higher number of pods per plant under khejri trees.

Bhutia *et al.* (2015) evaluated the performance of three pea varieties *viz.*, Solan Nirog, Azad P 1 and PB 89 which were grown with different doses of inorganic fertilizers + *Rhizobium* inoculation under three years old peach plantation and in open. The recommended dose of NPK + *Rhizobium* inoculation showed best results in most of the growth and yield attributes of pea crop *viz.*, plant height (cm), number of pods $plant^{-1}$, number of grains pod^{-1}, pod length (cm), pod breadth (cm), 100 grain weight (g), shelling percentage and total biomass production (g). Variety PB 89 exhibited better growth and yield attributes of pea but plant height and shelling percentage was maximum in Solan Nirog. The investigation concluded that pea variety PB 89 can be grown successfully under peach-based agroforestry system without much reduction in yield as compared to sole cropping. The study also suggested inoculation of seeds with rhizobium and 100 per cent recommended dose of NPK for obtaining maximum yield.

Gawali *et al.* (2015) conducted an experiment at Indira Gandhi Agricultural University, Raipur, Chattisgarh to evaluate the growth and yield of wheat varieties under *Ceiba pentandra* based agrisilviculture system. Better shoot growth and higher yield was obtained in sole wheat compared to wheat grown *C. pentandra* system. No significant effect was observed in leaf area index of wheat but significantly higher photo synthetically active radiation (PAR) interception was recorded in sole wheat and wheat intercropped under 4×8m spacing.

Dalal *et al.* (2016) conducted experiments during 2011-12 and 2012-13 in a 10 years old silvi-horti systems comprising of Shisham + Aonla, Shisham + Guava, Khejri + Aonla and Khejri + Guava planted at a spacing of 6m x 6m. Wheat was grown in interspaces of the silvi-horti systems. The findings revealed no significant effect of woody trees on wheat germination under agri-silvi-horticultural system in both years. Initially after 30 days of sowing, reduced plant height was observed in sole crop than under agroforestry system, but after 60, 90 ad 120 days of sowing, the plant height was significantly higher in sole crop than agri-silvi-horticulture system.

Rajalingam *et al*. (2016) conducted field experiments in western zone of Tamil Nadu to develop a suitable *Ailanthus excelsa* based silvihorticultural system for higher productivity. Green leafy vegetable crops *viz*., Chinese amaranth, spleen amaranthus, tropical amaranth, Chinese spinach and palak were intercropped with 4 years old *Ailanthus excelsa* to study the growth and productivity of these intercrops and their effect on tree growth. Results showed significant reduction in the number of branches at harvest in palak than sole cropping. The lowest reduction was reported in Chinese spinach. Among the five intercrops, maximum reduction in yield was observed in palak and minimum in Chinese spinach.

Pandey *et al*. (2016) assessed growth and yield performance of ginger crop (*Zingiber officinale*) under Sapota- Jatropha based agroforestry system in south Gujarat. The observations on growth and yield revealed more fresh rhizome yield, total number of fingers per plant, plant height, length of rhizome, width of rhizome and survival per cent of ginger under Sapota-Jatropha based agro-forestry system as compared to sole ginger cropping.

Kaur *et al.* (2017) conducted an experiment with different crops, *viz*., *Pennisetum glaucum* (pearl millet), *Triticum aestivum* (wheat), *Solanum tuberosum* (potato), *Trifolium alexandrinum* (Egyptian clover) and annual *Curcuma longa* (turmeric) under four agroforestry tree species *viz., Populus deltoides, Eucalyptus tereticornis, Melia composita* and *Toona ciliata* during 2005- 2011 at Ludhiana, Punjab. The experiment was conducted to see the effect on tree growth parameters, growth and yield parameters of intercrops and sole crops, soil organic carbon, nutrient status and economics of agroforestry systems. The diameter at breast height (DBH) and height of poplar and eucalyptus were higher than the other species after 6 years of age. Results showed that the grain yield of wheat and fodder yield of pearl millet was higher under toon than that under poplar and Melia plantations during different years of tree growth. Overall reduced growth and yield of intercrops was recorded under tree plantations. Toon plantation had the minimum adverse effect on understorey crops, whereas eucalyptus caused the maximum reduction in yield of all the intercrops.

Rao *et al.* (2017) conducted an experiment with three wheat varieties *viz.,* NW-1067, NW-1014 and HD-2643 grown at four distances (1, 2, 3 and 4m) from *Populus deltoides* with five replications. The maximum crop height was reported in wheat HD-2643 grown at 2 m distance, while the maximum number of shoots and grain yield (22.75 q/ha) was reported in

NW-1067 at 2 m distance. Significantly higher plant growth and yield was recorded in open compared to crop grown in poplar-based agroforestry system.

Singh *et al.* (2018) conducted studies to find out the growth and yield performance of wheat (*Triticum aestivum*) crop with weed control treatments under *Eucalyptus* based agroforestry system during winter season. The results indicated higher growth and yield of wheat crop in hand weeding than other weed management practices under *Eucalyptus* plantation.

Ajaykumar *et al.* (2022) carried out an agroforestry trial with eight treatments and three replications during kharif and rabi season 2019-20. Black gram crop varieties *viz.*, V_1 - CO6 and V_2 - VBN 6 were intercropped with 1.5 year old *Melia dubia* raised at different spacing S_1 (3 x 1.5 m), S_2 (3 x 3m) and S_3 (4 x 4m). Black gram varieties were also grown as sole crops without tree which served as control. The analysis of pooled results of two seasons revealed plant height (49.96 cm), number of branches (3.76), number of leaves (259.75), number of flowers (53.44), number of pods (22.85), seed yield per plant (5.38 g) and seed yield per hectare (0.82 tonnes) in open treatment. However, poor growth parameters of black gram were recorded in var. CO6 at closer spacing (3 x 1.5 m). Similarly, maximum height was recorded in S_1 spacing (3 x 3 m) and maximum diameter recorded in wider S_3 spacing (4 x 4m). Therefore, wider spacing of S_3 (4 x 4m) can be suggested for intercropping under *M. dubia* plantations upto 4 years.

2.2 Effect of agroforestry systems on soil physico-chemical properties of soil

Baber *et al.* (2006) investigated the physico-chemical characteristics of soil under agroforestry system at two depths (0-15 cm and 15- 45 cm). Soil samples were analyzed for pH, electrical conductivity (EC), organic matter (OM), P, K and micronutrients (Zn, Cu, Fe, and Mn). The study revealed decrease in the values of pH, EC, P, K and organic matter with increase in distance from the trees in the surface soil. On the other hand, organic matter and P content was decreased while pH, EC and K increased in the subsoil.

Mishra *et al.* (2006) performed an experiment to investigate the growth and productivity of soybean under *Populus deltoides* based agrisilviculture system at Raipur (Chhattisgarh), India. The system comprised of five poplar clones (G3, G48, 65/27, D121 and S7C1) planted in a randomized block design with three replications. The investigations reported significant increase in available N, P and K from 14.9 to 24.1 per cent, 17.2 to 23.3 per cent and 3.1 to 5.1 per cent in the soil after six years of poplar planting at 0-20 cm depth, respectively. However, N, P and K contents decreased with increase in soil depth under different clones of poplar.

Saha *et al*. (2007) planted various multipurpose tree species; *Alnus nepalensis*, *Gmelina arborea*, *Michelia* oblonga, *Parkia roxburghii* and *Pinus kesiya* on hilly terrain of north-east India. Analysis of soil physico-chemical parameters revealed increase in soil organic C by 96.2 per cent, porosity by 10.9 per cent, aggregate stability by 24.0 per cent and available soil moisture by 33.2 per cent and simultaneously reduced bulk density by 15.9 per cent and erosion ratio by 39.5 per cent.

Gupta *et al.* (2009) observed increase in average soil organic carbon from 0.36 in sole crop to 0.66 per cent in agroforestry soils. Higher soil organic carbon was obtained under agroforestry (2.9–4.8 Mg/ha) as compared to sole crop grown. Poplar trees sequester higher soil organic carbon in 0–30 cm profile during the first year of their plantation (6.07 Mg/ha/year) than the subsequent years (1.95–2.63 Mg/ha/year).

Sirinivasan *et al.* (2010) studied the effect of intercropping of three fast growing multipurpose trees *viz.*, Whistling pine (*Casuarina equisetifolia*), halmaddi (*Ailanthus triphysa*) and safed babool (*Leucaena leucocephala*) planted in one year old coconut plantations on soil physico-chemical and biological properties at the instructional farm, Kerala Agricultural University, Vellanikkara. Incorporation of the tree components improved water holding capacity, infiltration capacity, improvement in available N, P, K content and organic matter status in the soil in the coconut plots.

Das *et al.* (2011) conducted an intercropping trial during 2007–2010 on 6-year-old aonla (*Emblica officinalis*); cv. NA-7 orchard planted at 6 × 6 m spacing under rainfed calciorthent soil to identify the suitable and profitable intercrops. The intercrops grown were turmeric, ginger and arbi. It was confirmed that aonla-based agri-horticultural systems were effective in bringing improvement in the soil properties which was also reflected by the significant increase in organic carbon (32.4-56.8 per cent), available nitrogen (26.2-37.8 per cent) and phosphorus (22.2-30.8 per cent).

Swain *et al.* (2012) carried out an experiment in mango-based intercropping system to find out the effect of intercropping on soil health in the rainfed uplands of Orissa. The results revealed a gradual improvement in the physicochemical properties of soil due to intercropping systems. Among all intercropping systems, mango + guava + cowpea system showed best improvement in bulk density, electrical conductivity, water-holding capacity, organic carbon content, available nitrogen and potassium contents and pH within soil depths (0-15 cm and 15-30 cm). However, available phosphorus was recorded maximum in the mango + guava + mango ginger system which was at par with the mango + guava + cowpea system statistically.

Casals *et al.* (2013) conducted an experiment in silvopastoral system to study the status of soil organic C and nutrient contents under trees with different functional characteristics. The results revealed higher soil organic C, N stocks, available P, extractable K^+ and Ca^{2+} under the tree canopy than open grassland.

Dhara *et al.* (2015) laid out fruit-based agroforestry systems to identify a suitable agroforestry model in West Bengal, India. The fruit trees were planted at a spacing of 10m × 10m and *Eucalyptus tereticornis* were planted within the fruit plants at 5m spacing in between two mango rows and at boundary of the field as shelterbelt. The crops *viz.*, pigeon pea, black gram, bottle gourd, lady's finger and maize were cultivated during kharif and mustard in rabi season. Results revealed increased profitability and improved soil health in fruit-based agroforestry system. Under mango-based agroforestry system, the models T1: *E. tereticornis*+ Mango+ Pigeon pea and T2: *E. tereticornis*+ Mango+ Black gram showed increase in soil N by 34.3 per cent and 2 per cent, soil P by 35 per cent and 27 per cent, soil K by 18 per cent and 13 per cent, organic C by 29 per cent and 24 per cent, respectively after 2 years.

Ghimire and Bana (2015) elucidated the effect of different levels of Nitrogen (N), Phosphorus (P) and Potassium (K) on soil physico-bio-chemical properties under varying poplar tree densities with mustard intercropping during winter seasons 2008-10 at Agroforestry Research Centre, Pantnagar, India. Lower soil bulk density was recorded under tree canopy to sole crop in both the years. Whereas, soil pH, available N and K were not influenced by tree density.

Available soil nitrogen, phosphorous, exchangeable calcium, DTPA extractable zinc, copper and manganese were significantly higher under Poplar based agroforestry system as compared to sole crop. Higher concentration of nutrients were reported in surface layer i.e., 0- 15 cm which decreased significantly with successive increase in soil depth. (Uthappa *et al.* 2015).

While, available K, exchangeable Mg and available S were not significantly influenced by the tree density classes.

Kaushal *et al.* (2016) conducted quality assessment of soils in Grewia (*Grewia optiva*) based agroforestry system in Himalayan foothills. Soil samples from six different treatments *viz.*, Sole *Grewia*, *Grewia* + Finger millet (*Eleusine coracana*), *Grewia* + Barn yard millet (*Echinochloa crus-galli*), Finger millet alone, Barn yard millet alone and fallow were evaluated for different soil properties and soil quality. The results reported lowest soil bulk density (1.40 mg m^{-3}) in sole *Grewia* plot and highest (1.50 mg m^{-3}) in fallow plots. Similarly, increased organic carbon was reported in different treatments as compared to fallow plot. However, N, P and K were higher under sole *Grewia* and agroforestry plots.

Swain (2016) conducted an experiment to study the influence of various intercropping systems on plant and soil health of guava orchard. The guava based intercropping systems comprised of nine intercrops such as mango, ginger, turmeric, tomato, cowpea, french bean, ragi, niger, upland paddy and a control (without intercrop). The results revealed significant improvement in bulk density, electrical conductivity, water holding capacity, organic carbon content, available nitrogen, potassium and pH of orchard soil under guava + cowpea system.

Kaushik *et al.* 2017 studied soil chemical properties among four agri-silvi-horti systems and the results revealed highest available N content in Shisham + guava system with cluster bean–barley (155.00 kg/ha) and lowest under Khejri + aonla with pearl millet-oat (100.00 kg/ha) at surface soil depth. It was also reported that the available N, P and K content increased under agri-silvi-horti systems and decreased with increasing soil depth.

The influence of different spacings of Poplar based agroforestry system was observed by Sirohi and Bangarwa (2017). Under different spacings of Poplar-based agroforestry system the highest available soil N (366.3 kg/ha), P (21.4 kg/ha) and K (355.3 kg/ha) were observed under 5×4 m spacing compared to 10×2 m, 18×2×2 m (paired row) as well as sole cropping after wheat harvesting.

Sao and Prajapati (2018) investigated the nutrient status of soil and crop of wheat under *Ceiba pentandra* agri-silviculture system and reported high organic carbon and available N, P and K in the soil under wheat- *Ceiba pentandra* agroforestry system.

Devi *et al.* (2020) carried out investigations to evaluate the effect of agri-silvi-horticultural system on soil chemical properties and available nutrients at different depths during 2017-18 in Hisar. Soil samples from different tree-based agroforestry systems, kinnow + eucalyptus + wheat, kinnow + wheat and a control (no tree) were taken at 0-15, 15-30, 30-60 and 60-90 cm depths. Results revealed that soil pH and electrical conductivity reduced significantly under kinnow + eucalyptus + wheat system by 1.5 per cent and 25 per cent, respectively over control. Moreover, higher organic carbon content and available nutrients (N, P and K) were reported in kinnow + eucalyptus + wheat system than sole cropping at different depths. Hence, the authors stated that tree-based systems enhanced soil organic matter content, available nutrients and improved soil properties.

2.3 Effect of agroforestry systems on soil microbial biomass and flux of C, N, P

Chander *et al.* (1998) studied the effect of tree-crop combinations on soil organic matter, microbial biomass C, basal respiration, dehydrogenase and alkaline phosphatase activities. The results concluded improved organic matter status of the soil due to agroforestry practices.

Yeates and Saggar (1998) carried out a study to investigate responses of selected soil characteristics to vegetation changes in high country soils. Soil samples were collected from unburned *Chionochloa rigida* grassland, burned *C. rigida*, *Pinus radiata* trees and glades within pine forest where trees had failed to grow. Results showed lower soil pH and exchangeable Ca, Mg, K and Fe, and lower microbial C, N and P under *P. radiata*.

Kaur *et al.* (2000) analyzed the role of agroforestry systems in improving soil organic matter, microbial activity and nitrogen availability in study sites located at Karnal. The systems were characterized by a rice-berseem crop rotation which includes agrisilvicultural systems of *Acacia nilotica*, *Eucalyptus tereticornis* and *Populus deltoides* along with rice-berseem and single species tree plantations. Higher microbial biomass C and N was reported in tree-based systems and agrisilvicultural system as compared to monocropping. Based on the increased soil organic matter, soil microbial biomass pool and greater soil N availability, the study concluded agri-silvicultural systems as more ecologically sustainable land-use systems for utilizing moderately alkaline soils.

Manna and Singh (2001) conducted on-farm field experiments at two sites having 38 and 10 years-old orchard cropping systems under sub-tropical climatic regions to evaluate changes in organic carbon accumulation and chemical and microbiological properties of the soils. Results reported that the cultivation of coconut (*Cocos nucifera*) intercropped with guava (*Psidium guajava*) enhanced the soil microbial activity approximately 2-fold after 38 yrs over 10 yrs of the same intercropped system. The average level of soil microbial biomass carbon was 1158 kg hay^{-1} (0±0.15 m depth) and the organic carbon turnover rate was 8.5 yr^{-1} after 38 yrs of intercropped fruit trees.

Lee and Jose (2003) measured soil respiration rate and microbial biomass under two age classes (young and old) of a pecan (*Carya illinoinensis*) – cotton (*Gossypium hirsutum*) alley cropping system, two age classes of pecan orchards, and a cotton monoculture on a well-drained, Redbay sandy loam in southern USA. Results revealed that microbial biomass C was higher in the old alley cropping system (375 mg C kg^{-1}) and in the old pecan orchard (376 mg C kg^{-1}) compared to the young alley cropping system (118 mg C kg^{-1}), young pecan orchard (88 mg C kg^{-1}), and the cotton monoculture (163 mg C kg^{-1}). Soil respiration was correlated positively with soil temperature, microbial biomass, organic matter, and fine root biomass.

Yan *et al.* (2003) carried out an investigation in the different land use systems *viz.*, citrus orchard, citrus plus wheat mixed cropping, wheat alone and tea bush. Results showed improved soil quality in agroforestry systems. Microbial biomass carbon was found approximately four times for citrus/wheat (wheat area), forests area and tea bush area when compared to citrus/wheat (citrus area) and citrus alone where microbial biomass carbon was at par for tea bush.

Munoz *et al.* (2007) conducted a study to determine the effects of the canopy cover of *Acacia caven* (Espino) agroforestry system of the Mediterranean zone of central Chile on total soil organic carbon (SOC), soil respiration and the labile components of soil organic matter (microbial biomass, and light fraction. Results revealed that microbial biomass carbon was comparatively less upto a shallow depth of 10 cm in all agroforestry land use systems compared to treeless plots in the soil under canopy area of the tree.

