Performance of different teak based agroforestry systems in Cuttack district of Odisha

A Thesis submitted to the
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in Partial fulfilment of the Requirements for the Degree of
Master of Science in Forestry
(Silviculture and Agroforestry)

By
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CERTIFICATE – I

This is to certify that the thesis entitled **"Performance of different Teak based Agroforestry Systems in Cuttack District of Odisha"** submitted in partial fulfilment of the requirement for the award of degree of **MASTER OF SCIENCE IN FORESTRY (SILVICULTURE AND AGROFORESTRY)** to the Orissa University of Agriculture and Technology is a faithful record of *bona fide* and original research work carried out by **TRUPTI BARAI** under my guidance and supervision. No part of this thesis has been submitted for any other degree or diploma.

It is further certified that the assistance and help received by her from various sources during the course of investigation has been duly acknowledged.

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CERTIFICATE – II

This is to certify that the thesis entitled **"Performance of different Teak based Agroforestry Systems in Cuttack District of Odisha"** submitted by **TRUPTI BARAI** to the Orissa University of Agriculture and Technology, Bhubaneswar in the partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE IN FORESTRY (SILVICULTURE AND AGROFORESTRY)** has been approved by the students' advisory committee and the external examiner.

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ABSTRACT

A field experiment was conducted in four different villages of Athagarh block of Cuttack district, to study the performance of teak grown on the field bunds along with different field crops during the *kharif* season 2015. The field crops were paddy, arhar, colocasia, mango ginger, okra, brinjal and chilli. Observations on various growth parameters (Height, GBH, DBH and tree volume) of teak tree were recorded from ten numbers of tree species. Their associated soil properties and economics of the tree crop combination were also computed. Amongst the various tree – crop combination, the maximum tree height, DBH, GBH and volume were recorded with teak + chilli followed by teak + okra combination. Minimum values of all growth parameters were observed in teak + arhar system. The crop yield was found maximum with teak+ brinjal (12.98 t ha^{-1}) and the yield reduction was to the extent of 8.91 % over control. Teak + arhar system had the minimum crop yield of 0.74 t ha^{-1} (12.94% reduction in yield over control). The pH, Organic C and available N, P and K status of soil were found higher in teak + chilli system closely followed by teak + brinjal as compared to their respective control while the minimum values were observed with teak + arhar system. However, the, the pH of soil showed an increasing trend with increase in soil depth, and the electrical conductivity decreased with increasing soil depth. Although reduction in crop yield was observed when trees were there in the field bunds but gross return, net return and B: C ratio were significantly higher in tree based system as compared to controlled condition. Maximum net return (₹ 1,80,349 ha^{-1}) was obtained from teak + chilli agroforestry system while the B: C ratio was found to be the highest (3.68) in teak+ okra system. Available soil fertility after harvest of the crop with regard to organic carbon, available N, P and K was either maintained or improved in different teak based system suggesting sustainability of the system.

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ABBREVIATIONS USED

%	:	Percentage
ha	:	Hectare
q	:	Quintal
m	:	Metre
cm	:	Centimetre
mm	:	Millimetre
ml	:	Millilitre
kg	:	Kilogram
g	:	Gram
^{o}C	:	Degree centigrade
t	:	Tonne
i.e.,	:	That is
CD	:	Critical differences
SEm	:	Standard error mean
Fig.	:	Figure
GBH	:	Girth at Breast height
DBH	:	Diameter at Breast Height
BCR	:	Benefit-cost ratio
et al.,	:	Another

CHAPTER-I

INTRODUCTION

INTRODUCTION

Agroforestry is a land use management system in which trees or shrubs are grown around or among crops or pastureland. It combines shrubs and trees in agricultural and forestry ecosystems to create more diverse, productive, profitable, healthy, ecologically sound, and sustainable land-use systems. In the broadest sense, it encompasses a wide range of production systems, from forest to crop monoculture. In terms of composition, structure, management practices, and production functions, wide variations exist among these systems. Bene *et al.,* 1977 defines as a suitable land management system that increases total production, combines agricultural crops, tree crops, forest plants and/or animals simultaneously or sequentially and applies management practices compatible with cultural patterns of the local population. There must be significant ecological and economic interactions between the woody and non-woody components in an agroforestry system (Lundgren and Raintree, 1982). It is recognized as a land-use option in which trees provide both products and environmental services. In agroforestry systems, the trees grown on different farmlands in the same locality when aggregated can bring about improved wooded situation thereby enhancing environmental protection (Otegbeye, 2002).