Yadav *et al.* (2011) evaluated the effect of traditionally grown trees *Prosopis cineraria*, *Dalbergia sissoo, Acacia leucophloea* and *Acacia nilotica* on soil biological characteristics in an Entisol at farmer's field in Jaipur District, Rajasthan, India. Results revealed a significant and substantial improvement in soil biological activity in terms of microbial biomass C, N and P, dehydrogenase and alkaline phosphatase activity under different tree-based agroforestry systems as compared to control (cropping alone).

Benbi *et al.* (2012) studied the impact of three different land-use systems *viz.*, poplar-based agroforestry involving wheat-legume rotation, rice-wheat and maize-wheat agroecosystems on dynamics of total organic C, oxidisable soil organic C, very labile, labile, less labile, and recalcitrant C fractions, water extractable organic carbon, hot water-soluble C, microbial biomass C, and mineralizable C in the semi-arid subtropical India. The maize-wheat agroforestry systems showed 65–88% higher soil organic carbon stocks than the rice-wheat system and characterized as predominantly labile. The hot water-soluble C and microbial biomass C were also higher in maize-wheat agroforestry systems compared to rice-wheat system.

Ramesh *et al.* (2013) studied a 26 years old agroforestry plantation consisting of four multipurpose tree species *Michelia oblonga*, *Parkia roxburghii*, *Alnus nepalensis*, and *Pinus kesiya* maintained at ICAR Research Complex, Umiam, Meghalaya, India and it was compared with a control plot (without tree plantation) for soil fertility status and CO_2 efflux. Results reported 34 per cent more soil microbial biomass carbon and other physico-chemical parameters under multipurpose trees as compared to control.

Tian *et al.* (2013) studied the effect of agroforestry practice on soil fertility, organic carbon, total nitrogen, microbial biomass, basal respiration, and activity of soil enzymes at three soil depths (0–10, 10–20, and 20–30 cm) of ginkgo (*Ginkgo biloba*)–tea (*Camellia sinensis*) agroforestry systems at Yushan Farm in Changshu, Jiangsu Province, China. The results revealed higher C, N, microbial biomass, and enzyme activity in surface soil than in soil collected from the middle and lower layers whereas pH and metabolic quotient increased with soil depth.

Verma *et al.* (2014) evaluated the effect of intercropping systems on soil organic carbon, total nitrogen, available N, P and K, soil microbial biomass carbon and microbial biomass nitrogen under geranium (*Pelargonium graveolens* L.) intercropping systems with companion crops *viz.* wheat, barley, oats, barseem, lentil, mustard, radish, pea, cabbage and cauliflower. Geranium-based intercropping resulted in increased levels of soil organic carbon, total nitrogen and microbial respiration over geranium alone.

Rodrigues *et al.* (2015) investigated the soil microbial biomass C and activity under agroforestry system with different densities of babassu palm (*Attalea speciosa*) associated with

Brachiaria brizantha grass in northern Brazil. Soil microbial biomass C (MBC), soil microbial biomass N (MBN), MBC: total organic C ratio, fluorescein diacetate hydrolysis and dehydrogenase activity showed highest values in plots with high density of babassu palm.

Radhakrishnan and Varadharajan (2016) conducted an experiment to study the status of microbial diversity under different agroforestry systems including tree species *viz., Ailanthus excelsa, Tectona grandis, Gmelina arborea, Santalum album, Melia dubia* in Tamil Nadu. Results showed positive correlation of microbial population with the physicochemical properties of different soil samples. The presence of higher microbial diversity was due to the presence of diverse organic matter in soils under different agroforestry systems.

Lu *et al.* (2019) conducted a two-year field trial to compare the effects of intercropping with peanut and *Camellia oleifera* monoculture on soil characteristics, nutrients status as well as soil microbial activity. Compared with *C. oleifera* monoculture, the soil porosity in intercropping *C. oleifera* with peanut was increased by 11.45 and 8.41 per cent, the electrical conductivity by 14.74 and 16.90 per cent, the rhizosphere fungi populations by 21.46 and 15.38 per cent, the rhizosphere bacterial populations by 52.19 and 43.87 per cent, soil organic matter (SOM) by 4.72 and 5.69 per cent, the available nitrogen (N) by 10.71 and 14.51 per cent.

Senarathne and Udumann (2019) conducted a study to assess the impact of coconut based *Anacardium occidentale* (Cashew) agroforestry systems on soil fertility of degraded coconut lands in wet, intermediate and dry zones of Sri Lanka. Coconut based agroforestry systems intercropped with *A. occidentale* and sole coconut were evaluated as two treatments. Soils from three depths were analyzed for its chemical, physical and biological properties. Results showed higher soil microbial activity in *A. occidentale* intercropped system.

Singh *et al.* (2020) conducted experiment to understand the seasonal dynamics of microbial population and microbial biomass under agroforestry systems of sub-humid Gujarat, India. The study reported higher nutrient flux and dynamics of soil nutrients as well as soil microorganisms under tree-crop species land uses.

2.4 Effect of agroforestry systems on soil enzymatic properties

Frankenberger and Dick (1983) studied the relationship between the activities of different soil enzymes with microbial biomass through a field experiment. The study revealed higher alkaline phosphatase, amidase, alpha-glucosidase, and dehydrogenase activities where total biomass and microbial respiration was also high.

Chander *et al.* (1998) studied soils under a 12-year-old *Dalbergia sissoo* (a N_2-fixing tree) plantation intercropped with a wheat (*Triticum aestivum*), cowpea (*Vigna sinensis*) cropping sequence to check the effects of growing trees in combination with field crops on soil organic matter, microbial biomass C, basal respiration and dehydrogenase and alkaline phosphatase activities. Results revealed higher organic C, total N, microbial biomass C, basal soil respiration and activities of dehydrogenase and alkaline phosphatase in treatments with tree-crop combination than in the treatment without trees.

Goyal *et al.* (1999) studied the effect of inorganic fertilizers, a combination of inorganic fertilizers and organic amendments on soil properties *viz.*, organic matter, mineralizable C, N, microbial biomass C, dehydrogenase, urease and alkaline phosphatase activities under a pearl millet-wheat cropping system. The study reported increased microbial biomass C (423 mg kg^{-1}), increased urease and alkaline phosphatase activities in soils amended with wheat straw and inorganic fertilizers compared to unfertilized soil (147 mg kg^{-1}).

George *et al.* (2002) carried out an experiment to identify and quantify the phosphorus active root exudates released into the rhizosphere of agroforestry species (*Tithonia diversifolia Tephrosia vogrlii* and *Crotalaria grahamiana*) compared to maize. They observed highest phosphatase activity in the rhizosphere of all agroforestry species. Agroforestry species were found to increase the activity of acid phosphatase, while maize increased the activity of alkaline Phosphatase.

Michel and Matzner (2003) investigated the effect of mineral N on enzyme activities endoglucanase, β-glucosidase, polyphenol oxidase and β-glucosaminidase in the late stages of organic matter decomposition using Oa material (highly decomposed amorphous humus) from four mature Norway spruce (*Picea abies* (L.) Karst.) sites. The results revealed increased endoglucanase activity and decreased β-glucosidase activity by N additions in Oa material having wide C-to-N ratio. On the other hand, increased polyphenol oxidase activities were reported as a consequence of N addition in materials with low C-to-N ratio. Thus, the study revealed effect of N additions on enzymatic activities of organic matter in late stages of decomposition and related to the C-to-N ratio.

Lalita (2004) observed dehydrogenase activity in normal and in saline soil under different cropping systems *viz.*, rice-wheat, pearl-millet-wheat in Haryana, India. In normal soil, dehydrogenase activity was 103 per cent higher under tree canopies compared to rice-wheat cropping system, whereas in saline soil, it was 100 per cent under pearl millet- wheat cropping sequence than under tree canopies.

Prasad and Mertia (2005) studied dehydrogenase activity and VAM fungi association in rhizosphere of six agroforestry trees *viz.*, *Azadirachta indica*, *Acacia tortilis*, *Eucalyptus camaldulensis*, *Prosopis cineraria* and *Tecomella undulata* under irrigated and rainfed conditions in the arid zone of India. Results reported significantly higher (9.0-18.8 μg TPF g^{-1} 24 h^{-1}) deviation in dehydrogenase activity in soils under various tree species in irrigated conditions than that in rainfed conditions (9.9-15.0 μg TPF g^{-1} 24 h^{-1}).

Tripathi and Sharma (2005) studied the impacts of different land use systems on faunal density, nutrient dynamics and biochemical properties of soil in agrisilviculture system of Indian desert. The selected fields included trees *viz.*, *Zizyphus mauritiana*, *Prosopis cineraria*, *Acacia nilotica* and crops *Cuminum cyminum*, *Brassica nigra*, *Triticum aestivum* in different combinations. The results revealed higher soil temperature, moisture, organic carbon, nitrate and ammonical nitrogen, available phosphorus, soil respiration and dehydrogenase activity under trees than tree + cropping system.

Munna *et al.* (2007) conducted an experiment to evaluate the soil fertility in a 17- year old *Hardwickia binnata*- based agroforestry system at NRCAF, Jhansi. Result showed that across canopy positions, Dehydrogenase activity increase by 12.3 per cent in *H. binata*- based agroforestry system over control (no tree).

Udawatta *et al.* (2008) conducted a study to examine management and landscape effects on water stable soil aggregates (WSA), soil carbon, soil nitrogen, enzyme activity, and microbial community DNA. Treatments were row crop (RC), grass buffer (GB), agroforestry buffer (AG), and grass waterways (GWW). Grass buffers consisted of a mixture of redtop (*Agrostis gigantea*), brome grass (*Bromus* spp.) and birdsfoot trefoil (*Lotus corniculatus* L.) on contour within the watershed. Agroforestry buffers had pin oak (*Quercus palustris*) trees distributed down the center of the grass buffers on one half of the watershed. WSA was significantly different among treatments and landscape positions. WSA decreased from GWW > AG > GB > RC management treatments and also decreased from lower > middle > summit landscape positions. Soil carbon and nitrogen were highest for the GWW treatment and lowest for RC. Results showed that establishment of AG, GB, and GWW increased WSA, soil carbon, soil nitrogen, and enzyme activity.

Vallejo *et al.* (2010) conducted a study on soil enzymatic activities and microbial biomass in silvopastoral agroforestry systems, monoculture and a native forest in South America. The results showed that activities of urease, alkaline phosphatases, and β-glucosidase were more in silvopastoral systems as compared to native forest.

Kremer and Kussman (2011) conducted on-farm study with an objective to assess the effects of perennial legume kura clover (*Trifolium ambiguum*) on soil quality in a recently established pecan (*Carya illinoinensis*) orchard. Results reported significantly higher soil fertility, biological activity and forage quality under agroforestry system than sole crop. The study concluded higher fertility of the soil due to higher activity of β- glucosaminidase which leads to high levels of N mineralization in the agroforestry system.

Yadav *et al*. (2011) studied enzyme activities in *Prosopis cineraria, Dalbergia sissoo, Acacia leucophloea* and *Acacia nilotica* based agroforestry system at farmer's field in Jaipur District, Rajasthan, India. The results showed higher dehydrogenase and alkaline phosphatase activities in *Prosopis cineraria* based agroforestry system compared with sole cropping and supported the fact that trees in croplands provides contributive conditions for balanced functional diversity.

Tian *et al*. (2013) carried out an experiment to study the effect of agroforestry practices on soil enzymatic activity at different depths in *Ginkgo biloba, Camellia sinensis* (tea) based agroforestry systems. The study reported significantly higher enzymatic activity in Ginkgo–tea based agroforestry system than in the monoculture tea system. Higher enzyme activity was also correlated with soil organic C, total N and was influenced by agroforestry practices.

Wang and Cao (2013) reported increased soil microbial biomass carbon, microbial quotient, soil basal respiration, microbe numbers and enzyme activities in tree-crop combinations of Ginkgo (*Ginkgo biloba*) trees mixed with tea (*Camelia sinensis)* as compared to sole plantation. The activity of dehydrogenase enzyme increased from 33.3 to 42.6 µg TPF g^{-1} dry weight soil per 24 h and acid phosphatase activity increased from 106.4 to 127.8 µg p-nitrophenol g^{-1} dry weight soil h^{-1} due to agroforestry system.

Farooq *et al.* (2021) investigated intercropping of *Arachis hypogaea* (peanut) with tea plant *Camellia oleifera* and compared with mono-cropping of tea and peanut. Results reported significant impact on soil enzymatic activities sucrase, protease, urease, and catalase at different soil depths (0–10 cm, 10–20 cm, 20–30 cm, and 30–40 cm) under intercropping. The study concluded that an increase in the soil enzymatic activity in the intercropping pattern improved the reaction rate at which organic matter decomposed and released nutrients into the soil environment.

2.5 Economic evaluation of fruit-tree based agroforestry systems

Mendoza (1987) observed that the agri-horticultural system involving ber and mango as principal crops fetch high return of Rs. 3,000 on an average per annum under dryland conditions. Kumar (1996) conducted a study on bioeconomic appraisal of agroforestry systems in Himachal Pradesh and found that agrihorticulture system registered highest net returns followed by agrihortisilviculture, agrisilviculture and minimum in sole cropping.

Fan *et al.* (2000) studied crop yield and economics in intercropping system of apples (*Malus spp*.) planted in 1992 at 3×4 m spacing, and ginger (*Zingiber officinale*) on Taihang Mountain in Shanxi Province, China. The study reported 3 times more income from the apple tree and ginger intercropping system as compared with apple orchard alone.

Bhatt and Misra (2003) conducted the study in northeast Indian state of Meghalaya and reported that the guava and Assam lemon based agri horticultural agroforestry systems (i.e., farming systems that combine domesticated fruit trees and forest trees) gave 2.96 and 1.98-fold higher net return respectively. Average net monetary benefit to guava-based agroforestry systems was Rs.20,610/ha (US$ 448.00) and (Rs 13,787.60/ha or US$ 300.00 to Assam lemon-based agroforestry systems. Such systems are most useful livelihoods improvement strategies in the rain fed agriculture of Meghalaya.

Kareemulla *et al.* (2003) conducted experiments on aonla +black gram agroforestry system, as compared to pure aonla and pure black gram under rainfed condition. Economic analysis in terms of cost and returns, payback period and internal rate of return showed favourable results, in respect of aonla+crops system over a 11-year period. Thus, it was found that instead of going in either for pure grain crops, if the farmer in rainfed area goes for agroforestry systems, higher returns are possible.

Kumar *et al.* (2004) studied the net present value for the different agroforestry models on six years rotation in Haryana varied from Rs. 26626 to Rs. 72705 ha/yr, whereas the benefit-cost ratio and the internal rate of return varied from 2.35 to 3.73 and 94 to 389 per cent, respectively. Thus, agroforestry has not only uplifted the socioeconomic status of the farmers but also contributed towards the overall development of the region.

Tomar and Bhatt (2004) conducted a field experiment in a six-year-old plantation of guava (*Psidum guajava* cv. Allahabad safeda), Assam lemon (Citrus lemon [*Citrus limon*] cv. Local) and peach (*Prunus persica* cv. TA 170) during 2002 and 2003, on acid alfisol under rainfed conditions in Umiam, Meghalaya, India, to study the performance of upland rice cultivars as intercrops in the existing fruit plantation and to study the overall productivity of agri-horticulture systems. Their study reported that maximum net monetary benefit per hectare was recorded from peach intercropped with rice (Rs. 48 044), followed by guava (Rs. 27 887) and Assam lemon (Rs. 20 991), irrespective of rice cultivars. Peach, guava and Assam lemon exhibited 5.09-, 2.95- and 2.22- fold higher net return, respectively, compared to the control. Peach-based agroforestry system was found promising for rainfed agricultural conditions in the northeastern region of India in general and Meghalaya in particular.

In another study of wheat varietal response to different nitrogen levels in agri-horticultural system under rain fed condition involving peach tree (Verma *et al.* 2004) reported that net returns from agri-horticultural system were higher (Rs. 43,424.14) compared to sole crop (Rs. 26,876.73) at 100 kg/ha nitrogen level and the use of productive wheat cultivar HD-2380.

Lal *et al.* (2005) carried out field experiment during 1998-2003 to determine the economic viability of an agroforestry-based system in Allahabad district, Uttar Pradesh, India. The rabi (*Cicer arietinum* and *Vigna mungo*) and kharif (green gram *V. radiata*) crops were intercropped for utilization of interspace of papaya. The authors observed that the cultivation of papaya+crop was comparatively more profitable than the traditional cultivation (sole papaya and sole pulse crop). The cost-benefit ratio showed that the papaya+crop at discounted prices were highest (3.79) in the agroforestry system under irrigated conditions followed by sole papaya crop (2.65).

Sharma *et al.* (2008) studied the economics of kinnow based agroforestry system with wheat and gobhi- sarson in Himachal Pradesh. Average yields (q/ha) of wheat (18.68) and gobhi-sarson (10.34) under kinnow plants were less in comparison to that of wheat (22.34) and gobhi-sarson (12.00) grown in open. However, overall return from agrihorticulture system was higher in comparison to sole crops. Cultivation of gobhi-sarson with kinnow was observed to be more profitable than wheat. The maximum returns per hectare (Rs. 56407.55) were realized under kinnow-gobhi-sarson combination.

Das *et al.* (2011) performed an intercropping trial in six-year-old aonla (*Phyllanthus emblica* cv. NA-7) orchard planted at 6 x 6 m spacing under rainfed conditions to determine the suitable remunerative intercrops. Economic analysis of the system in terms of benefit cost ratio revealed that aonla + turmeric was the most lucrative (6.29) followed by aonla + ginger (3.44) and aonla + arbi (3.20).

Hossain *et al.* (2015) carried out an experiment with four tomato varieties (BARI Tomato 2, BARI Tomato 8, BARI Tomato 14 and BARI Tomato 15) under a six-year-old guava, mango, and olive orchard at the Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU) research farm during October 2011 to April 2012. The economic performance of fruit tree-based tomato production system revealed higher net returns and benefit-cost ratio in mango and guava-based system over olive-based system and control.

Verma *et al.* 2020 studied tree-crop association of agri-horti-silviculture system and economic return of the system. The results reported higher gross returns and net returns in Grewia + Almond + Wheat than Morus + Almond + Wheat. The increase in net returns was 2.69 times more in Grewia + Almond + Wheat association with 25 per cent higher nitrogen level than the recommended dose over the sole wheat crop. Cost: benefit ratio values were higher at this nitrogen level for Grewia + Almond + Wheat compared to sole wheat.

Rahman *et al.* (2021) evaluated the performance of radish, sweet gourd and mustard leaf cultivation under mango fruit tree-based agroforestry system to increase the production of vegetables by using the fallow land under mango garden and to increase income of the farmers in char areas of Jamalpur and Sherpur. The study supported more profit in radish cultivation under agroforestry systems than other winter vegetables cultivation.

Chapter-3

MATERIALS AND METHODS

The present investigation entitled "**Ecological and Economical Appraisal of Apple based Agroforestry Systems in Kullu Valley of Himachal Pradesh**" was carried out at apple orchards of Sh. Dinanath, Bhindi Bai Village, Bajaura, Kullu during the year 2021. Laboratory studies were conducted at College of Horticulture and Forestry, Neri, Hamirpur. The details of the experiment are as under:

3.1. EXPERIMENTAL SITE

3.2. EXPERIMENTAL DESCRIPTION AND METHODOLOGY

3.3. STATISTICAL ANALYSIS

3.1 EXPERIMENTAL SITE

3.1.1 Location

The present studies were conducted at agricultural farm of Sh. Dinanath, Bhindi Bai Village, Bajaura, Kullu where agricultural crops *viz.,* tomato, brinjal, capsicum and black gram were grown in and outside the eleven-year-old apple orchard. The experimental farm is located at 31.85° N and 77.08° E with an elevation of 1600 m above mean sea level. The location map of the study site is given in Figure 3.1.

3.1.2 Climate

The study area falls in temperate mid hill zone of Himachal Pradesh, India. December to January months are mostly dry and cold. Heavy frost occurs during these months accompanied with snowfall. The mean annual rainfall during the study period was about 80 cm and the minimum and maximum temperature remained 3 °C and 38.8 °C, respectively.

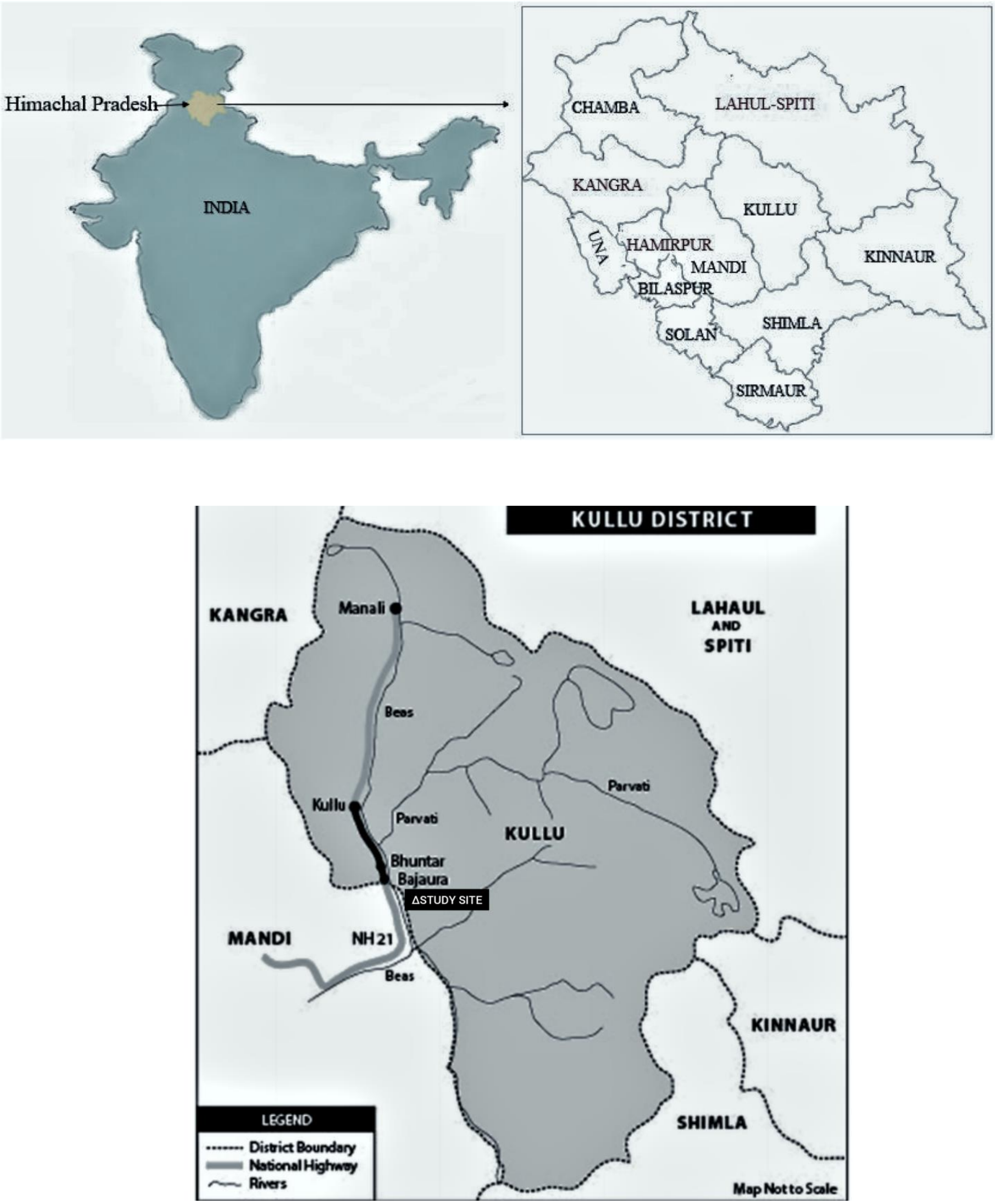

Fig. 3.1: Physical map showing different districts of Himachal Pradesh along with study site in Kullu district

3.2. EXPERIMENTAL DESCRIPTION AND MEHODOLOGY

The experimental details and methodology used are described as below:

3.2.1. Structural and functional components of the agroforestry systems

A. Tree species

Apple (*Malus domestica*)

Year of planting	:	2010
Spacing	:	7.5 m x 7.5 m
Age of trees	:	11 years
Variety	:	Royal delicious

B. Agricultural/Field crops

Tomato (*Lycopersicon esculentum* L.) var. Himsona

Spacing : 90 cm x 30 cm

Brinjal (*Solanum melongena* L.) var. Nisha

Spacing : 80 cm x 30 cm

Capsicum (*Capsicum annuum* L.) var. Indra

Spacing : 100 cm x 30 cm

Black gram (*Vigna mungo* L.) var. Kullu-4

Spacing : 30 cm x 100 cm

3.2.2. Experiment No. 1: To assess growth and yield of agricultural crops grown with and without apple trees

For comparison of growth and yield parameters of each crop grown under apple canopy and in open, the experiment was laid out as per detail given below;

Treatments

S_0	:	Sole agricultural crop (control)
S_1	:	Apple + Agricultural crop
Statistical tool	:	Student's 't' – test

3.2.3. Selection of plants for recording growth and yield

Five representative plots (2m x 2m) were laid out in the apple orchard and same number of plots outside the orchard as well. Five representative plants of agricultural crops per plot were selected randomly to record observations on growth and yield parameters and average was worked out for comparison under the two land use systems. Total number of plants per plot were also recorded.

A. Observations recorded

3.2.3.1. Number of plants per m^2

Total number of plants in 1 m^2 sampling plot were counted as expressed as number of plants per m^2.

3.2.3.2. Plant height (cm)

Plant height was measured from base to the tip of the leading shoot of the plant in cms.

3.2.3.3. Number of leaves per plant

Total number of leaves per plant were counted and data of five plants were averaged to work out number of leaves per plant.

3.2.3.4. Number of branches per plant

Number of branches per plant were recorded, by counting the branches present on the main stem.

3.2.3.5. Number of fruits per plant

Number of fruits per plant was recorded from five randomly selected plants and averaged to work out the number of fruits per plant.

3.2.3.6. Fruit length (cm)

Fruit length from 5 randomly selected fruits per plot was measured from base to tip of the fruit with the help of graduated scale and was averaged to work out fruit length in cm.

3.2.3.7. Fruit diameter (cm)

Fresh fruit diameter was determined in cm using vernier caliper.

3.2.3.8. Fruit/Seed yield (q/ha)

The fruit/seed harvested from all plants of the whole plot were weighed after each picking and their totals were summed up at the end for this purpose.

3.2.3.9. Number of pods per plant (Black gram)

Total pods of five plants per sampling plot were counted and averaged to obtain the number of pods per plant.

3.2.3.10. Pod length (cm)

Pod length was measured from base to tip of the pod with the help of graduated scale in cm.

3.2.3.11. Number of seeds per pod

Total ten pods selected randomly from five plants were measured and mean value was worked out.

3.2.4. Experiment No. 2: Estimation of carbon sequestration potential, economic returns and soil properties under different land uses

An experiment was conducted to assess carbon sequestration potential, economic returns and soil physico-bio-chemical properties under different land use systems as per detail given below:

Treatments	:	9
T1	:	Apple
T2	:	Tomato
T3	:	Brinjal
T4	:	Capsicum
T5	:	Black gram
T6	:	Apple + Tomato
T7	:	Apple + Brinjal
T8	:	Apple + Capsicum
T9	:	Apple +Black gram
Replication	:	3
Statistical Design	:	RBD

To assess carbon sequestration potential, one tree per replication of apple and five plants of agricultural crops per plot (2m x 2m) under treatments (T2 to T9) were selected randomly to work out the biomass per plant and biomass per ha. Each plot served as one replication.

For soil properties, composite samples were prepared by mixing soil taken from three representative sites under each treatment which served as one replication. Nine composite samples were collected per replication and total 27 for nine treatments at 0-15 cm and 27 samples at 15-30 cm depths.

A. Observations recorded for Apple tree

3.2.4.1. Tree height (m)

Tree height from base to tip of the tree was measured with the help of wooden rod and expressed in meters.

3.2.4.2. Tree diameter (cm)

Tree diameter was measured in cm at breast height i.e., 1.37m above the ground level with the help of tree caliper.

3.2.4.3. Estimation of tree biomass

The non-destructive method was used to estimate biomass of standing trees employing volume equations developed for specific tree species for specific region (FSI, 1996). The stem volume calculated by volume equation for apple tree was as follows:

$$\mathbf{V = 0.193297 - 2.267002D + 10.679492D^2}$$

Where V= Volume,

D= Diameter

Stem biomass was calculated by multiplying the stem volume with wood density.

$$\textbf{Stem biomass (t ha}^{-1}\textbf{) = VOB x WD}$$

Where, VOB = Volume Over Bark

WD = Wood Density

The wood density *viz.* 0.61 for *Malus domestica* (Apple) was used as recommended by FAO (1997).

3.2.4.4. Above ground biomass

The above ground biomass of trees (stem + leaves + branches) was calculated by multiplying biomass of stem with a biomass expansion factor as suggested by IPCC (2006).

$$\textbf{Above ground biomass (t ha}^{-1}\textbf{) = Stem biomass (t ha}^{-1}\textbf{) x BEF}$$

Where, BEF = biomass expansion factor

The biomass expansion factor i.e., 1.50 was used for apple tree as per Brown and Lugo (1992).

3.2.4.5. Below ground biomass

Below ground biomass of the tree species is calculated by multiplying its above ground biomass with the root: shoot ratio. Due to unavailability of the root: shoot ratio, a standard factor of 0.20 (IPCC, 2006) was used. The sum of above ground and below ground biomass was taken as total biomass of the tree.

3.2.4.6. Crown spread/ crown diameter (m)

The crown spread was measured in meters by holding tape beneath the canopy of the tree at points vertically under the tips of most extending branches from east to west and north to south directions. The average of the two was taken as crown spread.

$$\mathbf{CS = \frac{D_1 + D_2}{2}}$$

Where,

CS= Crown Spread

D_1= Crown spread in N-S direction (m)

D_2= Crown spread in E-W direction (m)

3.2.4.7. Crown volume (m^3)

The volume occupied by canopy was estimated by the formula given by Avery and Burkhart, 2002 as:

$$\textbf{Crown volume } (\mathbf{m^3}) = \frac{\pi Db^2 L}{12}$$

Where,

Db= Diameter (m) at crown base

L= Crown length (m)

3.2.4.8. Fruit yield (kg per plant)

Fruit yield was recorded during harvesting by weighing the total number of fruits on each plant and expressed in kg per plant on fresh weight basis.

3.2.5. Agricultural crop biomass

Five plants of agricultural crop per plot (2m x 2m) under treatments (T2 to T9) were selected randomly to work out the biomass per plant and biomass per ha.

3.2.5.1. Above and below ground biomass per plant of agricultural crops

The biomass production of different agricultural crops was determined by excavating five plants from 2m x 2m quadrat replicated three times for treatment (T_2 to T_9). Total harvest method was carried out by digging out the crop plants along with the roots. The soil was gently removed by tapping. All crop samples were then washed to completely remove the soil particles and were stored properly. Roots and shoot(s) of plants were separated and oven dried at 70°C till a constant weight was achieved. The dried samples of root and shoot were weighed to determine above ground and below ground biomass of each crop.

3.2.5.2. Carbon stock

Carbon stock per ha was worked out by multiplying biomass per ha with 0.5 in case of trees (IPCC, 2006) and with 0.45 in respect of agricultural crops (Woomer, 1999).

3.2.6. Economic Analysis

Economic appraisal of different tree-crop combinations and sole crops was done for comparison and selecting the best combination for recommendation to the farmers. Cost of cultivation, gross and net returns per ha were calculated on the basis of prevailing market prices at the time of termination of the experiment.

3.2.6.1. Cost of cultivation (Rs.)

Explicit costs of cultivation for apple and the intercrops were recorded throughout the time of the investigation. The cost items such as seeds, manures, fertilizers, ploughing, weeding, stacking materials, harvesting, grading, packing and transportation etc. were calculated based on the prevailing local prices.

3.2.6.2. Gross returns (Rs.)

The prevailing local market prices were used to convert yield of field crops and apple fruits into gross returns per ha. Gross returns were obtained by multiplying the quantity of produce with the prevailing prices per unit in the market.

3.2.6.3. Net returns (Rs.)

Net returns were worked out by subtracting the cost of cultivation from the gross returns.

$$\textbf{Net returns ha}^{-1} = \textbf{Gross returns ha}^{-1} - \textbf{Cost of cultivation ha}^{-1}$$

3.2.6.4. Benefit: Cost ratio

Ratio of the gross returns per rupee invested was calculated as per following formula:

BCR= Gross returns/ Total cost of cultivation

3.2.7. Soil properties

3.2.7.1 Collection and preparation of soil samples

Composite soil samples from each sampling plot (treatment) were collected separately at 0-15 cm and 15-30 cm depths with the help of post hole auger. The collected samples were placed in cloth bags, tagged and transported to laboratory. The samples were air dried, crushed thoroughly, passed through 2 mm sieve and analyzed for various soil parameters listed below:

Table 3.1: Methods employed to estimate soil properties

S. No.	Parameters	Method employed	Reference
Physico-chemical properties			
1.	Bulk Density (g cm^{-3})	The weight of oven dried soil filled in Pycnometer by gentle tapping divided by its volume.	----
2.	Particle Density (g cm^{-3})	Pycnometer method	----
3.	Porosity (%)	One minus ratio of bulk density to particle density and multiplied by 100	----
4.	Soil Moisture Content (%)	Gravimetric method	Reynolds (1970)
5.	Organic Carbon (%)	Rapid titration method	Walkley and Black (1934)
6.	Soil pH	Potentiometric method	Jackson (1973)
7.	Electrical Conductivity (dS/m)	Conductimetric method	Jackson (1973)
8.	Available Nitrogen (kg ha^{-1})	Alkaline potassium permanganate method	Subbiah and Asija (1956)
9.	Available Phosphorus (kg ha^{-1})	Olsen's method	Olsen *et al.* (1954)
10.	Available Potassium (kg ha^{-1})	Neutral 1 N ammonium acetate solution method	Merwin and Peach (1951)
Biological properties			
11.	Microbial C (*C* mic)	Fumigation extraction method	Vance *et al.* (1987)
12.	Microbial N (*N* mic)	Fumigation extraction method	Brookes *et al.* (1985)
13.	Microbial P (*P* mic)	Fumigation extraction method	Brookes *et al.* (1982) Srivastava and Singh (1988)
14.	Flux of C, N, P	-	Brookes *et al.* (1982); Jenkinson and Ladd (1981)
15.	Dehydrogenase Assay	Thalmann method (TTC method)	Casida *et al*. (1964).
16.	Acidic Phosphatase Assay	p-nitrophenyl phosphate method	Tabatabai and Bremner (1969)
17.	Alkaline Phosphatase Assay	p-nitrophenyl phosphate method	Tabatabai and Bremner (1969)

18.	Catalase Assay	Titration method	Zhou *et al.* (2011)

3.2.7.2 Microbial biomass

Microbial biomass C (*C*mic), N (*N*mic) and P (*P*mic) were determined using the fumigation extraction methods by Anderson and Ingram (1989). The soil samples were fumigated using chloroform ($CHCl_3$) in desiccators and were stored in the dark room for 24 h as suggested by Srivastava and Singh (1988).

Two sets of 10 g soil samples were taken in 50 ml beakers. One set was stored in refrigerator and second set was used for fumigation in a vacuum desiccator. Around 40 ml of chloroform was taken in a separate beaker and placed at the center of the desiccator. The lid of the desiccators was sealed with grease connected with vacuum pump and kept on. Next day, the vacuum was released and performed back suction to remove excess chloroform. Both fumigated and non-fumigated soil samples were transferred in conical flask and 25 ml of 0.5 M K_2SO_4 was added. The flasks were shaken for 30 minutes and filtered with Whatman filter paper to obtain soil extract.

3.2.7.2.1 Microbial biomass carbon:

*C*mic was measured by modified Vance method: Eight ml of the filtered extract and 2 ml of $K_2Cr_2O_7$ (66.7 mM), and 15 ml of a mixture containing 2 parts H_2SO_4 and one-part H_3PO_4 were taken in a 500 ml conical flask. Blank containing 10 ml distilled water was run and kept on hot plate for 30 minutes. The mixture was boiled for 30 min, cooled and diluted with 20- 25 ml water. The residual dichromate was measured by back titration with 0.4 M ferrous ammonium sulphate solution using 25 mM 1, 10 phenanthroline to indicate colour change from purple to green. The amount of dichromate consumed was that remained in a blank digestion with 8 ml 0.5 M K_2SO_4 (hot blank), less that remaining in the digest of the extract. Extractable C was calculated assuming that 1 ml 66.7 mM (0.4 N) $K_2Cr_2O_7$ is equivalent to 1200 µg C.