The tree based land-use agroforestry system is an ideal scientific approach in restoring soil fertility and improving its quality in several ways. Agroforestry systems have the potential to reduce erosion and run-off, and to maintain soil organic matter, improve soil physical properties and augment nitrogen fixation and promote efficient nutrient cycling (Nair, 1984). Addition of plant biomass and nutrient pumping from deeper layers in agroforestry systems improves the soil fertility. The fertility of soil improves under the tree cover, which checks soil erosion adds soil organic matter, available nutrients and replenishes the nutrients through effective recycling mechanisms. However, in certain situations trees may have an adverse effect on soils. The magnitude of benefits or adverse effects depends on a number of site-specific factors and attributes of associated tree species.

Rural people have been discovered to have a wealth of indigenous knowledge and have incorporated trees in production systems in areas where they lived for a very long period of time (Evans and Alexander, 2004). Intercropping of agroforestry trees with crop plants includes sequential systems, where the trees and crops occupy the same piece of land at different times, and simultaneous systems, where the trees and crops are grown on the same piece of land at the same time. Simultaneous systems can vary greatly in the relative proportions of trees and crops and in their spatial arrangement (Young, 1989).

The emergence of agroforestry as an important land-use activity has raised the issue of agroforestry species. Agroforestry species usually refers to woody species and come to known as "multipurpose trees" (MPTs) or "multipurpose trees and shrubs" (MPTS). Multipurpose trees in agroforestry refer to their use for more than one service or production function in an agroforestry system (Burley and Wood, 1991). The MPTs are said to most distinctive component of agroforestry and the success of agroforestry as a viable land-use option depends on exploiting the potential of the multipurpose trees. The fast growing multipurpose trees with selected attributes of tree species widely used in agroforestry systems of Odisha are *Acacia mangium, Tectona grandis, Dalbergia sissoo and Gmelina arborea.*

Teak (*Tectona grandis* Linn. F.) is one of the most valuable timber tree species of the world. It occurs naturally between 9° to 26° N latitude and 73° to 140° E longitude in the tropical and sub-tropical regions of south and south-east Asia which include peninsular India, Myanmar, Thailand and Laos (White, 1991). India has the maximum genetic variability of teak with natural distribution of over 8.9 million ha (Tewari, 1992). The total area of natural teak forests in India has been estimated to be 9.77 m ha, which is about 13% of the total forest area of the country (Keswani, 2002). Large scale plantations of teak have been raised, both within and outside its range of natural distribution due to ever increasing demand of its timber. It is cultivated throughout the tropics in varying extent. Globally, teak ranks third among the tropical hardwood species in plantation area and constitutes about 8% of the plantations (Pandey and Brown, 2000).

In India, the history of teak planting dates back to the year 1842 when the first teak plantation was attempted at Nilambur in Kerala state (Prabhu, 2003). Presently, there is more than 1.5 million ha area under teak plantation in India. Teak plantations are being raised at an average annual rate of about 50,000 ha (Subramanian *et al.*, 2000).

Teakwood is a valuable multipurpose timber preferred for quality and decorative applications and exported for centuries from India. It is excellent for furniture, doors, decorative veneer, plywood and all sorts of constructions. Teakwood has high rating in most of the timber qualities such as strength, durability and workability. It has been described as one of the most durable timbers of the world (Pearson and Brown, 1932). Traditional use of teak poles for electricity transmission is a time tested testimony of its suitability for outdoor uses. Among Indian timbers, only sandalwood and rosewood command a higher price than that of teak wood. The inherent good qualities of the timber, its early fast growth and the ease in plantation establishment makes teak the most preferred species among users, foresters, farmers and private entrepreneurs in many countries (Indira and Basha, 1999). Due to high timber value of teak, the participation of intended cultivators and farmers in plantation activities and agroforestry practices is increasing day- by- day in India.

In Coastal district of Odisha, teak plantation in field bunds under rainfed uplands are being taken up by farmers under system diversification programme to ensure more return to the farmers. Upland crops arhar, colocasia, mango ginger, paddy and vegetables like chilli, brinjal and okra are grown in field bund planted teak in early years of tree growth for additional return from the same land management unit. But the information available either from research or farmers field on these aspects is meagre.

Keeping in view the above facts, a study on "Performance of different Teak-based Agroforestry Systems in Cuttack District of Odisha" was undertaken with the following objectives:

1. To study the growth performance of teak and associated crops in the system
2. To study the soil chemical properties of Teak based Agroforestry systems.
3. To work out the economics of teak based Agroforestry systems

CHAPTER-II

REVIEW OF LITERATURE

CHAPTER-II

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Agroforestry systems are gaining popularity worldwide because of their multiple benefits especially suitability to varying climatic conditions, soil types, higher productivity and profitability as well as resilience to climatic change besides socio-economic benefits. In the recent past agroforestry plantations has also been extensively adopted by farmers of Odisha. *Tectona grandis* has been accepted widely in recent past as a suitable species for agroforestry systems because of its highly economic timber, deciduous nature and open canopy. Though, much work has been done in the past in different parts of world on its performance in plantations and agroforestry systems, its effect on soil physico-chemical properties, allelopathic effect on crops, productivity and profitability, little work has been done in these aspects in Odisha condition. Therefore, an attempt has been made in this chapter to review some related literature which has either direct or indirect bearings on these aspects and are presented under the following heads;