C (µg ml^{-1}) = (Hbl - S) x N x Q/A x B x 1000

Where: Hbl = titration solution consumed by hot blank,

S = titration solution consumed by sample,

N = normality of $K_2Cr_2O_7$ = 0.4,

Q = quantity of $K_2Cr_2O_7$ = 2 ml,

A = aliquot quantity = 8 ml,

B = 3 = conversion of Cr VI to Cr III,

1000 = to change into µg

gives: Hbl - S/ 3.33 x 10^{-5}

$$C\ \mu g\ g^{-1}\ OD\ soil = C\ (\mu g\ ml^{-1}) \times \frac{EX + MC}{DWt\ soil}$$

where: EX = quantity of extractant,

MC = moisture content of soil used,

DWt = dry weight of soil used

Biomass carbon was calculated from: C = 2.64 (EC_F- EC_{NF})

where EC = the difference between the carbon extracted from the fumigated sample and the carbon extracted from the non-fumigated sample.

3.2.7.2.2 Microbial biomass N:

*N*mic in the extract was measured by microKjedahl digestion method as suggested by Bremner and Mulvaney (1982). Thirty ml of K_2SO_4 extracts was taken into digestion tube and refluxed for 3 h. The extract was set aside for cooling and further 20 ml water was added to tubes. Again 25 ml of 10 M NaOH was added to the tubes, slowly, taking care to mix thoroughly after each addition of alkali. The samples were steam distilled into a titration vessel containing 5 ml 2% boric acid which adsorbs the evolved NH_3, until 40 ml of distillate had been collected. The solutions were titrated to pH 4.7 with 50 mM H_2SO_4 using a standard burette. Total N extracted was calculated by following equation:

N (µg g^{-1} od soil) = (Vs-Vb) x M x At x 1000 x 0.15/W

Where: Vs = volume H_2SO_4 used to titrate the sample

Vb = volume H_2SO_4 used to titrate the blank

M= the molarity of H_2SO_4= 0.05

At = Atomic weight of Nitrogen = 14

1000 to convert into micrograms.

0.15= the fraction of extractant used for the titration (i.e.) 30/200

W= K_2SO_4 extractant + Soil moisture content/ Oven dried weight of soil

Biomass Nitrogen was calculated as:

$$BN = F_N / kN$$

Where: F_N= the N mineralised from the biomass =Fumigated N - NON fumigated N

$$kN = 0.54$$

3.2.7.2.3 Microbial biomass P:

Measurement of Pmic was also done in preconditioned soil samples as suggested by Brookes *et al*. (1982). Soil was fumigated in the same way as that of *C*mic estimation. *P*mic was calculated from the difference between the amount of inorganic P (Pi) from fumigated and unfumigated soil. Inorganic-P (Pi) in the extracts was determined by ammonium-molybdate-staneous chloride method given by Olsen *et al.* (1954) in which 50 ml bicarbonate extractant and 1 g of Darco-G-60 was added to 1 g soil in a 100 ml conical flask. Further, it was kept on a shaker and filtered. Five ml of this filtrate was taken in a 25 ml conical flask and added 5 ml of molybdate reagent and diluted it to about 20 ml with distilled water. At the end, 1 ml working solution of stannous chloride was added and volume was made to 25 ml by adding distilled water. Color intensity was measured at 660 nm wavelength. Pmic was then computed as the ratio of $CHCl_3$ release Pi with a *kp* value of 0.40 as suggested by Brookes *et al.* (1982) and Srivastava and Singh (1988) by assuming that 40% of the Pi in the soil microbial biomass was made extractable as Pi by $CHCl_3$.

3.2.7.3. Nutrient Flux

Flux of C, N and P through the microbial biomass was calculated by the formula given by Brookes *et al.* (1984) by assuming a turnover time of 1.25 years as suggested by Jenkinson and Ladd (1981).

C, N and P flux (kg ha^{-1} $year^{-1}$) = Biomass C, N or P (kg ha^{-1})/Turnover time (1.25).

3.2.7.4. Soil enzymes

3.2.7.4.1 Dehydrogenase activity

Soil dehydrogenase activity was measured by the method given by Casida *et al*. (1964). In the method, 1 g of soil sample was taken into test tube, added 0.5 ml of glucose and 1 ml of 3% 2, 3, 5-triphenyl tetrazolium chloride (TTC) solution. The samples were incubated at 37 °C for 24 h. After incubation, the product of hydrolytic reaction was extracted from samples with methanol. The tubes were shaken well and the filtrate was collected. The color intensity of pink colored supernatant was taken with spectrophotometer at 485 nm and production of triphenyl formazan (TPF) was measured. Dehydrogenase activity was measured from the calibration curve of TPF and results were expressed as TPF formed per h per g soil.

3.2.7.4.2 Acid and alkaline phosphatase

The assay of alkaline phosphatase was carried out according to the method of Tabatabai and Bremner (1969) with MUB buffer of pH 6.5 for acid phosphatase and MUB buffer of pH 9.5 for alkaline phosphatase using p-nitrophenyl phosphate disodium salt as substrate. One gram of air-dried soil was taken in a test tube and to this, 0.2 ml toluene, 4 ml MUB buffer and 1 ml p-nitrophenyl phosphate solution were added. The samples were incubated at 37 °C for 1 h. The reaction was stopped by adding 4 ml of 0.5 M NaOH and 1 ml of 0.5 M $CaCl_2$ and filtered to prevent interference from possible precipitates. The yellow color intensity was measured at 440 nm. The phosphatase activity was expressed as amount of p-nitrophenol released per minute per gram of dry soil.

3.2.7.4.3 Catalase activity

Catalase activity was measured by incubating 5 g soil with 5 ml 0.3 % H_2O_2 for 30 min at 30 °C. The suspension was titrated with 0.1 mol L^{-1} $KMnO_4$ solution. Activity was expressed as 0.1 mol L^{-1} $KMnO_4$ ml g^{-1} soil 30 min^{-1}, as done by Zhou *et al*. (2011).

3.3 STATISTICAL ANALYSIS

The data originated from the present studies were statistically analyzed by employing analysis of variance (ANOVA) for Randomized Block Design (RBD) in accordance with the procedure suggested by Gomez and Gomez (1984). Where effects exhibited significance at 5 per cent level of probability, critical difference (CD) was calculated. The growth and yield data of agricultural crops grown under apple and in open was compared and the significance was ascertained employing Student's t - test.

Table 3.2: Skeleton for analysis of variance (ANOVA)

Sources of variation	**Degrees of freedom**	**Sum of squares**	**Mean sum of squares**	**F_{cal}**
Replication	(r-1)	SS_R	SS_R/(r-1) = MSR	MSR/MSE
Treatment	(t-1)	SS_t	SS_t/(t-1) = MS_t	MS_t/MSE
Error	(r-1)(t-1)	ESS	ESS/(r-1)(t-1) = MSE	
Total	(rt-1)	TSS		

Chapter-4

RESULTS AND DISCUSSION

The present study entitled "**Ecological and Economical Appraisal of Apple based Agroforestry Systems in Kullu Valley of Himachal Pradesh**" was carried out during the year 2021 in apple orchards at Bhindi Bai Village, Bajaura, Kullu. The study was aimed at determining the effect of apple trees on growth and yield parameters of agricultural crops and also the effect of agroforestry systems on the physico-bio-chemical properties of soil besides studying the carbon sequestration potential and economics of the systems. The results thus, obtained are described under the following heads:

4.1 Growth and yield parameters of agricultural crops grown under agroforestry and in sole cropping system

4.1.1. Growth and yield parameters of tomato (*Lycopersicon esculentum* L.)

4.1.2. Growth and yield parameters of brinjal (*Solanum melongena* L.)

4.1.3. Growth and yield parameters of capsicum (*Capsicum annuum* L.)

4.1.4. Growth and yield parameters of black gram (*Vigna mungo* L.)

4.2 Growth and yield parameters of apple tree (*Malus domestica*)

4.3 Carbon sequestration potential of apple-based agroforestry systems

4.4 Bio-economics of apple-based agroforestry systems

4.4.1. Cost of cultivation

4.4.2. Gross returns

4.4.3. Net returns

4.4.4. Benefit: Cost ratio

4.5 Effect of agroforestry systems on soil physico-chemical properties

4.6 Effect of agroforestry systems on soil biological properties

4.1 Growth and yield parameters of agricultural crops grown under agroforestry and in sole cropping system

4.1.1. Growth and yield parameters of tomato (*Lycopersicon esculentum L.*)

The data pertaining to the growth and yield parameters of tomato (*Lycopersicon esculentum* L.) grown in open and under apple (*Malus domestica*) trees are presented in Table 4.1.

4.1.1.1. Number of plants per m^2

The data presented in Table 4.1 revealed that the mean number of tomato plants per m^2 was highest (4.02) in open conditions compared to the number of plants recorded under apple-based agroforestry system (3.20). The difference between the mean number of tomato plants per m^2 in sole and under apple trees was statistically significant.

4.1.1.2. Plant height (cm)

The plant height of tomato was found to be increased significantly under trees as compared to that of the crop grown in open (Table 4.1). The maximum plant height (152.79 cm) was observed under apple trees and the minimum in sole crop (150.18 cm).

4.1.1.3. Number of branches per plant

The mean number of branches per plant was higher under tree canopy (12.78) than in open (11.68). The difference between the mean number of branches per plant of tomato grown as solecrop and under apple was statistically significant (Table 4.1).

4.1.1.4. Number of leaves per plant

The mean number of leaves per plant of tomato recorded under apple (47.48) was statistically alike to that observed in open (44.32).

4.1.1.5. Number of fruits per plant

The mean number of fruits per plant under tree canopy (8.26) was higher and statistically significant over the mean number of fruits per plant (7.64) registered in tomato grown in open.

4.1.1.6. Fruit length (cm)

The fruit length (5.20 cm) of tomato recorded under apple tree was more than that observed in open compared to open (4.75 cm) and the difference between the two was statistically significant.

4.1.1.7. Fruit diameter (cm)

Alike fruit length, fruit diameter was also found more in the tomato plants grown under apple over open crop and the difference was also statistically significant.

4.1.1.8. Fruit yield (q per ha)

Significantly higher fruit yield of tomato (118.86 q per ha) was observed under apple in comparison to open (115.24 q per ha).

Table 4.1: Growth and yield parameters of tomato under apple trees and in sole cropping system

Parameters	Treatment		T_{cal} at 5 %	Significance
	Sole Tomato	Apple + Tomato		
No. of plants per m^2	004.02	003.20	7.68	S
Plant height (cm)	150.18	152.79	4.42	S
No. of branches per plant	011.68	012.78	4.82	S
No. of leaves per plant	044.32	047.48	2.75	NS
No. of fruits per plant	007.64	008.26	11.49	S
Fruit length (cm)	004.75	005.20	3.37	S
Fruit diameter (cm)	004.84	005.08	3.41	S
Fruit yield (q/ha)	115.24	118.86	5.69	S

The results indicated that most of the growth and yield parameters of tomato were found to be significantly affected under the apple tree canopy. The growth parameters except number of leaves per plant, were significantly higher under agroforestry system over the open system. Likewise, the yield parameters were also statistically superior under agroforestry system over the open system.

Tomato cultivation in the kharif season as apple inter-crop was found to be successful. The data showed maximum plant height inside the canopy as compared to the open control. The yield parameters such as number of fruits per plant and fruit yield per plant were also higher. The reason for higher yield of tomato under apple canopy can be ascribed to the shade tolerant nature of tomato crop (Agena, 2009). Similar results were also reported on ginger-apple inter-cropping by Zhang JinSong *et al.* (2001) in China. The study reported 34 per cent increase in ginger yield over the sole crop which suggested that crop yields in tree-based agroforestry systems can be increased if shade-tolerant species are planted as under crops. Similar results were also reported by Chandra (2014) who registered increase in plant length and yield of *Curcuma longa* and *Amorphophallus paeonifolius* as intercrops under guava. Singh (2007) also reported that plant height of *Ocimum sanctum* was higher in agroforestry combinations than the sole crop. Islam *et al.* (2013) too recorded the higher growth and yield of misridana, turmeric, ginger, onion and chilli under guava and sissoo based agroforestry system.

4.1.2. Growth and yield parameters of brinjal (*Solanum melongena* L.)

The data pertaining to the growth and yield parameters of brinjal (*Solanum melongena*) grown in open and under apple (*Malus domestica*) trees are presented in Table 4.2.

4.1.2.1. Number of plants per m^2

The results revealed less average number of brinjal plants per m^2 under apple trees (Table 4.2). The average number of plants per m^2 (4.16) was higher under sole cropping and lower under apple trees (3.90). However, the difference between the average number of brinjal plants per m^2 under both land uses was statistically significant.

4.1.2.2. Plant height (cm)

Taller plants of brinjal were noticed under open conditions (80.64 cm) as compared to those under apple trees (78.70 cm). Significant difference was noticed in means of height of brinjal plants grown in open and under trees.

4.1.2.3. Number of branches per plant

The mean number of branches per plant of brinjal (11.48) recorded more in the sole brinjal crop and lesser (10.72) under apple trees (Table 4.2). The difference between average number of branches per plant of brinjal observed under apple trees and in open was statistically significant.

4.1.2.4. Number of leaves per plant

Higher number of leaves per plant of brinjal i.e., 10.56 was recorded in open conditions compared to 10.12 number of leaves per plant under apple trees. The difference in the average number of leaves per plant was, however little and statistically non-significant.

4.1.2.5. Number of fruits per plant

Like number of leaves per plant, number of fruits per plant of brinjal was also recorded high in open conditions (4.87) which decreased under trees (4.48), however the difference was statistically significant.

4.1.2.6. Fruit length (cm)

Bigger sized fruits of brinjal in terms of length (14.92 cm) were observed in the sole brinjal crop over those recorded under apple trees (13.72). The mean fruit length of brinjal observed under apple trees was statistically inferior.

4.1.2.7. Fruit diameter (cm)

Diametric growth of brinjal was better in open grown crops (5.02 cm) over the crops raised underapple (4.92 cm) however the difference in diameter was statistically non-significant.

4.1.2.8. Fruit yield (q per ha)

The mean fruit yield was significantly reduced under the trees (Table 4.2). Mean fruit yield washigher (127.85 q per ha) in open conditions and the lower (122.74 q per ha) under apple trees.

Table 4.2: Growth and yield parameters of brinjal under apple trees and in sole cropping system

Parameters	Treatment		T_{cal} at 5 %	Significance
	Sole Brinjal	Apple + Brinjal		
No. of plants per m^2	04.16	03.90	3.59	S
Plant height (cm)	80.64	78.70	4.01	S
No. of branches per plant	11.48	10.72	3.97	S
No. of leaves per plant	10.56	10.12	0.86	NS
No. of fruits per plant	04.87	04.48	2.79	S
Fruit length(cm)	14.92	13.72	3.63	S
Fruit diameter (cm)	05.02	04.94	0.51	NS
Fruit yield (q/ha)	127.85	122.74	8.59	S

The results indicated that plant density of brinjal was significantly lower under apple trees. Some of the growth and yield parameters of brinjal were significantly and negatively affected under the apple tree canopy. The values for the growth parameters *viz.*, plant height and number of branches per plant were higher in open field conditions than those in the intercropped field. The growth parameter i.e., number of leaves per plant was also higher in sole cropping but the difference in mean values was non-significant. The yield parameters *viz.*, number of fruits per plant, fruit length and fruit yield per plant were found better and statistically significant in open conditions than in intercropping. Fruit diameter was also found higher in sole crop but the difference was non-significant.

Brinjal growth in the kharif season as apple inter-crop was not found much encouraging as higher values of growth parameters were observed in sole cropping than intercropping. It is due to the negative effect of apple canopy on the performance of intercrops i.e., competition for light, water and nutrients between the main crop and the intercrop. Similar findings by Raut and Jain (2013) mentioned that the brinjal grown in the open field as sole crop has better opportunities to reap more solar energy for photosynthetic activity, lesser intraspecific competition for critical resources like water, nutrients and photosynthetically active radiation. The favourable factors resulted in higher values of growth parameters in brinjal grown in the open field. The findings of present study are in line with the findings of Dhillon *et al.*, (1984), Chauhan (2000), Thakur and Singh (2002), Dalal (2014) and Bhat (2015). In addition, Prasad *et al.* (2010) reported reduction in yield under plantation due to shade and reduced photosynthetic rates, whereas, Chaturvedi and Jha (1998) found that root competition for water and nutrients was primarily responsible for yield decline at the tree crop interface in agroforestry.

4.1.3. Growth and yield parameters of capsicum (*Capsicum annuum* L.)

The data pertaining to the growth and yield parameters of capsicum (*Capsicum annuum*) grownin open and under apple (*Malus domestica*) trees are presented in Table 4.3.

4.1.3.1. Number of plants per m^2

The data revealed higher number of capsicum plants per m^2 under sole capsicum (3.30), while only 2.88 under apple + capsicum combination (Table 3). The value recorded for the number of plants per m^2 for sole capsicum crop was superior over the value recorded for the combination.

4.1.3.2. Plant height (cm)

The mean plant height (78.20 cm) of capsicum observed in open condition was higher than that recorded under apple trees (76.32 cm) which proved statistically inferior (Table 4.3).

4.1.3.3. Number of branches per plant

Lesser number of branches per plant of capsicum (10.86) were registered under apple trees as compared to open field conditions (12.60). The number of branches per plant recorded under apple was statistically inferior to that observed in open.

4.1.3.4. Number of leaves per plant

The values for number of leaves per plant varied significantly from 7.82 under apple + capsicum combination to 9.14 in open field conditions (Table 4.3).

4.1.3.5. Number of fruits per plant

Higher number of fruits per plant of capsicum i.e., 7.09 was recorded in open conditions which decreased to 6.18 under apple trees. The difference in the mean number of fruits per plant under the two was statistically significant.