1. Concept of agroforestry
2. Growth Performance of teak in plantations and agroforestry systems
3. Performance of understorey crops in teak base agroforestry systems
4. Advantages of agroforestry systems
5. Allelopathic effect of *Tectona grandis* on crops
6. Soil Improvement by agroforestry systems
7. Economics of teak plantations

2.1 Concept of agroforestry

Agroforestry is a collective name for land-use systems in which woody perennials such as trees, shrubs and bamboos are grown in association with herbaceous plants such as crops, pasture and/or livestock in spatial or temporal arrangements in which there are both ecological and economic interactions between the tree and non-tree components of the system (Young, 1989). The main components of agroforestry systems are trees, shrubs, crops, pastures and livestock together with environmental factors of climate, soils and landforms. Essentially there must be interaction between the tree and non-tree parts of the system. Agroforestry also covers biomass transfer of biological material such as incorporation of the leaf litter into the soil or feeding of such litter as browse to livestock with subsequent return to the soil as manure (Young, 1988).

Cultivating trees in combination with crops and livestock is an ancient practice. However, several factors have contributed to a rising interest in agroforestry since the 1970s: the deteriorating economic situation in many parts of the developing world; increased tropical deforestation; degradation and scarcity of land because of population pressures; growing interest in farming systems; intercropping and environment (Nair, 1993).

Main agroforestry practices include improved fallows, taungya (growing annual agricultural crops during the establishment of a forestry plantation), home gardens, alley cropping, growing multipurpose trees and shrubs on farmland, boundary planting, farm woodlots, orchards or tree gardens, plantation/ crop combinations, shelterbelts, windbreaks, conservation hedges, fodder banks, live fences, trees on pasture and apiculture with trees (Nair, 1993; Sinclair, 1999).Recently ICRAF defined that, "Agroforestry as a dynamic, ecologically based natural resources management system that through the integration of trees on farmland and in the agricultural landscape, diversifies and sustains production or increased social, economic and environmental benefits for land users at all levels." Vergara (1982) defined that agroforestry as a "system of combining agricultural and tree crops of various longevity (ranging from annual through biennial and perennial plants), arranged either temporally (crop rotation) or spatially intercropping to maximize and sustain agricultural production."

Agroforestry is an ideal land-use option as it optimizes tradeoffs between increased food production, poverty alleviation and environmental conservation (Izac, 2000). Agroforestry also mitigates the demand for wood and reduces pressure on natural forests (Pandey, 2002). India is estimated to have between 14,224 million (Ravindranath and Hall, 1995) and 24,602 million (Prasad *et al.*, 2000) trees outside forests, spread over an equivalent area of 17 million ha (GOI, 1999) supplying 49% of the 201 million tonnes of fuelwood and 48% of the 64 million cum of timber consumed annually (Rai and Chakrabarti, 2001). Forestry mitigation projects provide an opportunity to promote agroforestry in India.

Ajit *et al.* (2010) mentioned that in India, agroforestry practices are very age old but the advent story of organized agroforestry research began in 1979 at Imphal, the capital of Manipur when a seminar on agroforestry was organized by the Indian Council of Agricultural Research (ICAR), New Delhi to accumulate and compile the data pertaining to the research and development of agroforestry in India.

2.2 Growth performance of teak in plantations and agroforestry systems

From a study on the performance of Teak (*Tectona grandis* Linn. F.) in sole and agroforestry plantation on Wheat Fields in Eastern Uttar Pradesh, it found out that the growth parameters of teak viz. tree height, bole height, DBH, crown length, crown width and number of branches showed significantly ($p<0.05$) higher values indicating thereby better teak growth in wheat based agroforestry system as compared to its sole plantation. The height of teak in agroforestry system was 9.67 m while in sole plantation it was only 8.42 m. The DBH and bole height of teak ranged from 20.15 to 22.09 cm and 2.72 to 3.96 m under sole and agroforestry plantation, respectively. For wheat crop, it was found that morphological growth and yield attributing characters as well as grain yield were all significantly ($p<0.05$) higher in sole wheat crop than in interaction with *T. grandis*. The grain yield in sole wheat crop was 30.9 q ha^{-1} compared with 24.7 q ha^{-1} under agroforestry system (Sharma *et al.* 2011).