4.1.3.6. Fruit length (cm)

The fruit length of capsicum was observed as 5.01 cm in the sole capsicum crop while 4.90 cm under apple trees (Table 4.3). The values observed under apple trees and in open were statistically non- significant.

4.1.3.7. Fruit diameter (cm)

The mean values of fruit diameter of capsicum ranged from 5.10 cm under apple trees to 5.80 cm in sole which were statistically significant (Table 4.3).

4.1.3.8. Fruit yield (q per ha)

Average fruit yield was 99.80 q per ha in open conditions and 96.27 q per ha under apple trees. The difference in the means of fruit yield was substantial and statistically significant.

TABLE 4.3: Growth and yield parameters of capsicum under apple trees and in sole cropping system

Parameters	Treatment		T_{cal} at 5 %	Significance
	Sole Capsicum	Apple + Capsicum		
No. of plants per m^2	03.30	02.88	8.73	S
Plant height (cm)	78.20	76.32	4.07	S
No. of branches perplant	12.60	10.86	7.59	S
No. of leaves per plant	09.14	07.82	6.57	S
No. of fruits per plant	07.09	06.18	12.04	S
Fruit length (cm)	05.01	04.90	1.00	NS
Fruit diameter (cm)	05.80	05.10	4.35	S
Fruit yield (q/ha)	99.80	96.27	5.75	S

The results of the present investigations revealed negative effect on growth and yield parameters of capsicum grown under apple trees over sole cropping. This could be ascribed to shade effect of the trees and competitions for limited resources *viz.*, soil moisture, nutrient etc. besides allelopathic effects of trees.

The recorded data showed that the number of plants per m^2, plant height, number of branches per plant, number of leaves per plant, number of fruits per plant, fruit diameter, fruit length of sole capsicum crop was significantly higher as compared to those under apple trees (Table 4.3). These results are in compliance with the findings of Rana *et al.* (2007) and Verma and Rana (2014) who witnessed reduction in yield of paddy and wheat under agroforestry system in comparison to the sole cropping. Kaushal and Verma (2003) have also reported negative impact of trees on growth and yield of the crop which were grown near to the tree trunks. Lower number of fruits per plant under relatively more and prolonged shaded conditions was probably due to poor photosynthetic activity of plants. The decreasing photosynthetic capacity of shaded plants was attributed to both stomata and mesophyll cell activities (Wolff, 1990). The present results supported by the findings of Rahman (2006) who found the highest number of fruits per plant of eggplant in open field over the crop grown under multistoried system.

4.1.4. Growth and yield parameters of black gram (*Vigna mungo* L.)

The data pertaining to the growth and yield parameters of black gram (*Vigna mungo*) grown in open and under apple (*Malus domestica*) trees are presented in Table 4.4.

4.1.4.1. Number of plants per m^2

The difference observed between the number of plants per m^2 of black gram intercropped with apple and in open field was statistically significant (Table 4.4). However, the mean number of plants per m^2 was higher in open system (11.12) as compared to black gram intercropped with apple (10.96).

4.1.4.2. Plant height (cm)

The data showed significant difference in plant height (cm) of black gram grown in open and under apple trees (Table 4.4). The mean plant height of black gram crop in open and under apple trees was 62.42 cm and 60.64 cm, respectively.

4.1.4.3. Number of branches per plant

The data revealed non-significant difference for number of branches per plant of black gram grown in open and under apple trees (Table 4.4). The average number of branches per plant of black gram crop in open and under apple trees were 5.44 and 5.40, respectively.

4.1.4.4. Number of leaves per plant

Remarkably higher number of leaves per plant (41.36) of black gram was recorded in sole cropping systems over apple + black gram (27.60) interface. Significant difference was noticed in the mean number of leaves per plant of black gram grown under apple and in open (Table4.4).

4.1.4.5. Number of pods per plant

Perusal of data exhibited significant difference in the number of pods per plant of black gram raised under agroforestry and in open system (Table 4.4). The mean number of pods per plant in black gram was higher (35.92) in sole as compared to that recorded under intercropping with apple (33.15).

4.1.4.6. Pod length (cm)

Significant difference was noticed for pod length of black gram grown under apple and in open system (Table 4.4). The mean pod length of black gram grown as intercrop with apple was lower (2.50 cm) over sole crop (2.86 cm).

4.1.4.7. Number of seeds per pod

The data revealed significant difference in number of seeds per pod of black gram grown as intercrop with apple and as sole crop (Table 4.4). The mean number of seeds per pod in intercropped black gram was however, lower (6.45) as compared to that of sole crop (7.79).

4.1.4.8. Seed yield (q per ha)

Analysis of the data presented in Table 4.4 revealed that seed yield was significantly higher (7.20 q per ha) in sole cropping of black gram in comparison to that intercropped with apple (5.27 q per ha).

Table 4.4: Growth and yield parameters of black gram under apple trees and in sole cropping system

Parameters	Treatment		T_{cal} at 5 %	Significance
	Sole Black gram	Apple+ Black gram		
No. of plants per m^2	11.12	10.96	7.18	S
Plant height (cm)	62.42	60.64	4.40	S
No. of branches per plant	05.44	05.40	0.15	NS
No. of leaves per plant	41.36	27.60	12.43	S
No. of pods per plant	35.92	33.15	3.56	S
Pod length (cm)	02.86	02.50	13.47	S
No. of seeds per pod	07.79	06.45	59.78	S
Seed yield (q/ha)	07.20	05.27	13.60	S

The results of the present investigations revealed that growth and yield parameters of black gram except number of branches per plant were found to be significantly and adversely affected under apple trees as compared to open conditions. This may be due to above and below ground interactions between trees and crops for limited resources *viz.*, soil moisture, nutrients etc. Besides, shade as well as allelopathic effects of trees which resulted in suppression of growth and ultimately yield of under storey crop. While in the open conditions i.e., without any interference and no competition with trees, black gram attained better growth resulting in higher production.

Similar results have been reported by Dinssa (1993) who reported better growth and higher yield of soybean, black gram, horse gram and cowpea under monocultures as compared to intercropping with *Morus alba*. Singh (2002) reported higher number of pods per plant in *Phaseolus mungo* and *Pisum sativum* under open conditions and reduction in number of pods plant with increase in canopy size of *Morus alba*. The results of the present investigation are also in line with the findings of Solaniappan *et al.* (2002), Thakur and Singh (2008), Tanni *et al*. (2010) and Kaur and Puri (2013). These researchers also observed higher growth and yield of field crops in open condition as compared to the crops grown under trees or close to tree trunk.

4.2 Growth and yield parameters of apple tree (*Malus domestica*)

The growth and yield parameters of apple grown as pure crop and under agroforestry systems were recorded. Results showed significant influence on fruit yield and crown volume of apple grown with and without field crops. However, no significant effect was observed on crown spread, diameter and tree height (Table 4.5).

Table 4.5: Growth and yield parameters of apple tree (*Malus domestica*)

Treatments ↓ / Parameters →	Tree height (m)	Diameter (cm)	Crown spread (m^2)	Crown volume (m^3)	Fruit yield/plant (kg)
Sole Apple	4.04	24.70	1.25	0.83	103.13
Apple + Tomato	3.97	23.53	1.51	1.00	106.16
Apple + Capsicum	3.99	23.27	1.38	1.02	103.37
Apple + Brinjal	4.00	23.33	1.44	1.04	104.47
Apple + Black gram	3.96	22.90	1.41	1.15	107.16
SE(d)	0.07	00.62	0.09	0.07	000.45
$CD_{0.05}$	NS	NS	NS	0.16	103.13

The crown volume of apple was found to be affected significantly under agroforestry systems (Table 4.5). Though the highest value of crown volume (1.15 m^3) was observed in apple trees in combination with black gram yet it was statistically alike to the values recorded under all the tree-crop combinations except under sole apple trees where the difference was significant from statistical analysis point of view. Better growth and fruit yield of apple under apple-based agroforestry system is attributed to better intercultural operations and additional inputs applied to the intercrops than in sole plantation (control). Addition of leaf biomass to the soil and their further decomposition in the soil must have favoured better source-sink relationship, resulting in increased fruit yield under apple-based agroforestry system. Positive influence of crop sequences on yield of perennial crops have also been reported by Dhyani and Tripathi (1999), Gill *et al.* (2000), Bhatt and Mishra (2003), Awasthi *et al.* (2009), Arya *et al.* (2010), Negi *et al.* (2013) and Patle *et al.* (2016).

4.3 Carbon sequestration potential of apple-based agroforestry and sole crop systems

Significant variation was observed among the different tree-crop combinations and sole crops with respect to total biomass and total carbon stock of the systems (Table 4.6). Sole cultivation of agricultural crops had less total biomass and total carbon stock as compared to that of tree-crop associations. However, the highest total biomass (44.05 t per ha) was recorded under apple + tomato and lowest (1.75 t per ha) in case of sole black gram cropping. Like biomass, total carbon stock was also maximum (21.73 t per ha) in apple + tomato and minimum (00.79 t per ha) in case of black gram in open field conditions. All the treatments registered significant difference over one another with regard to total biomass and total carbon stock.

Combination of apple with different agricultural crops showed higher biomass and carbon stock over sole cropping. This may be due to judicious use of space by apple trees and understorey crops in agroforestry systems as compared to sole cropping system. This is consistent with the findings of Tomich *et al.* (2002) and Yadav and Bisht (2014). Benbi *et al.* (2012) and Jose and Bardhan (2012) who reported higher biomass and total carbon stock of agroforestry systems over annual cropping systems. Cultivating agricultural crops with fruit tree plantation, therefore, is an attractive option for storage of atmospheric CO_2. Yadav *et al.* (2015)

also reported that fruit tree-based land use systems in Indian Himalayas have higher potential for carbon stocking and atmospheric carbon sequestration.

Table 4.6: Carbon sequestration potential of apple-based agroforestry and sole crop systems

Tree-crop combination (Treatment)	Total Biomass of the System (t/ha)	Total Carbon Stock of the System (t/ha)
Sole Apple	39.76	19.88
Tomato	05.71	02.56
Brinjal	04.95	02.23
Capsicum	04.34	01.95
Black Gram	01.75	00.79
Apple + Tomato	44.05	21.73
Apple + Brinjal	43.29	21.39
Apple + Capsicum	42.68	21.12
Apple + Black Gram	40.09	19.95
$CD_{0.05}$	00.04	00.02

4.4 Bio-economics of apple-based agroforestry system

The economics of apple-based agroforestry systems integrating tomato, brinjal, capsicum and black gram as intercrops as well as sole crops have been worked out by calculating cost of cultivation, gross returns, net returns and benefit cost ratio to know the economic feasibility of different land uses. The data pertaining to the bio-economics of the agroforestry systems are presented in Table 4.7.

4.1 Cost of Cultivation

Among all tree-crop combinations, maximum (425070.00 Rs/ha) cost of cultivation was workedout in case of apple + tomato and minimum (45640.10 Rs/ha) for sole black gram.

4.2 Gross Returns

Perusal of the data revealed the maximum (991971.00 Rs/ha) gross returns from apple + tomato combination closely followed by apple + capsicum (972837.25 Rs/ha), while the minimum (72000.00 Rs/ha) from sole black gram cultivation.

4.3 Net Returns

Wide variation was observed with respect to net returns from different sole crops and tree-crop combinations which ranged from Rs. 26359.95 per ha (sole black gram) and Rs. 566900.96 per ha (apple + tomato). Association of trees with agricultural crops revealed higher net returns over sole apple or sole agricultural crop cultivation.

4.4 Benefit: cost ratio

Growing agricultural crops with apple trees though increased the cost of cultivation yet substantially higher net returns were realised by integrating the tree component, which resulted in higher benefit: cost ratio. Among all the tree-crop combinations, the highest (2.33) benefit: cost ratio was registered under apple + tomato while the lowest (1.58) under sole black gram.

Table 4.7: Bio-economics appraisal of apple-based agroforestry systems

Treatments	Cost of cultivation (Rs/ha)	Gross returns (Rs/ha)	Net returns (Rs/ha)	B:C Ratio
Sole Apple	352800.00	746281.00	393480.92	2.12
Tomato	208002.00	345000.00	136998.00	1.66
Brinjal	120031.00	191970.00	071939.00	1.60
Capsicum	184991.00	299430.00	114438.84	1.62
Black gram	045640.10	072000.00	026359.95	1.58
Apple + Tomato	425070.00	991971.00	566900.96	2.33
Apple + Brinjal	413378.00	918268.75	504890.72	2.22
Apple + Capsicum	419990.00	972837.25	552847.01	2.32
Apple + Black gram	372100.00	814828.94	442728.92	2.19

Results of the present investigations exhibited that growing agricultural crops with apple is profitable over sole agricultural crop cultivation. This shows that agroforestry is an efficient land use system which makes judicious use of space and other limiting factors like nutrients, moisture, etc. The total net returns were substantially higher under agroforestry compared to sole cropping systems. The higher net returns under agroforestry intervention may be due to additional income realised from the apple trees. The results are in line with the findings of Chauhan (2000) who reported that adoption of poplar-based agroforestry system increased the farm income remarkably over sole crops. Similar studies were reported by Dutt and Thakur (2004), Bhatt and Mishra (2003), Sharma *et al.* (2008).

The findings of the present study suggested that growing selected vegetables with apple was more profitable than sole crop cultivation.

4.5 Effect of agroforestry system on soil physico-chemical properties

4.5.1. Physical properties of soil under apple-based agroforestry system

4.5.1.1. Bulk density (g/cm^3)

Bulk density was found to be affected significantly under different tree-crop combinations and sole crops at two different soil depths (Table 4.8). The maximum value of bulk density (1.33 g/cm^3) was observed in sole apple and the minimum in apple + capsicum (1.22 g/cm^3) at 0-15 cm depth. Similarly, the highest value of bulk density (1.34 g/cm^3) was recorded in T_1 (sole apple), whereas the lowest (1.26 g/cm^3) was recorded under T_8 (apple + capsicum) at 15-30 cm depth. The bulk density increased with the increase in soil depth.

4.5.1.2. Particle density (g/cm^3)

Like bulk density, particle density was also found impacted significantly under different treatments. At 0-15 cm soil depth, the particle density varied from 2.34-2.40 g/cm^3 whereas it ranged between 2.37- 2.42 g/cm^3 at soil depth 15-30 cm. The particle density increased with the increase in soil depth under the respective treatment from 0-15 cm to 15-30 cm.

4.5.1.3. Porosity (%)

The analysis of data presented in Table 4.8 revealed that soil porosity (%) was changed significantly at 0-15 cm soil depth under different treatment. The values found to be ranged between 44.52 (sole apple) to 47.28 (apple + tomato). All the treatments registered significantly higher values of porosity over T_1 (sole apple). However, no significant difference was noticed in porosity under different treatments at 15-30 cm soil depth.

4.5.1.4. Soil moisture content (%)

Though soil moisture content was found to be changed under various treatments from 20.04- 26.99 % at 0-15 cm and 19.09 – 27.03 % at 15-30 cm soil depth yet the difference among the treatments was non-significant at both soil depth.

Table 4.8: Physical properties of the soil under apple-based agroforestry systems and sole crops

Treatments ↓ / Soil Depth →	Bulk density (g/cm^3)		Particle density (g/cm^3)		Porosity (%)		Soil moisture (%)	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Sole apple (T_1)	1.33	1.34	2.40	2.42	44.56	44.52	20.04	19.09
Tomato (T_2)	1.28	1.29	2.36	2.38	46.96	46.78	24.37	24.11
Brinjal (T_3)	1.27	1.28	2.34	2.39	47.05	46.05	25.54	24.62
Capsicum (T_4)	1.27	1.28	2.35	2.38	46.22	46.18	23.24	24.42
Black Gram (T_5)	1.26	1.27	2.34	2.38	47.08	46.56	22.28	22.49
Apple + Tomato (T_6)	1.26	1.30	2.39	2.40	47.28	46.98	26.99	26.29
Apple + Brinjal (T_7)	1.27	1.29	2.35	2.37	45.78	45.67	26.04	27.03
Apple + Capsicum (T_8)	1.22	1.26	2.33	2.37	46.84	46.73	25.12	19.96
Apple + Black Gram (T_9)	1.25	1.29	2.38	2.41	45.80	45.47	22.99	22.60
$CD_{0.05}$	0.04	0.03	0.02	0.02	0.84	NS	NS	NS

Perusal of data revealed that maximum soil bulk density (1.33 g/cm^3) was recorded in sole cropping system (apple only) and minimum in T_8 (1.22 g/cm^3) at 0-15 cm depth. Similar results were found at 15-30 cm soil depth as well. The maximum soil bulk density was recorded under apple (T_1) over any other treatment. Similar findings have been reported by Biswas *et al.* (2003) and Oyedele *et al.* (2009). Gupta and Sharma (2008) revealed inverse relation between soil organic matter and soil bulk density. Similar relation has been noticed in the present study.

The maximum particle density was registered under sole apple (2.40 g/cm^3) at 0-15 cm depth. At 15-30 cm depth, the highest value (2.42 g/cm^3) was again observed in sole apple. Comparatively, lower values of particle density were noticed under sole agricultural crops and various tree-crop combinations in comparison to sole apple. This may be primarily due to the addition of more organic matter resulting in higher soil organic carbon content under agricultural crops and tree- crop combinations. Similar results were reported by Tandel *et al.* (2009).

More pore space observed at 0-15 cm soil depth under different crops and, tree + crop combinations over sole apple may be due to augmentation of organic matter through agricultural crops and penetration of the roots in the rhizosphere. Similar findings have been reported by Tandel *et al.* (2009). The results obtained in the present study are also in agreement with the findings of Singh *et al.* (2010).

Though soil moisture varied under different tree-crop combinations yet the variation was non- significant. The increased soil moisture (26.99% in apple + tomato) was observed in agroforestry systems as compared to sole apple (20.04 %). Higher moisture content under sole agricultural crops and tree-crops combinations over sole apple can be attributed to reduced water evaporation and thus, conservation of available water in soil (Agele 2000). Similar trend of results was reported by Dutt (2004), Dubey (2010) and Siriri *et al.* (2013).

4.5.2. Chemical properties of soil under apple-based agroforestry system

4.5.2.1. Electrical conductivity (dS/m)

Electrical conductivity (EC) was recorded maximum (0.35 dS/m) in sole capsicum. Similarly, the minimum (0.27 dS/m) in T_6 and T_8 treatments at 0-15 cm soil depth, whereas at depth of 15-30 cm, the highest EC (0.31 dS/m) was also estimated in sole capsicum and the minimum (0.24 dS/m) in apple + tomato.

4.5.2.2. Soil pH

Analysis of the data revealed that there was a significant difference in the soil pH among different treatments (Table 4.9). At 0-15 cm depth, the highest value was recorded under apple + brinjal (7.55) and the lowest in sole apple (5.64). Similarly, at 15-30 cm soil depth, the maximum (7.60) soil pH was estimated under apple + brinjal and the minimum (5.87) under sole apple cropping. The soil pH was found to be increased with the increase in soil depth.

4.5.2.3. Organic carbon (%)

Different tree-crop combinations had significant effect on soil organic carbon at various soil depths. At 0-15 cm soil depth, the highest (2.49 %) organic carbon was estimated under apple + tomato and the lowest (1.50%) under sole brinjal which was significantly lower as compared to that under tree-crop combinations (Table 4.9). The organic carbon contents under sole crops recorded lesser as in comparison to tree- crop combinations. No consistent trend was observed for organic carbon under different tree-crop combinations and sole crops at soil depth 15-30 cm. Organic carbon however, decreased as soil depth increased.

Table 4.9: Chemical properties of the soil under apple-based agroforestry systems and sole crops

Treatments ↓ / Soil depth →	Electrical Conductivity (dS/m)		Soil pH		Organic Carbon (%)	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Sole Apple (T_1)	0.28	0.23	5.64	5.87	1.98	1.25
Tomato (T_2)	0.32	0.30	6.47	6.65	1.86	1.31
Brinjal (T_3)	0.31	0.29	7.34	7.45	1.50	1.07
Capsicum (T_4)	0.35	0.31	6.58	7.08	1.66	1.14
Black gram (T_5)	0.30	0.28	6.71	7.01	1.65	1.21
Apple + Tomato (T_6)	0.27	0.24	6.59	7.14	2.49	1.57
Apple + Brinjal (T_7)	0.29	0.25	7.55	7.60	2.26	1.33
Apple + Capsicum (T_8)	0.27	0.25	6.84	7.16	2.37	1.48
Apple + Black gram (T_9)	0.28	0.26	6.72	7.05	2.13	1.22
$CD_{0.05}$	0.04	0.05	1.06	0.99	0.35	0.24

Different tree-crop combinations showed significant effect on electrical conductivity. Perusal of data revealed the maximum electrical conductivity (0.35 dS/m) under sole capsicum and the minimum electrical conductivity (0.27 dS/m) under agroforestry systems, T_6 and T_8 at 0-15 cm depth. Lowest EC found in agroforestry systems may be attributed to uptake of bases by tree biomass and acidic nature of litter after its decomposition. These results are in conformity with the findings of Tufa *et al.* (2019).

Assessment of soil pH revealed acidic (5.64) to slightly alkaline pH (7.55) at 0- 15 cm soil depth. Exactly, the soil pH was recorded acidic to slightly alkaline at soil depth 15-30 cm also (Table 4.9). The acidic nature of the soils could be due to the organic acids liberated from the decomposition of the organic matter. The findings are in line with many researchers who reported pH of different apple orchard soils of Himachal Pradesh to as acidic to slightly acidic (Attar, 2006). Acidic nature of apple growing soils in Himachal Pradesh was also reported by Das (1999), Sharma and Bhandari (1992) and Bhandari and Randhawa (1978).

The present study revealed that soil organic carbon was significantly influenced by different treatments. Organic carbon content was found the maximum (2.49 %) under apple + tomato and the minimum (1.50 %) under brinjal at 0-15 cm depth. Similar results were observed at 15-30cm depth. Organic matter content was higher at 0-15 cm soil depth over 15-30 cm which may be ascribed to addition of more leaf litter and higher fine root turnover in the top soil layer as compared to the lower one. The repeated application of tree biomass to the top soil increases soil organic matter in the upper layer. Gupta *et al.* (2009), Singh *et al.* (2010), Yadav *et al.* (2011), Benbi *et al.*(2012) and Bhat (2015) have also reported the similar trend of organic matter contents at different soil depths.

4.5.3. Soil nutrient dynamics under apple-based agroforestry systems

4.5.3.1. Available nitrogen (kg/ha)

The available nitrogen content in the soil varied significantly under different tree + crop associations and sole cropping systems (Table 4.10). The highest (375.00 kg/ha) available nitrogen content was recorded under apple + black gram combination followed by apple + tomato (372.88 kg/ha) at 0-15 cm depth while the lowest (235.20 kg/ha) was observed under brinjal grown without trees. The maximum (353.01 kg/ha) available nitrogen was found under apple + black gram followed by apple + capsicum (332.93 kg/ha) and the minimum (213.48 kg/ha) under sole brinjal crop at 15-30 cm soil depth. The available nitrogen was found more in the upper layer of soil which decreased with soil depth.

4.5.3.2. Available phosphorus (kg/ha)

Available phosphorus under crop + tree associations was more as compared to that under sole agricultural cropping systems (Table 4.10). The highest (29.31 kg/ha) available phosphorus was recorded under apple+ brinjal while the minimum (21.09 kg/ha) under sole capsicum crop at soil depth 0-15 cm. Likewise, maximum (18.06 kg/ha) available phosphorus was estimated under apple + brinjal while minimum (14.70 kg/ha) under brinjal cultivation without trees at 15-30 cm soil depth. However, the available phosphorus content was found to decrease with the increase in the soil depth from 0-15 cm to 15-30 cm.

4.5.3.3. Available potassium (kg/ha)

The data presented in Table 4.10 revealed that the available potassium (K^+) content in the soil at both the soil depths i.e., 0-15 cm and 15-30 cm was significantly affected under various tree-crop combinations and sole cropping systems. The highest (280.52 kg/ha) available potassium content was recorded under apple+ black gram closely followed by apple + tomato (277.57 kg/ha) and the lowest (222.82 kg/ha) under sole brinjal crop at 0-15 cm soil depth. Similarly, the maximum available potassium (271.19 kg/ha) was estimated under apple + black gram which was closely followed by apple + tomato (269.16 kg/ha) and the minimum (214.23 kg/ha) under sole brinjal at 15-30 cm soil depth. Higher values of available potassium content were, however, estimated in top layer of the soil (0-15 cm) which decreased with the increase in soil depth under each treatment.

Table 4.10: Soil nutrient dynamics under apple-based agroforestry systems and sole crops

Treatments ↓ / Soil depth →	Nitrogen (kg/ha)		Phosphorus (kg/ha)		Potassium (kg/ha)	
	0-15 cm	**15-30 cm**	**0-15 cm**	**15-30 cm**	**0-15 cm**	**15-30 cm**
Sole Apple (T_1)	349.84	319.33	28.18	17.15	262.05	221.14
Tomato (T_2)	247.34	218.94	21.70	15.71	256.17	241.19
Brinjal (T_3)	235.20	213.48	22.21	14.70	222.82	214.23
Capsicum (T_4)	242.49	223.45	21.09	14.87	232.86	228.30
Black gram (T_5)	237.87	213.97	22.81	15.42	241.84	238.16
Apple + Tomato (T_6)	372.88	323.38	27.56	17.96	277.57	269.61
Apple + Brinjal (T_7)	320.04	307.23	29.31	18.06	271.86	268.41
Apple + Capsicum (T_8)	359.96	332.93	26.35	17.49	274.55	267.39
Apple + Black gram (T_9)	375.00	353.01	28.54	17.44	280.52	271.19
$CD_{0.05}$	00.53	0.37	0.24	0.28	0.54	0.87

Perusal of the data obtained from analysis of soil under different tree-crop combinations and sole crops indicated significant effect on available N, P and K contents in soil at both the soil depths (0-15 cm and 15-30 cm). However, the available N, P and K contents decreased with the increase in soil depth under respective treatments which may be due to more organic matter, added through plant residues/leaf litter in the top soil.

Ahmed *et al.* (2010) also reported that tree species helped in building up of soil fertility which then attributed to addition of pruned material and decomposition thereof. Similarly, Wang and Cao (2011) reported higher available N, P and K under gingko and mulberry plantation due to more litter fall as compared to sole mulberry plantation. The results of the present findings are also in line with the findings of Cardoso *et al.* (2001), Chaudhary *et al.* (2007), Lima *et al.* (2010), Benbi *et al.* (2012), Santiago *et al.* (2013), Bhat (2015) and Shah *et al.* (2017).

4.6 Effect of agroforestry system on soil biological properties

4.6.1. Microbial carbon (mg/kg)

Cropping systems had significant effect on microbial carbon at different soil depths (Table 4.11). The microbial carbon content under different tree-crop associations was more as compared to sole cropping systems (Table 4.11). The highest (469.70 mg/kg) microbial carbon content was recorded under apple + tomato at soil depth 0-15 cm, while the lowest (275.26 mg/kg) under sole capsicum crop. At soil depth 15-30 cm also, the maximum (360.40 mg/kg) microbial carbon content was estimated under apple + tomato and the minimum (245.75 mg/kg) under capsicum cultivation only. The microbial carbon content decreased with the increase in soil depth.

4.6.2. Microbial nitrogen (mg/kg)

The microbial nitrogen (N) in the soil was found to be increased significantly under trees + crop associations as compared to sole agricultural cropping systems (Table 4.11). The highest microbial N content was observed under apple + tomato combination (350.48 mg/kg) followed by apple + capsicum (348.37 mg/kg) while the lowest under sole brinjal (189.80 mg/kg) at 0-15 cm soil depth. Similarly, the maximum microbial N was found under apple + tomato (253.18 mg/kg) followed by apple + black gram (226.81 mg/kg) and the minimum under sole brinjal crop (111.08 mg/kg) at 15-30 cm soil depth.

4.6.3. Microbial phosphorus (kg/ha)

The data given in Table 4.11 revealed that microbial P in the soil at both the soil depths i.e., 0-15 cm and 15-30 cm was significantly affected under various tree-crop combinations. Like microbial nitrogen, the highest microbial phosphorus was also recorded under apple + tomato (19.96 kg/ha) and the lowest under sole brinjal crop (12.28 kg/ha) at 0-15 cm soil depth. Similarly, the maximum microbial P was estimated under apple + tomato (12.46 kg/ha) and the minimum under sole brinjal (6.82 kg/ha) at 15-30 cm soil depth. Higher values of microbial P were estimated in surface layer of the soil (0-15 cm).

Table 4.11: Soil biological properties under apple-based agroforestry systems and sole crops

Treatments ↓ / Soil depth →	C_{mic} (mg/kg)		N_{mic} (mg/kg)		P_{mic} (mg/kg)	
	0-15 cm	**15-30 cm**	**0-15 cm**	**15-30 cm**	**0-15 cm**	**15-30 cm**
Sole Apple (T_1)	417.29	306.43	306.48	214.75	16.28	10.53
Tomato (T_2)	303.63	280.42	206.40	138.77	18.17	11.60
Brinjal (T_3)	302.13	285.80	189.80	111.08	12.28	06.82
Capsicum (T_4)	275.26	245.75	218.41	158.50	16.46	08.41
Black gram (T_5)	282.20	262.74	278.75	135.02	19.40	12.16
Apple + Tomato (T_6)	469.70	360.40	350.48	253.18	19.96	12.46
Apple + Brinjal (T_7)	431.69	355.37	309.28	211.87	12.46	07.92
Apple + Capsicum (T_8)	384.57	324.80	348.37	220.83	12.89	08.90
Apple + Black gram (T_9)	441.83	342.56	327.98	226.81	16.58	10.38
$CD_{0.05}$	17.89	10.86	32.59	32.00	2.39	1.46

Measurement of soil microbial biomass is an indicator of both the size of total microbial community as well as the mass of potential plant nutrients contained within the microbial cells. Microbial biomass is normally related to organic matter content of the soil. Agroforestry practices lead to an increase in organic matter input through litter fall and in turn, enhances the amount of nutrients for soil micro flora, which ultimately leads to an increased microbial biomass. The data reflected significant effect of different tree-crop combinations on soil biological properties. Soil microbial biomass C and N also indicates the status of nutrient turnover and nutrient bioavailability (Fernandes *et al.* 2005). Among all treatment combinations, the highest microbial C and N were recorded under agroforestry system, apple + tomato at both soil depths, 0-15 cm and 15-30 cm. Higher soil microbial activity observed in intercropping system than sole cropping systems is mainly due to more organic matter contributed by intercropping practices. It is found that soil microbial biomass C and N decreased with soil depth. Difference in soil microorganisms in the upper layer among different systems could be the result of combinations of a variety of factors, for example root biomass and turnover, lignin content of crop residues, root and litter fall, and the environmental conditions (Wang *et al.* 2005). Deposition of organic matter into the soil leads to enhanced microbial activities in soil. The results suggested that trees in agroforestry system have the potential to enhance soil fertility and sustainability of farmland by improving soil microbial activity through residual soil carbon. Though the maximum microbial P was also recorded under apple + tomato but no consistent trend was observed for different tree-crop combinations and sole crops.

4.6.4. C Flux

Integration of apple with the selected agricultural crops resulted in substantial increase in C flux at both the soil depth (0-15 cm, 15-30 cm). However, the maximum C flux was recorded under apple + tomato (313.13 mg/kg/year) and the minimum underneath the sole capsicum crop (183.51 mg/kg/year) at 0-15 cm soil depth and 240.27 mg/kg/year and 163.84 mg/kg/year at 15-30 cm soil depth, respectively.

4.6.5. N flux

Data emerged out of the present study revealed that the highest N flux was under apple + tomato (280.38 mg/kg/year) and the lowest under sole brinjal crop (151.84 mg/kg/year) at 0-15 cm soil depth. Similarly, the maximum N flux was found under apple + tomato (202.54 mg/kg/year) and the minimum under sole brinjal crop (88.86mg/kg/year) at soil depth 15-30 cm.

4.6.6. P flux

Analysis of the soil samples revealed the maximum P flux value under apple + tomato (15.97 mg/kg/year) and the minimum in sole cropping of brinjal (9.82 mg/kg/year) at soil depth 0-15 cm. At depth 15-30 cm, the highest P flux was also found under apple + tomato (9.97 mg/kg/year) the lowest under sole brinjal (5.46 mg/kg/year). Substantial decrease was observed in respect to P flux with the increase in soil depth from 0-15 cm to 15-30 cm.

Tale 4.12: Flux of C, N and P under apple-based agroforestry systems and sole crops

Treatments ↓ / Soil Depth →	C flux(mg/kg/year)		N flux(mg/kg/year)		P flux(mg/kg/year)	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Sole apple (T_1)	278.19	204.28	245.18	171.80	13.02	8.42
Tomato (T_2)	202.42	186.95	165.12	111.01	14.93	9.28
Brinjal (T_3)	201.42	190.54	151.84	088.86	9.82	5.46
Capsicum (T_4)	183.51	163.84	174.73	126.80	13.17	6.73
Black gram (T_5)	188.13	175.16	223.00	108.01	15.52	9.73
Apple + Tomato (T_6)	313.13	240.27	280.38	202.54	15.97	9.97
Apple + Brinjal (T_7)	287.79	236.91	247.42	169.49	9.96	6.34
Apple + Capsicum (T_8)	256.38	216.53	278.38	176.66	10.31	7.12
Apple + Black gram (T_9)	294.55	228.38	262.38	181.44	13.26	8.3

Data presented in Table 4.12 revealed similar trend for flux and microbial biomass of C, N and P. Annual flux of C and N was higher under apple-based land uses in comparison to sole agricultural cropping systems. (Table 4.12). Increase in C and N flux through microbial biomass has been reported by Srivastava and Singh (1991). Similarly, Brookes *et al.* (1984) reported higher microbial P flux (22.7 kg/ha/year) under grassland compared to arable soils (6.8 kg/ha/year). The findings suggested that soil micro-organisms are major source of plant nutrients in the agroforestry systems, however, the entire fluxes of microbial nutrients are not available for plant growth.

4.6.1. C_{mic}: N_{mic}

As evident in Table 4.13, C_{mic}: N_{mic} at depth 0-15 cm was the maximum under sole brinjal (1.59) closely followed by sole tomato (1.47) and the minimum under sole black gram (1.01). At depth 15-30 cm, the highest C_{mic}: N_{mic} ratio was registered under sole brinjal (2.57) andthe lowest under apple + tomato (1.42).

4.6.2. N_{mic}: P_{mic}

Analysis of data exhibited the maximum N_{mic}: P_{mic} was recorded under apple + capsicum (27.03) and the minimum under sole tomato (11.36). At depth 15-30 cm, the maximum ratio was recorded under apple + brinjal (26.75) and the minimum under sole black gram (11.10).

4.6.3. C_{mic}: P_{mic}

The scrutiny of data revealed the highest C_{mic}: P_{mic} under apple + brinjal (34.65) and the lowest under sole black gram (14.55) at soil depth 0-15 cm whereas at soil depth 15-30cm, it was the maximum under apple + brinjal (44.87) and the minimum under sole black gram (21.61).