Heque and Osman (1993) measured height and DBH in 26 years old plantation in pure teak and in mixed plantation of *Tectona grandis* (60%) with *Dipterocarpus turbinatus* (30%), *Syzygium grande* (7%) *and Amoora rohituka* (3%) at Kaptai, Bangladesh. They observed that height and diameter did not vary significantly between two pure teak plantations but the diameter was significantly higher in mixed plantation. The average height of teak was found to be 18.30 m in mixed plantation and 16.17 m and 18.91 m in two pure stands where as the average DBH was found to be 35.59 cm in mixed plantation and 23.14 cm and 24.59 cm in two pure stands. In mixed plantation teak performed better than other species.

The effect of intercropping teak with *Leucaena* in a simulated taungya system in humid tropical region of Central Kerala, India was studied. It was revealed that although mean height and DBH of teak and *Leucaena* did not vary significantly between treatments during first 2 years, yet from 35 months after planting, inter-planting treatments exerted a profound influence of teak growth. Teak saplings in 1:2

teak- *Leucaena* mixture showed significantly higher radial growth than other combinations. They were also consistently taller than other treatments. Average height and diameter decreased in the order of 1:2 teak- *Leucaena* > 1:1 teak- *Leucaena* > 2:1 teak- *Leucaena* > 100% teak (Kumar *et al.* 1998).

Zahabu *et al.* (2015) studied the effects of planting spacing on growth of teak planted at square spacing regimes of 2m, 3m and 4m at Longuza Forest plantation, Tanzania. They found out that the mean total heights at the age of 14 years were significantly lower in spacing of 2m x 2m (19.52m) as compared with other two remaining spacing regimes of 3m x 3m (23.09m) and 4m x 4m (24.05m). The mean D.B.H also increased significantly with increase in spacing but the basal area and total volume tends to be higher in 3m spacing followed by 4m and 2m spacing.

A study was carried out on the suitability of tree species in an agroforestry system comprising of arable crops (paddy, maize, sunhemp), silvicultural crops (*Eucalyptus tereticornis, Casuarina equisetifolia, Acacia molucana, Tectona grandis, Dalbergia sissoo*), horticultural crop (Sapota) and pasture at Dharwad in which it was inferred that highest DBH recorded by *A. molucana* (122cm) followed by *D. sissoo* (47.8cm) and teak (46.5cm). However, highest plant height was recorded by *Eucalyptus* (20.4m) followed by *Casuarina*. Lowest plant height was recorded in *D. sissoo* (7.7m) and teak (9.4m). Timber volume was also higher in *Eucalyptus* (273.6 m^3 ha^{-1}) and lowest in teak (42 m^3 ha^{-1}) and *D. sissoo* (35.4 m^3 ha^{-1}) which is due to slow growth of these trees. (Patil *et al.*, 2000)

2.3 Performance of understorey crops in teak based agroforestry systems

Mutanal *et al.* (2009) reported a slight decrement in yield of crops with the advancement of age of trees while conducting an experiment with agroforestry comprising arable crops (sorghum, groundnut, chilli and ragi), silvicultural crop (teak), horticultural crop (papaya) and pasture crops (subabul and guinea grass) during 1984 on red gravelly soil at Dharwad, Karnataka. They have also found out that inclusion of groundnut in agroforestry system had positive effect in improving the grain yield of succeeding crop. Of the 4 arable crops, one crop was grown each year in fixed rotation in the interspaces of teak rows from 1994-2005. Grain yield of arable crops was higher in 20 m alley of teak + papaya rows as compared to 10m alley of teak+ papaya. Among the four crops, average grain yields were obtained in the order teak- *Leucaena* mixture showed significantly higher radial growth than other combinations. They were also consistently taller than other treatments. Average height and diameter decreased in the order of 1:2 teak- *Leucaena* > 1:1 teak- *Leucaena* > 2:1 teak- *Leucaena* > 100% teak (Kumar *et al.* 1998).

[illegible] with two distances (0 - 2 m [illegible] m) from teak alley in teak based agroforestry systems on medium black soil under rainfed condition at MARS, Dharwad during *kharif* 2007 and 2008. They found out that plant height among the legumes was highest in teak + greengram (22.6 cm) followed by teak + soybean (22.2 cm) at harvest. Plant height was reduced by 5 per cent in agroforestry system as compared to sole cropping systems. The highest number of leaves 26.5 was recorded in teak + soybean as compared to other treatments. Plant height and number of leaves were significantly lower at 2 m distance as compared to 4 m distance from teak alley.

A study on the effect of teak on the growth and yield of Maize at different inter-crop spacing was carried out in which they conducted trials under young teak plantations in blocks of 200 m x 500 m at ages 1 to 3 years at Ashanti Mampong and found out that highest mean crop height of maize occurred under Teak aged 2 years at spacing 40cm x 150cm, i.e. 75.0 cm^{-1} and lowest occurred under Teak aged 1 years at spacing 40cm x 80cm, i.e. 50.3 cm^{-1}. It was also observed that highest mean crop leaf count occurred under Teak aged 2 years at spacing 40cm x 80cm, i.e. lowest occurred under Teak aged 1 years at spacing 40cm x 80cm. (Quarcoo, 2010)

Pujar *et al.* (2007) studied suitable medicinal and aromatic plants as intercrops with teak. There were eight treatment combinations of four medicinal and four aromatic plants viz., aloe (*Aloe vera*), kalmegh (*Andrographis peniculata*), Coleus (*Coleus forskohli*), Stevia (*Stevia rebaudiana*), citronella (*Cymbopogon wintereanus*), lemongrass (*Cymbopogon flexuosus*), palmarosa (*Cymbopogon martinii*) and patchouli (*Pogostemon patchouli*) grown under teak (*Tectona grandis*). The significantly higher herbage yield was obtained in aloe (24.50 t ha^{-1}) than in other crops. The next best crop in terms of herbage yield was lemongrass (21.01 t ha^{-1}) which was significantly superior to remaining crops. Herbage yield ranged from 0.98 to 10.07 t per ha in remaining crops. Compared to their respective sole crops there was marginal reduction (-2.39 to -14.02%) in herbage yield of all the medicinal and aromatic crops (except *Coleus*) when they were grown with teak. Whereas, herbage yield of *Coleus* was increased by 12.93 per cent when grown with teak. This can also be evidenced from significantly higher relative crop yield (112.93%) in case of *Coleus*. In remaining crops, relative crop yield was less than 100 per cent indicating that herbage yield in association with teak was lesser than their sole crops.

In an evaluation of the performance of crops in agroforestry with teak (*Tectona grandis*), maharukh (*Ailanthus excelsa*) and tamarind (*Tamarindus indica*) on reclaimed salt affected soils, it was advocated that a reduction in yield of all the crops interplanted in the plantations compared with the control (outside plantation), but the reduction was minimum with tamarind because of less canopy. Lentils, gram, sorghum, berseem, wheat and rice could be grown successfully with tamarind without much reduction in yield, but with teak only berseem and gram could be grown, while with maharukh only gram could be grown with 25% reduction in yield. All the tree species benefitted by growing all the interspace crops because additional water was made available to them through irrigation. (Dagar *et al.*, 1995)

Purwanto *et al.* (2003) conducted an experiment in which yields were determined in cassava (*Manihot esculenta*), maize (*Zea mays*), rice (*Oryza sativa*), groundnut (*Arachis hypogea*) and soybean (*Glycine max*) which were grown in a planted teak (*Tectona grandis*) forest under agroforestry management in a moist tropical region in Medium Forest District, East Java, Indonesia during 2000-2001. The average yields were 16.1, 3.2, 3.4, 1.8 and 1.3 tons ha^{-1} in the cassava, maize, groundnut and soybean in the Medium Forest District were higher than those of average yields in ordinary fields of Indonesia and also in most of other tropical countries despite of growing on the rainfall conditions. These high yields of the crops are considered partly because of humid and high temperature climate conditions in East Java. However, the high yield of crops under agroforestry management seemed more influenced by the teak plantation management in East Java including an application of intensive cultural practices such as soil management (tillage in land preparation and weeding), fertilizer application with chemicals or manure and leaf litter supply from teak forests.

A survey was conducted on an existing agroforestry plantation in the Madurai district of Tamil Nadu, India, where rice was the predominant crop, to determine the mutual influence of teak (*Tectona grandis*) and rice in an agrisilvicultural system. Teak trees were planted on the bunds of rice fields. Ten years after planting, the teak trees attained 7 to 8 m in height, 53.5 cm diameter at breast height and a total biomass of 8448.73 kg ha^{-1} (dry weight). The grain yield of rice was 4480, 4600 and 4460 kg ha^{-1} at 2, 4 and 6 m distance, respectively from the base of the teak trees. They also inferred that teak can be successfully intercropped with rice under irrigated and rainfed conditions in the sub-humid and semi-arid zones of Tamil Nadu and similar areas. (Rajendran *et al.*, 2003)

2.4 Advantages of agroforestry systems

Various workers at various places have reported the advantages of agroforestry. Most of the findings were in favour of this system with increased productivity and improved soil conditions. Higher yields of crops have been observed in forest-influenced soils than in ordinary soils. In the Tarai area of Uttar Pradesh, taungya cultivators harvested higher yields of crops such as maize, wheat, pulses, etc. without fertiliser. Approximately, 20% higher yields of grains and wood have been reported in agroforestry areas of Haryana and western Uttar Pradesh than from pure agriculture (Dwivedi and Sharma, 1989). Experiments conducted at IGFRI, Jhansi indicate that the total yield of fodder is more when fodder grasses are grown with fodder trees than pure fodder grass cultivation. *Leucaena leucocephala* inter-cropped with agricultural crops and fodder grasses, increased the total yield of food grains, fodder and fuel (Pathak, 1989).