Table 4.13: Cmic: Nmic, Nmic: Pmic, Cmic: Pmic and Cmic: Nmic: Pmic of sole cropping and agroforestry

Treatments ↓ / Soil depth →	C_{mic}: N_{mic}		N_{mic}: P_{mic}		C_{mic}: P_{mic}		C_{mic}: N_{mic}: P_{mic}	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Sole apple (T_1)	1.36	1.43	18.83	20.39	25.63	29.10	25.63:18.83:1	18.82:13.19:1
Tomato (T_2)	1.47	2.02	11.36	11.96	16.71	24.17	16.71:11.36:1	15.43:7.64:1
Brinjal (T_3)	1.59	2.57	15.46	16.29	24.60	41.91	24.60:15.46:1	23.27:9.05:1
Capsicum (T_4)	1.26	1.55	13.27	18.85	16.72	29.22	16.72:13.27:1	29.22:18.85:1
Black gram (T_5)	1.01	1.95	14.37	11.10	14.55	21.61	14.55:14.37:1	21.61:11.10:1
Apple + Tomato (T_6)	1.34	1.42	17.56	20.32	23.53	28.92	23.53:17.56:1	28.92:20.32:1
Apple + Brinjal (T_7)	1.40	1.68	24.82	26.75	34.65	44.87	34.65:24.82:1	44.87:26.75:1
Apple + Capsicum (T_8)	1.10	1.47	27.03	24.81	29.83	36.49	29.83:27.03:1	36.49:24.81:1
Apple + Black gram (T_9)	1.35	1.51	19.78	21.85	26.65	33.00	20.66:19.78:1	33.00:21.85:1

The data given in Table 4.13 indicated substantial variations in the ratio of C_{mic}: N_{mic}, N_{mic}: P_{mic}, C_{mic}: P_{mic} and C_{mic}: N_{mic}: P_{mic}. The findings of the present study are in line with the results obtained by Yadav *et al.* (2011), who analyzed microbial biomass C, N and P in different tree based traditional agroforestry systems. There is a close relationship between proportions of elements in soil, plant residues and microorganisms. Lower C_{mic}: N_{mic} and C_{mic}: P_{mic} ratios among agroforestry systems revealed that composition of soil micro flora was affected by the different tree-based land uses and the rate of mineralization (Hassink *et al.* 1991). A wider C_{mic}: N_{mic} ratio indicates a high proportion of fungi compared to bacteria and actinomycetes (Cambell *et al.* 1991). The C_{mic}: N_{mic} ratio of fungal hyphae is in the range of 7–12, whereas that of bacteria usually between 3 and 6 (Jenkinson 1978; Anderson and Domsch 1980). Similarly, Brookes *et al.* (1984) reported that the C_{mic}: P_{mic} ratio ranged from 10.6 to 35.9 in grassland soils and cultivated fields in the United Kingdom. In present studies, C_{mic}: P_{mic} ratio varied from 14.55 to 29.83 which is well within the range. With smaller C_{mic}: P_{mic} ratio, the biomass is enriched in P and hence, has a high potential to release these nutrients in mineralization or turnover processes. The C_{mic}: P_{mic} ratio in soil organic matter can provide a reliable basis to determine the level of nutrients availability (Kirkby *et al.* 2011). The C_{mic}: N_{mic}: P_{mic} ratio is crucial for microbial element stoichiometry pattern and nutrient cycling (Cleveland and Liptzin, 2007). Depending on the C_{mic}: N_{mic} ratio or C_{mic}: P_{mic} ratio, the residues decompose in a certain time frame and release N and P in ionic forms (mineralization). The C_{mic}: N_{mic}: P_{mic} ratio depends on the type of organic matter present in the soil and determines immobilization of nutrients in the microbial biomass Griffiths *et al.* (2012).

4.7 Effect of agroforestry system on soil enzymatic properties

4.7.1. Dehydrogenase (μg/g dry soil/hour)

Analysis of the data revealed that dehydrogenase activity was statistically significant under different tree-crop combinations at both soil depths (Table 4.14). The maximum (13.63 μg/g dry soil/hour) activity was recorded under apple + tomato and the minimum (6.56 μg/g dry soil/hour)in sole black gram at 0-15 cm. Similarly, the highest dehydrogenase activity was found under apple + tomato (11.23 μg/g dry soil/hour) and the lowest (5.07 μg/g dry soil/hour) under sole black gram at 15-30 cm soil depth. Dehydrogenase activity, however found to be reduced with the increase in soil depth.

4.7.2. Catalase (mg $KMnO_4$/g dry soil/hour)

Tree-crop combinations also showed significant effect on catalase activity. Data presented in Table 4.12 revealed the highest catalase activity in apple + tomato (4.90 mg $KMnO_4$/g dry soil/hour) followed with non-significant difference by apple + brinjal by (4.78 mg $KMnO_4$/g dry soil/hour) and the lowest under sole brinjal (3.21 mg $KMnO_4$/g dry soil/hour) at 0-15 cm depth. The maximum activity was found in apple + tomato (4.58 mg $KMnO_4$/g dry soil/hour) and the minimum in sole apple (1.58 mg $KMnO_4$/g dry soil/hour) at 15-30 cm soil depth.

4.7.3. Phosphatase

4.7.3.1. Acid phosphatase (µg/g dry soil/hour)

The different tree-crop combinations revealed significant effect on the activity of acid phosphatase at both soil depths (Table 4.14). The maximum activity was recorded under apple + tomato (6.45 µg/g dry soil/hour) and the minimum under sole brinjal (2.48 µg/g dry soil/hour) at 0-15 cm soil depth. Likewise, the highest activity was found under apple + tomato (5.25 µg/g dry soil/hour) and the lowest under sole brinjal (1.38 µg/g dry soil/hour) at soil depth 15-30 cm. The acid phosphatase activity decreased with the increasing soil depth upto 30 cm under all tree-crop combinations except apple + capsicum whereas slight increase was noticed with increase in soil depth.

4.7.3.2. Alkaline phosphatase (µg/g dry soil/hour)

Significant effect of different land uses (tree-crop combinations) on the activity of alkaline phosphatase at both the soil depths was observed (Table 4.14). The highest activity was recorded under apple + tomato (4.88 µg/g dry soil/hour) and the lowest under sole apple trees (1.12 µg/g dry soil/hour) at 0-15 cm soil depth. Similarly, the maximum alkaline phosphatase activity was found in agroforestry system, apple + tomato and the minimum under sole apple at 15-30 cm soil depth.

Table 4.14: Soil enzymatic properties under apple-based agroforestry systems and sole crops

Treatments ↓ / Soil depth →	Dehydrogenase (µg/g dry soil/hour)		Catalase (mg KMnO4/g dry soil/hour)		Acidic Phosphatase (µg/g dry soil/hour)		Alkaline Phosphatase (µg/g dry soil/hour)	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Sole Apple (T_1)	12.38	11.22	3.32	1.58	3.06	1.72	1.12	1.81
Tomato (T_2)	9.17	8.06	4.04	2.97	2.83	2.74	2.27	1.93
Brinjal (T_3)	11.67	10.07	3.21	2.85	2.48	1.38	3.01	3.19
Capsicum (T_4)	9.10	8.34	3.59	3.33	3.48	3.18	3.33	3.23
Black gram (T_5)	6.56	5.07	4.02	3.00	3.86	3.20	4.37	3.40
Apple + Tomato (T_6)	13.63	11.23	4.90	4.58	6.45	5.25	4.88	3.78
Apple + Brinjal (T_7)	11.97	10.26	4.78	4.22	5.39	3.66	3.83	3.11
Apple + Capsicum (T_8)	10.36	9.07	4.26	4.01	5.21	5.23	4.31	2.06
Apple + Black gram (T_9)	10.19	9.09	4.26	4.23	5.31	4.93	3.77	3.03
$CD_{0.05}$	0.91	0.27	0.92	0.49	0.87	0.65	0.67	0.28

Soil enzyme activity is critically important for soil quality and is indicative of changes in metabolic capacity and nutrient cycling (Zhou *et al.* 2011). Enzyme activity is different in soils supporting different types of vegetation (Michel and Matzner 2003). All the biological activities proceed through enzymatic processes in soil. Several physical, chemical and environmental factors affect different enzyme activities in soils. The enzyme acts as an eye of the needle through which all the microbial process passes. The increased enzymatic activities could be due to higher microbial biomass in the rhizosphere. These results are in agreement with the findings of Panwar *et al.* (2003) and Maseko and Dakora (2013). This significant variation in enzyme activity may be due to difference in functional microbial diversity (Paudel *et al.* 2011). Numerous studies have reported significantly higher activity of these enzymes in intercropping systems compared to monocultures (Wang *et al.* 2005; Wang and Cao 2011; Zhou *et al.* 2011).

Dehydrogenase enzyme represents metabolic activity of total microbial biomass. The dehydrogenase activity, irrespective of tree- crop combination, decreased considerably with soil depth. Apple trees significantly increased dehydrogenase activity as compared to open field conditions. The increase under agroforestry system was higher under both surface and sub-surface soil in comparison to open systems. Higher organic material provides favorable conditions for the growth and development of microorganisms resulting in enhanced dehydrogenase activity in comparison to the open field where organic matter is low. Prasad and Mertia (2005) reported higher microbial activities in tree rhizosphere as compared to non-rhizosphere. Similar results were also documented by Yadav *et al.* (2011) and Lalita (2004).

Catalase is an enzyme that catalyzes the decomposition of hydrogen peroxide to water and oxygen and oxidizes H donors thereby protecting soil organisms and plants from H_2O_2 toxicity (Li *et al*. 2017). Catalase activity is used as a proxy for soil biological oxygenation that is closely related to the activity of aerobic microorganisms and soil fertility (Li *et al*. 2010). In agroforestry system, the catalase activity is high because of enhancement in litter quality and quantity and amount of root exudates. In this study, increased catalase activity in agroforestry system may be because of increased organic matter and litter quality. Increased enzyme activity is proportionally linked to microbial function, leading to improved nutrient cycling and availability, which favours root growth, promotes beneficial plant-microbial interactions, and eventually increases the total carbon pool of soil (Udawatta *et al*. 2009) Increased amounts of root exudates supply additional organic substrates to microorganisms which favours microbial growth and the turnover of nutrients for crop growth (Li *et al*. 2016; Li *et al*. 2017).

Phosphatases are the important enzymes which are involved in soil organic P mineralization. The phosphate activity was found higher in surface soil layer under agroforestry systems as compared to sole cropping. In the present study, acid phosphatase activity was higher in agroforestry-based system compared to sole cropping. The pH of soils ranges from acidic to neutral. In acidic soils, the activity of acid phosphatase enzyme is considered to be higher compared to other phosphomonoesterases (Touhami *et al*. 2020). In contrast to acid phosphatase activity, alkaline phosphatase is produced by plant roots, fungi and bacteria (Baker *et al.* 2011) and its activity is used as an index to evaluate the ability of soils to mineralize organic P (Pascual *et al.* 1998). The increased phosphatase activity may be attributed to the input of humic acid that may increase the availability of phosphate esters (Liu *et al.* 2017) the diversity, abundance and activity of bacterial communities controlling P cycling (Tamil selvi *et al.* 2015; Monreal and Zhang 2018) secretions of the enzyme by roots and microorganisms (Zhang *et al.* 2011). Chander *et al*. (1998) also reported that the soil biological activity was significantly affected by the tree-crop combinations. Wang *et al*. (2005) also supported the findings. The authors evaluated the effect of growing crops in combination with young Chinese fir (*Cunningharnia lanceolata*) and reported that the alkaline phosphatase activities were higher in the soil under crops grown in association with trees. Present investigations are also in line with the findings of Vallejo *et al*. (2010) who reported that the activities of urease, alkaline phosphatases and catalase were more in silvopastoral systems as compared to open area. (Ramos *et al*. 2010) and Kremer and Kussman (2011) also supported the present findings.

Chapter-5

SUMMARY AND CONCLUSION

The study entitled "**Ecological and Economical Appraisal of Apple based Agroforestry Systems in Kullu Valley of Himachal Pradesh**" was carried out during the year 2021 in apple orchards at Bhindi Bai Village, Bajaura, Kullu. The study site is located at 31.85^0 N and 77.08^0 E with an elevation of 1600 m above mean sea level.

The experiment was laid out in Randomized Block Design, having nine treatment combinations (sole apple, sole tomato, sole brinjal, sole capsicum, sole black gram, apple + tomato, apple + brinjal, apple + capsicum and apple + black gram) with three replications in order to assess the biomass, carbon stock, soil physico-bio-chemical properties and to work out economics of the various tree-crop combinations while for comparing growth and yield parameters of agricultural crops grown under agroforestry and sole cropping, Student 't' test was employed. The observations on growth and yield parameters of agricultural crops were recorded at the time of harvesting whereas for assessing soil properties, the composite soil samples under each treatment were taken at the end of the experiment. The summary of the results is given below:

5.1. Growth and yield parameters of agricultural crops grown under agroforestry and in sole cropping system

The results indicated that most of the growth and yield parameters of tomato were found to be significantly and positively influenced under the apple tree canopy. The yield of tomato grown with apple (118.86 q per ha) was found statistically better in comparison to sole tomato (115.24 q per ha). Whereas, the growth and yield parameters of remaining crops (brinjal, capsicum and black gram) were found to be negatively affected under the apple canopy.

5.2. Growth and yield parameters of apple trees

Fruit yield and crown volume of apple grown as pure crop and under agroforestry systems showed variation. Fruit yield and crown volume was the highest in apple + black gram (107.16 kg/tree and 1.15 m^3) and the lowest under sole apple (103.13 kg/tree and 0.83 m^3), respectively. However, no significant effect was observed on crown spread, diameter and tree height.

5.3. Carbon sequestration potential of apple based agroforestry systems

Significant variation was observed among the different tree-crop combinations with respect to total biomass and total carbon stock of the systems. Sole cultivation of agricultural crops revealed less total biomass and total carbon stock as compared to that recorded under respective tree-crop combinations. The highest total biomass (44.05 t per ha) was recorded under apple + tomato and lowest (1.75 t per ha) in case of sole black gram. Like biomass, total carbon stock was also the maximum (21.73 t per ha) in apple + tomato and the minimum (00.79 t per ha) in case of black gram in open field conditions.

5.4. Bio-economics of apple based agroforestry systems

The bio-economics of different tree-crop combinations indicated highest cost of cultivation (Rs. 425070.00 per ha) in case of apple + tomato. The maximum gross returns (Rs. 991971.00 per ha) were also obtained from apple + tomato cultivation while, the minimum (Rs. 72000 per ha) for sole black gram cropping. The maximum net returns (Rs. 566900.96 per ha) were also worked out for apple + tomato. The benefit cost ratio among various tree-crop combinations was observed highest (2.33) under apple + tomato cultivation.

5.5. Effect of agroforestry systems on soil physico-chemical properties

Among all the physical properties; bulk density, particle density and soil porosity were found to be affected significantly while, soil moisture remained unaffected under different tree-crop combinations at soil depths, 0-15 cm and 15-30 cm. Bulk density and particle density was found to be higher in sole apple crop as compared to other treatments. Porosity and soil moisture content exhibited its lower values at 15-30 cm soil depth over 0-15 cm. Porosity and soil moisture content was the highest under agroforestry combination, apple + tomato in comparison to sole cropping system.

Soil chemical properties *viz.*, pH, electrical conductivity and organic carbon were found to be affected significantly under different tree-crop combinations. Acidic to slightly alkaline soils were found under different tree-crop combinations. Electrical conductivity was found to be lower under agroforestry systems as compared to respective sole agricultural crops. At both the soil depths, organic carbon had higher values under the agricultural crops grown with the trees over sole agricultural crops. The results also indicated that with increase in the soil depth from 0-15 cm to 15-30 cm, pH increased whereas reverse trend was observed for soil organic carbon an EC.

The tree + crop combinations had significant effect on the available N, P and K contents at various soil depths. The available N, P, K contents in soil were higher under agrihorticulture system as compared to sole agricultural crops. However, the available N, P and K contents were found to be decreased with the increase in soil depth from 0-15 cm to 15-30 cm. Among various agricultural crops, the maximum nitrogen and potassium contents were observed under apple + black gram while, the maximum phosphorus was recorded under apple + brinjal.

5.6. Effect of agroforestry systems on soil biological properties

The data reflected significant effect of different tree-crop combinations on soil biological properties. Microbial C, N and P were recorded highest under agroforestry system, apple + tomato at both soil depths. The nutrient flux i.e., C flux, N flux and P flux was also found to be the highest under apple + tomato. However, there was decrease with increase in soil depth. The soil enzymatic activities *viz.,* dehydrogenase, catalase and acid phosphatase were also better under agroforestry systems than respective sole cropping systems. Among all the tree-crop combinations enzymatic activities were the highest under apple + tomato.

Conclusions

- It was concluded from the study that apple competed with agricultural crops (brinjal, capsicum and black gram) for moisture, nutrients and other limiting resources which resulted in poor performance (growth and yield) of agricultural crops except tomato which performed better under apple tree canopy. Better yield of tomato under the apple may be due to the tree-crop compatibility and micro environmental conditions favourable for tomato growth

- The intercropping has enhanced the fertility of soils in terms of available N, P and K which otherwise in pure agricultural crops have shown comparatively lower values indicating the likelihood of becoming limiting factor over the years.

- Integration of the trees with crops improved biomass production of the system substantially. Thus, the studied agroforestry systems are potential carbon sinks over agricultural cropping system.

- Higher net returns obtained from vegetables as intercrop over black gram indicated that these vegetables should be preferred under existing environmental and market conditions.

- Microbial biomass C, N and P, as well as activities of dehydrogenase, catalase, acidic and alkaline phosphatase activity were observed highest under apple + tomato agroforestry system. Annual flux of C, N and P through C_{mic}, N_{mic} and P_{mic} was also recorded highest under apple-based land use, apple + tomato over sole cropping. Incorporating trees led to significant increment in all the biological properties.

- Among all the studied tree-crop combinations, apple + tomato proved as the best combination and the farmer of the area should adopt from ecological and economical point of view.