Sharrow and Ismail (2004) studied about the carbon and nitrogen storage in agroforests, tree plantations and pastures in western Oregon, USA in 11 year old Douglas fir (*Pseudotsuga menziesii*) + perennial rye grass (*Lolium perenne*) + subclover (*Trifolium subterraneum*) agroforests, rye grass + subclover pastures and Douglas fir timber plantations near Corvallis, Oregon. They concluded that agroforests accumulated approximately 740 kg ha^{-1} $year^{-1}$ more carbon than forests and 520 kg ha^{-1} $year^{-1}$ more carbon than pastures over 11 years since planting. Total nitrogen content of agroforests and pastures, both of which included a nitrogen-fixing legume, were approximately 530 and 1200 kg ha^{-1} greater than plantations, respectively. They also suggested that agroforests such as silvopastures, may be more efficient at accreting carbon than plantation or pasture monocultures. However, pastures may accrete more nitrogen than agroforests and plantations.

A study about the role of agroforestry systems in improving soil organic matter status, microbial activity and nitrogen availability to manage the fertility of moderately alkaline soil effectively was conducted at Karnal in various systems including rice-berseem crop rotation; agrisilvicultural systems of Acacia; Eucalyptus and Populus along with rice- berseem and single species tree plantations. They found out that microbial biomass carbon was low in rice- berseem crops (96.14 $\mu g\ g^{-1}$ soil) and increased in soils under tree plantations (109.12- 143.40 $\mu g\ g^{-1}$ soil) and agrisilvicultural systems (133.80- 153.40 $\mu g\ g^{-1}$ soil). Microbial biomass was higher by 42% (microbial carbon) and 13% (microbial N) in tree based system as compared to monocropping. They also found out that soil carbon increased by 11-52%, nitrogen levels by 8-74% and nitrogen mineralization by 12-37% in tree based systems as compared to monocropping. (Kaur *et al.*, 2000)

Sanchez (1987) stated that appropriate agroforestry systems improve soils, physical properties, maintain soil organic matter and promote nutrient cycling. Nitrogen fixing trees are mentioned as one of the most promising components of agroforestry system. The leaf litter after decomposition forms humus, releases nutrients and improves various soil properties. It also reduces the fertiliser needs. Growing of trees and fodder crops, including fodder trees is more economical, particularly on marginal lands. Observations taken in hot arid and semi-arid areas of Rajasthan indicate that marginal lands are incapable of sustaining stable and dynamic cultivation of agricultural crops. Silvopasture consisting of growing trees such as *Prosopis, Albizia, Zizyphus* and *Acacia* species may provide many times more returns per unit of land than agriculture under such conditions (Gupta and Mohan, 1982).

Sharma (2012) opined that, out of the several benefits accrued from agroforestry systems in terms of soil quality, nutrient cycling is the most predominant. In a soil-plant system, plant nutrients are in a state of continuous, dynamic transfer. Plants take up nutrients from the soil and use them for metabolic activities. In turn, these nutrients are returned back to the soil either naturally as litter falls in and as pruning in some agroforestry systems or through root senescence. These plant parts are decomposed as a result of microbial activities and release the nutrients held in them into the soil. The nutrient then becomes available for plant uptake once again (Nair *et al.*, 1999). Thus, the agroforestry land use systems play a tremendous role in influencing the nutrient flows and overall soil quality.

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Nair *et al.* (2009) suggested agroforestry as an integrated approach of sustainable land use due to its production and environmental benefits. They also inferred about its perceived potential which is based on the premise of the greater efficiency of integrated systems in resource capture and utilization than single species systems, thus resulting in greater net carbon sequestration.

2.5 Allelopathic effect of *tectona grandis* on crops

A study on the bioassay of the aqueous extracts of the leaves of *T. grandis* was carried out and it was found that seed germination and seedling growth of *V. mungo* were inhibited. It was also reported that the reduction of seed germination was found to be up to 48% at 10% concentration. At this concentration, the epicotyls showed 67.3% reduction in length when compared to the control and the hypocotyl demonstrated 64.7% reduction in length. In pot culture experiments, a 4% aqueous extract of the leaves was found to inhibit seed germination and the growth of the seedlings. This concentration of leaf extracts reduced seed germination percentage to the tune of 70%. There was reduction in shoot length to about 33.3% and the root length about 54.3. Higher concentration of aqueous extracts of the leaves prevented seed germination and aqueous extracts of the leaves of *T. grandis* caused a corresponding reduction of the biomass of *V. Mungo*. (Evangeline *et al.*, 2012)

Leela and Arumugam (2014) reported that the aqueous leaf extract of teak adversely reduced the germination percentage of green gram and chilli. The magnitude of reduction differed depending upon the crop and the concentration of the extracts applied. But an exception, at 2.5% concentration of teak leaf extract promoted the germination of both crop seeds and higher concentrations (5, 10, 15 and 20%) inhibited the germination percentage. They also stated that chilli was found to be most sensitive than green gram. The germination inhibition was 48% in green gram and 55% in chilli at 20% teak leaf extract concentrations. The root length was significantly reduced with increasing extract concentration in green gram and chilli. The seedling growth of both green gram and chilli showed a gradual increase in root length and shoot length when treated with 2.5% of teak leaf extract over control. Among the concentrations of the teak leaf extract the 2.5% extract alone showed a promotory effect while the other concentrations exhibited inhibitory effect on seedling growth of green gram and chilli. The radicle length inhibition was more at 20% concentration of leaf extract in chilli (70.8%) and in green gram (65.4%).

From an assessment on the allelopathic effect of *T. grandis* leaves extract on antioxidant enzymes in the seeds of *Vigna mungo* L. (Black gram) and *Vigna radiata* L. (Green gram) at coastal area of Cuddalore District, Tamil Nadu, it was found that the leaf extract of *T. grandis* exhibited a promontory effect in enzymes catalase, peroxidase and polyphenol oxidase in 5% extract treatment and an inhibitory effect in all other concentrations employed over control and it was also suggested that the intensity of inhibition was directly proportional to the concentration of the extract employed and the intensity of decrease was concentration dependent. There was a gradual decrease in catalase, peroxidise and polyphenol oxidase content of black gram and green gram with the increase of concentration of extract. The intensity of inhibition increased as the concentration of leaf extract decreased. (Manimegalai and Manikandan, 2010)

Mensah *et al.* (2015) studied about the allelopathic effect of topsoil extract from *Tectona grandis* plantation on the germination of *Lycopersicum esculentum*. They conducted a study to determine the effect of variation of masses of topsoil extracts from teak plantation on the germination and growth response of tomato seeds planted on another soil. They found that the top soil extracts were able to suppress the germination of tomato seeds and the effect increased with the mass used, i.e. 5 kg, 5.5 kg, 6 kg, 6.5 kg. There was a significantly progressive decrease in mean tall lengths of the seedlings with the mass of top soil indicating a growth inhibition. They also found that the effect was not very much pronounced in the comparison of the mean value of the short lengths of the seedlings.

A study on the effect of teak leaf extracts on the germination of rice and two weeds, i.e. jungle0rice (*Echinochloa colona*) and sedge (*Cyperus difformis*) was carried out and it was inferred that methanol extract of deciduous leaves exhibited sustained inhibitory action (Germination inhibition Index ~ 56- 61%) on jungle rice where as water extract inhibited sedge germination by 25- 45% and none of the extract exhibited significant inhibition on rice. (Kole *et al.*, 2011)

2.6 Soil improvement by agroforestry systems

Tornquist *et al.*, (1999) considered agroforestry systems as sustainable land-use alternatives for the humid tropics because they may imitate characteristics of natural ecosystems notably those that have beneficial effects on soil properties. Lower exchangeable bases and soil pH were noted in agroforestry treatments as compared to pastures. Extractable P was higher in the surface 25 cm of agroforestry plots. Total soil N, soil organic C and soil C: N ratios were not influenced by agroforestry systems. Agroforestry systems did not appear to improve soils in this study compared to pasture.

From a study, the increase in soil organic carbon status of surface soil 0.39 % to 0.52 % under *Acacia nilotica* + *Saccharum munja* and 0.44% to 0.55% under *Acacia nilotica*+ *Eulaliopsis binata* after 5 years was observed and it was suggested that *Acacia nilotica* + *Eulaliopsis binata* are conservative but more productive and less competitive with trees and suitable for eco- friendly conservation and rehabilitation of degraded lands of Shivalik foot hills of sub-tropical northern India. (Samra and Singh, 2000)

Pandey *et al.* (2000) advocated that improvement of soil fertility in agroforestry is mainly a consequence of increased above- and below ground organic matter inputs, nutrient cycling and protection of soil from erosion and N_2 fixation, depending on tree species (Nair, 1993 and Palm, 1995). Agroforestry systems are believed to increase, or at least maintain the organic matter of soils (Young, 1989). Consistent increase of organic matter promotes soil aggregation which in turn improves soil texture, structure and microbial biomass (Singh and Singh, 1995 and 1996). The immobilized nutrients in microbial biomass constitute a reservoir of mineralisable N and other nutrients, which upon biological transformation become available to plants (Singh *et al.*, 1989). However, the concentration and availability of nutrients under tree crown vary with depth of soil and distance from tree bole (Mazzarino *et al.*, 1991).