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APPENDIX

APPENDIX I: Cost of cultivation of tomato (*Lycopersicon esculentum* L.) (Rs/ha)

Sr No.	Particulars	Units	Units required	Price per unit	Total Cost
A.	**Variable Cost**				
1)	**Human Labour**				
i)	**Family Labour**	days	50	300	15000
ii)	**Hired Labour**	days	71	300	21300
2)	**Material cost**				
i)	**Seed**	10g	21	6229.44	130818.24
ii)	**FYM Cost**	quintals	50	250	12500
iii)	**Fertilizer Cost**				
iv)	**N**	kg	90	40	3600
v)	**P**	kg	50	50	2500
vi)	**K**	kg	40	50	2000
vii)	**Plant Protection**	-	-	-	1500
viii)	**Packaging**	-	-	-	500
ix)	**Staking**	-	-	-	4000
	Total	-	-	-	193718.24
	Interest on Working Capital@5%	-	-	-	9685.912
	COST A				203404.152
B.	**Fixed cost**				
i)	**Land Revenue**				40
ii)	**Depreciation**				560
iii)	**Rental Value of Land**				4000
iv)	**Total Fixed Cost (Cost B)**				4600
	Total cost (A+B = C)				
C.	**COST C**				208002.00

APPENDIX II: Cost of cultivation of brinjal (*Solanum melongena* L.) (Rs/ha)

Sr No.	Particulars	Units	Units required	Price per unit	Total Cost
A.	**Variable Cost**				
1)	**Human Labour**				
i)	**Family Labour**	days	15	300	4500
ii)	**Hired Labour**	days	20	300	6000
2)	**Material cost**				
i)	**Seed**	10g	18	4327.74	77899.32
ii)	**FYM Cost**	quintals	50	250	12500
iii)	**Fertilizer Cost**				
iv)	**N**	kg	90	40	3600
v)	**P**	kg	50	50	2500
vi)	**K**	kg	40	50	2000
vii)	**Plant Protection**	-		-	1000
viii)	**Packaging**	-		-	500
	Total	-		-	110499.32
	Interest on Working Capital@5%				
		-		-	5524.966
	COST A				116024.286
B.	**Fixed cost**				
i)	**Land Revenue**				40
ii)	**Depreciation**				560
iii)	**Rental Value of Land**				3407.26
	Total Fixed Cost (Cost B)				4007.26
	Total cost (A+B = C)				
C.	**COST C**				120031.00

APPENDIX III: Cost of cultivation of capsicum (*Capsicum annuum* L.) (Rs/ha)

Sr No.	Particulars	Units	Units required	Price per unit	Total Cost
A.	Variable Cost				
1.	Human Labour				
i)	Family Labour	days	15	300	4500
ii)	Hired Labour	days	20	300	6000
2.	Material cost				
i)	Seed	10g	15	3724.5	55867.5
ii)	FYM Cost	quintals	50	250	12500
iii)	Fertilizer Cost				
iv)	N	kg	90	40	3600
v)	P	kg	50	50	2500
vi)	K	kg	40	50	2000
vii)	Plant Protection	-	-	-	1000
viii)	Packaging	-	-	-	500
	Total	-	-	-	88467.5
	Interest on Working Capital@5%				4423.375
	COST A				92890.875
B.	Fixed cost				
i)	Land Revenue				40
ii)	Depreciation				560
iii)	Rental Value of Land				3000
	Total Fixed Cost (Cost B)				3600
	Total cost (A+B = C)				
C.	COST C				184991.16

APPENDIX IV: Cost of cultivation of black gram (*Vigna mungo* L.) (Rs/ha)

Sr No.	Particulars	Units	Units required	Price per unit	Total
A.	**Variable Cost**				
1)	**Human Labour**				
i)	**Family Labour**	days	15	300	4500
ii)	**Hired Labour**	days	20	300	6000
2)	**Material cost**				
i)	**Seed**	kg	7	833	5831
ii)	**FYM Cost**	quintals	50	250	12500
iii)	**Fertilizer Cost**				
iv)	**N**	kg	90	40	3600
v)	**P**	kg	50	50	2500
vi)	**K**	kg	40	50	2000
vii)	**Plant Protection**	-			2500
	Total	-			39431
	Interest on Working Capital@5%	-			1971.55
	COST A				41402.55
B.	**Fixed cost**				
i)	**Land Revenue**				40
ii)	**Depreciation**				560
iii)	**Rental Value of Land**				3597
	Total Fixed Cost (Cost B)				4197
	Total cost (A+B = C)				
C.	**COST C**				45640.05

APPENDIX V: Cost of cultivation of apple (*Malus domestica*) (Rs/ha)

Item of Cost	Units	Quantity	Unit Rate	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total (Rs)
Irrigation	MD	-	300	600	650	700	720	760	800	850	850	900	900	920	8650
Bush Clearing	MD	25	300	7500	0	0	0	0	0	0	0	0	0	0	7500
Fencing and land preparation	Rs.	-	-	30000									0	0	30000
Digging of pits @25 pits/MD	MD	6	300	1800	0	0	0	0	0	0	0	0	0	0	1800
Cost of seedlings	Seedlings	142	100	14200	0	0	0	0	0	0	0	0	0	0	14200
Planting and refilling of pits	MD	5	300	1500	0	0	0	0	0	0	0	0	0	0	1500
Cost of FYM @3 kg per pit	kg	3	300	900	600	600	630	650	700	720	750	750	770	800	7870
Fertilizer	Rs.	-	-	2800	2800	3000	3300	3800	4100	4400	4500	4500	5000	5500	48200
Insecticide/pesticide	Rs.	-	-	2000	2500	2500	3000	3400	3600	3600	3800	4000	4000	4200	56600
Intercultural operations	MD	-	500	500	500	520	550	600	650	700	780	1000	1500	2500	9800
Fruit extraction	MD	-	-	0	0	0	0	0	0	0	400	450	500	550	1900
Packaging and storage	Rs.	-	-	0	0	0	0	0	0	0	8000	9000	10000	15000	42000
Transportation	Rs.	-	-	0	0	0	0	0	0	0	2500	3000	5000	7000	17500
Miscellaneous	Rs.	-	-	500	550	550	600	700	750	800	800	850	1000	2000	9100
Interest on working capital-5%	Rs.	-	-	3085	347.5	358.5	404	457.5	490	511	1076.5	1177.5	1388.5	1877.5	14173.5
Land Revenue	Rs.	-	-	40	40	40	40	40	40	40	40	40	40	40	440
Land rental fee	Rs.	-	-	5729	5729	5729	5729	5729	5729	5729	5729	5729	5729	5729	63019
Interest on fixed capital (15%)	Rs.	-	-	865.35	865.35	865.35	865.35	865.35	865.35	865.35	865.35	865.35	865.35	865.35	11018.85
Depreciation and	Rs.	-	-	650	650	650	650	650	650	650	650	650	650	650	7150
Maintenance															
Grand total	Rs.	-	-	72669.35	15231.85	15512.85	16488.35	17651.85	18374.35	18865.35	30740.85	32911.85	37342.85	47631.85	352800.08

APPENDIX VI -: Analysis of variance of t_{cal} Number of plants per m^2, Plant height (cm), Number of branches per plant and Number of leaves per plant of tomato under apple trees and in sole cropping system

Number of plants per m^2			Plant height (cm)		Number of branches per plant		Number of leaves per plant	
Parameters	**Sole Tomato**	**Apple + Tomato**	**Sole Tomato**	**Apple + Tomato**	**Sole Tomato**	**Apple + Tomato**	**Sole Tomato**	**Apple + Tomato**
Mean	4.02	3.20	150.18	152.79	11.68	12.78	44.32	47.48
Variance	0.14	0.02	0.38	1.77	0.58	1.37	3.13	3.73
Standard deviation	0.37	0.17	0.62	1.33	0.76	1.17	1.77	1.93
Standard error	0.14	0.06	0.28	0.59	0.34	0.52	0.79	0.86

APPENDIX VII -: Analysis of variance of t_{cal} Number of fruits per plant, Fruit length (cm), Fruit diameter and Fruit yield (q/ha) of tomato under apple trees and in sole cropping system

Number of fruits per plant			Fruit length (cm)		Fruit diameter (cm)		Fruit Yield(q/ha)	
Parameters	**Sole Tomato**	**Apple + Tomato**	**Sole Tomato**	**Apple + Tomato**	**Sole Tomato**	**Apple + Tomato**	**Sole Tomato**	**Apple + Tomato**
Mean	7.64	8.26	4.75	5.20	4.84	5.08	115.24	118.86
Variance	0.03	0.00	0.02	0.04	0.17	0.09	1.28	0.34
Standard deviation	0.17	0.06	0.15	0.21	0.41	0.31	1.13	0.59
Standard error	0.07	0.03	0.07	0.09	0.18	0.14	0.51	0.26

APPENDIX VIII-: Analysis of variance of t_{cal} Number of plants per m^2, Plant height (cm), Number of branches per plant and Number of leaves per plant of brinjal under apple trees and in sole cropping system

Number of plants per m^2			Plant height (cm)		Number of branches per plant		Number of leaves per plant	
Parameters	**Sole Brinjal**	**Apple + Brinjal**	**Sole Brinjal**	**Apple + Brinjal**	**Sole Brinjal**	**Apple + Brinjal**	**Sole Brinjal**	**Apple + Brinjal**
Mean	4.16	3.90	80.64	78.70	11.48	10.72	10.56	10.12
Variance	0.03	0.02	0.29	0.97	0.11	0.20	1.43	2.99
Standard deviation	0.18	0.16	0.54	0.98	0.39	0.44	1.19	1.73
Standard error	0.08	0.07	0.24	0.44	0.15	0.20	0.53	0.77

APPENDIX IX-: Analysis of variance of t_{cal} Number of fruits per plant, Fruit length (cm), Fruit diameter and Fruit yield (q/ha) of brinjal under apple trees and in sole cropping system

Number of fruits per plant			Fruit length (cm)		Fruit diameter (cm)		Fruit Yield(q/ha)	
Parameters	**Sole Brinjal**	**Apple + Brinjal**	**Sole Brinjal**	**Apple + Brinjal**	**Sole Brinjal**	**Apple + Brinjal**	**Sole Brinjal**	**Apple + Brinjal**
Mean	4.87	4.48	14.92	13.72	5.02	4.94	127.85	122.74
Variance	0.00	0.07	0.09	0.32	0.12	0.13	0.37	0.53
Standard deviation	0.06	0.27	0.30	0.57	0.34	0.36	0.61	0.73
Standard error	0.02	0.12	0.13	0.25	0.15	0.16	0.27	0.33

APPENDIX X-: Analysis of variance of t_{cal} Number of plants per m^2, Plant height (cm), Number of branches per plant and Number of leaves per plant of capsicum under apple trees and in sole cropping system

Number of plants per m^2			Plant height (cm)		Number of branches per plant		Number of leaves per plant	
Parameters	**Sole Capsicum**	**Apple + Capsicum**	**Sole Capsicum**	**Apple + Capsicum**	**Sole Capsicum**	**Apple + Capsicum**	**Sole Capsicum**	**Apple + Capsicum**
Mean	3.30	2.88	78.20	76.32	12.60	10.86	9.14	7.82
Variance	0.00	0.01	0.27	1.05	0.72	0.24	1.11	0.61
Standard deviation	0.04	0.08	0.52	1.03	0.85	0.49	1.05	0.78
Standard error	0.02	0.04	0.23	0.46	0.38	0.22	0.47	0.35

APPENDIX XI-: Analysis of variance of t_{cal} Number of fruits per plant, Fruit length (cm), Fruit diameter and Fruit yield (q/ha) of capsicum under apple trees and in sole cropping system

Number of fruits per plant			Fruit length (cm)		Fruit diameter (cm)		Fruit Yield(q/ha)	
Parameters	**Sole Capsicum**	**Apple + Capsicum**	**Sole Capsicum**	**Apple + Capsicum**	**Sole Capsicum**	**Apple + Capsicum**	**Sole Capsicum**	**Apple + Capsicum**
Mean	7.09	6.18	5.01	4.90	5.80	5.10	99.80	96.27
Variance	0.03	0.00	0.05	0.00	0.10	0.00	0.52	0.52
Standard deviation	0.17	0.08	0.22	0.05	0.31	0.06	0.72	0.72
Standard error	0.03	0.01	0.10	0.02	0.14	0.03	0.32	0.32

APPENDIX XII-: Analysis of variance of t_{cal} Number of plants per m2, Plant height (cm), Number of branches per plant and Number of leaves per plant of black gram under apple trees and in sole cropping system

Number of plants per m^2			Plant height (cm)		Number of branches per plant		Number of leaves per plant	
Parameters	**Sole Black gram**	**Apple + Black gram**	**Sole Black gram**	**Apple + Black gram**	**Sole Black gram**	**Apple + Black gram**	**Sole Black gram**	**Apple + Black gram**
Mean	11.12	10.96	62.42	60.64	05.44	5.40	41.36	27.60
Variance	0.01	0.00	1.07	0.17	0.61	0.44	3.31	1.90
Standard deviation	0.10	0.07	1.04	0.41	0.78	0.66	1.82	1.38
Standard error	0.05	0.03	0.46	0.18	0.35	0.30	0.81	0.62

APPENDIX XIII-: Analysis of variance of t_{cal} Number of pods per plant, Pod length (cm), Number of seeds per pod and Seed yield (q/ha) of black gram under apple trees and in sole cropping system

Number of pods per plant			Pod length (cm)		Number of seeds per pod		Seed Yield(q/ha)	
Parameters	**Sole Black gram**	**Apple + Black gram**	**Sole Black gram**	**Apple + Black gram**	**Sole Black gram**	**Apple + Black gram**	**Sole Black gram**	**Apple + Black gram**
Mean	35.92	33.15	2.86	2.50	7.79	6.45	7.20	5.27
Variance	0.51	0.01	0.00	0.00	0.00	0.00	0.04	0.22
Standard deviation	0.72	0.09	0.04	0.04	0.05	0.05	0.20	0.47
Standard error	0.32	0.04	0.02	0.02	0.02	0.02	0.09	0.21

APPENDIX XIV -: Analysis of variance of growth and yield parameters of apple tree (Malus domestica)

Source of variation	df	Mean sum of squares				
		Tree height (m)	Tree diameter (cm)	Crown spread (m^2)	Crown volume (m^3)	Fruit Yield (kg/plant)
Treatment	4	0.003	1.401	0.027	0.040	9.273
Error	8	0.007	0.578	0.011	0.007	0.054

APPENDIX XV -: Analysis of variance of carbon sequestration potential of apple-based agroforestry and sole crop systems

Source of variation	df	Mean sum of squares	
		Total Biomass of the System (t/ha)	Total Carbon Stock of the System (t/ha)
Treatment	8	1,197.91	292.114
Error	16	0.001	0.001

APPENDIX XVI -: Analysis of variance of physical properties under apple-based agroforestry systems

Source of variation	df	Mean sum of squares					
		Bulk density(g/cm^3)		Particle density(g/cm^3)		Porosity (%)	
		0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Treatment	8	0.004	0.002	0.002	0.001	18.041	1.945
Error	16	0.001	0.001	0.001	0.001	14.823	0.008

APPENDIX XVII-: Analysis of variance of chemical properties under apple-based agroforestry systems

Source of variation	df	Mean sum of squares					
		Electrical Conductivity (dS/m)		Soil pH		Organic Carbon(%)	
		0-15 cm	15-30 cm	0-15 cm	15-30 Cm	0-15 cm	15-30 cm
Treatment	8	0.012	0.004	0.922	0.828	0.362	0.076
Error	16	0.002	0.001	0.003	0.001	0.002	0.001

APPENDIX XVIII-: Analysis of variance of nutrient dynamics under apple-based agroforestry systems

Source of variation	df	Mean sum of squares					
		Nitrogen (kg/ha)		Phosphorus (kg/ha)		Potassium (kg/ha)	
		0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Treatment	8	11778.39	10501.82	33257	6377	1329.51	1551.08
Error	16	0.092	0.0462	0.018	0.026	0.096	0.247

APPENDIX XIX -: Analysis of variance of soil biological properties under apple-based agroforestry systems and sole crops

Source of variation	df	Mean sum of squares					
		C_{mic}		N_{mic}		P_{mic}	
		0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Treatment	8	17619.378	13450.09	1948.499	1729.72	40.490	11.890
Error	16	5.201	3.09	2.98	1.76	4.468	0.004

APPENDIX XX-: Analysis of variance of soil enzymatic properties under apple-based agroforestry systems and sole crops

Source of variation	df	Mean sum of squares							
		Dehydrogenase (µg/g dry soil/hour)		Catalase (mg KMnO4/g dry soil/hour)		Acidic Phosphatase (µg/g dry soil/hour)		Alkaline Phosphatase (µg/g dry soil/hour)	
		0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Treatment	8	13.581	10.967	0.754	3.294	5.814	6.425	4.084	1.502
Error	16	0.05	0.03	0.141	0.092	0.001	0.036	0.002	0.003

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Title of the thesis	**:**	**"Ecological and Economical Appraisal of Apple based Agroforestry Systems in Kullu Valley of Himachal Pradesh"**
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Minor/Specialization	**:**	Agroforestry
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ABSTRACT

The study entitled "Ecological and Economical Appraisal of Apple based Agroforestry Systems in Kullu Valley of Himachal Pradesh" was carried out in apple orchard of Bhindi Bai Village, Bajaura, Kullu. The experiment was laid out in Randomized Block Design, having nine treatments (sole apple, sole tomato, sole brinjal, sole capsicum, sole black gram, apple + tomato, apple + brinjal, apple + capsicum and apple + black gram) with three replications in order to assess the biomass, carbon stock, soil physico-bio-chemical properties and to work out economics of the various tree-crop combinations while for comparing growth and yield parameters of agricultural crops grown under agroforestry and sole cropping, Student 't' test was employed. The studies revealed that apple competed with agricultural crops (brinjal, capsicum and black gram) for moisture, nutrients and other limiting resources which resulted in poor performance (growth and yield) of agricultural crops except for tomato which performed better as an intercrop. Among all tree + crop combinations, the highest total biomass (44.05 t/ ha) and total carbon stock (21.73 t /ha) were recorded under apple + tomato. From economics point of view, the maximum (991971 Rs/ha) gross returns, net returns (566900.96 Rs/ha) and benefit-cost ratio (2.33) were obtained for apple + tomato. Among all the physico-chemical properties, bulk density, particle density, soil porosity, pH and organic carbon were found to be affected significantly while, the soil moisture remained unaffected. Results also indicated that with increase in soil depth from 0-15 cm to 15-30 cm, particle density, bulk density and pH increased whereas, reverse trend was observed for porosity, EC, soil moisture and soil organic carbon. The available N, P and K contents decreased with the increase in soil depth under all treatments. Among all treatments, the maximum nitrogen and potassium contents were observed under apple + black gram while, the maximum phosphorus was recorded under apple + brinjal**.** Microbial biomass and annual flux of C, N and P were recorded the highest under apple + tomato agroforestry system at both soil depths. However, microbial biomass and flux decreased with the increase in soil depth. The soil enzymatic activities *viz.,* dehydrogenase, catalase, acid and alkaline phosphatase were also observed highest under apple + tomato.

The improvement in soil physico-chemical properties indicated that the selected tree-crop combinations are sustainable. Agroforestry system integrating fruit tree (apple) with agricultural crops (tomato, brinjal, capsicum and black gram) resulted in higher biomass production and are potential carbon sinks over agricultural cropping system. Among all the studied tree-crop combinations, apple + tomato proved as the best combination, the farmer of the area should adopt from ecological and economical point of view.

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Whethersponsoredbysome State/CentralGovt./Univ./SAARC : NA

Scholarship/Stipend/Fellowship, any Other financial assistance received During the study period : University stipend

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