Nair (1984) reported that agroforestry, agri-horticultural and agripastoral systems have the potential to reduce erosion and runoff, and to maintain soil organic matter, improve soil physical properties and augment nitrogen fixation and promote efficient nutrient cycling. Many other workers have also emphasized the importance of agri-horticultural and agroforestry systems (Kang *et al.*, 1981 and 1984: Kang and Wilson, 1987; Kessler and Breman, 1991; Jaradat, 1990; Mac Dicken, 1990 and Das *et al.*, 1993). Further, some research studies have revealed that management practices such as use of N-fixing in trees has helped in improving nutrients status in soil and enhanced the growth of the trees (Ramesh *et al.*, 2007 and 2008).

The role of agroforestry in enhancing and maintaining long-term soil productivity and sustainability has been well documented. The incorporation of trees and crops that are able to biologically fix nitrogen is fairly common in tropical agroforestry systems. Non N-fixing trees can also enhance soil physical, chemical and biological properties by adding significant amount of above and below ground organic matter releasing and recycling nutrients in agroforestry systems (Nair and Latt, 1997; Young, 1997; Buck *et al.*, 1998; Schroth and Sinclair, 2003; Jose *et al.*, 2004).

2.6.1 Effect of Teak on Soil Chemical properties

From an assessment of the soil properties under sole and agroforestry plantation of Teak (*Tectona grandis* Linn. F.) on Wheat Fields in Eastern Uttar Pradesh, it was found that teak as agroforestry component improved quality of sodic soil by lowering soil pH and increasing organic carbon as well as available nitrogen, phosphorus and potash as compared to its sole plantation. The exchangeable sodium percentage show marginal increase under agroforestry system. The organic carbon (%), pH, EC (dS m^{-1}, ESP was found to be 0.27, 8.54, 0.36, 24.20 and 0.24, 8.74, 0.38, 23.61 under agroforestry plantation and sole crop respectively. The available nitrogen, phosphorus and potash were found to be 180.44, 11.13, 207.31 and 176.8, 9.36, 203.62 under agroforestry plantation and sole crop respectively. (Sharma *et al.*, 2011)

Kumar *et al.* (1998) studied the effects of intercropping *Leucaena* on early teak growth and soil properties in a simulated taungya system in a humid tropical region of central Kerala in peninsular India. They found out that Soil pH values were modestly higher during the northeast monsoon period. Soil organic C also varied across the southwest monsoon; inter monsoon and northeast monsoon periods. Nitrogen and available P concentrations were generally lower during the inter monsoon period. Available K levels were greatest during the southwest monsoon. Soil acidity was significantly different among the various teak-*Leucaena* combinations but did not follow a consistent pattern. Organic C also was significantly different among treatments but also did not follow a consistent pattern. Total N content of the soil increased with increasing relative proportion of *Leucaena.* Available P levels were highest in the 1:1 teak-*Leucaena* mixtures, while available K was highest in the 1:2 teak-*Leuceana* or pure *Leuceana* plots. Available P increased with increasing proportion of *Leucaena* up to 50% and after that it declined.

A study was conducted on the nutrient dynamics and the impact of teak plantations on physico-chemical properties of soil at different stages of growth in age-series teak plantations at Seoni district of Madhya Pradesh, India and it was found out that organic matter content increased with age, due to decomposition of leaf litter and formation of humus, however, there is no definite trend in change of soil pH. Available nitrogen showed increase in plantations of 3.5, 7.5 and 18.5 years of age, as compared to open land. Initially, the available P_2O_5 did not show any increase but appreciable increase was observed in older plantations. No marked difference was observed in the status of available K_2O. Cation Exchange capacity (CEC) and exchangeable cations showed decrease up to 18.5 years of age. However, slight increase in these values was noticed in the oldest plantation of 23.5 years. (Shukla, 2009)

Urmalia and Bansal (2014) have studied the soil status under teak plantations of Umaria District in Madhya Pradesh. They opined that the available water holding capacity of soil exhibits a decreasing order up to 23 years of teak plantation, while electrical conductivity shows an inverse order. Average hydrogen ion concentration of soil was found to be acidic in nature (ranging from 6.40 to 6.73 pH). They also inferred that available potassium content exhibits increasing order with the age of teak plantation while nitrogen and calcium content exhibit this order till 23 years of teak plantation and then it decreases. They also suggested that phosphorus and carbonic matter have shown an erratic order.

Mongia and Bandayopadhyay (1992) compared changes occurring in soils of tropical forests after clear felling for high value plantation crops of *Pterocarpus dalbergiodes* (Pandauk), *Tectona grandis* (Teak), *Hevea brasiliensis* (Rubber) and *Elaeis guineensis* (oil palm). Their results indicated a decline in OM, P and available K when the forest was removed for raising plantation crops. Also $CaCO_3$ content was completely lost from the soil profiles. Similarly in South Andaman, India, Mongia and Bandayopadhyay (1994) soil N, P, K, organic carbon C and pH were found to be lowest under teak, rubber, oil palm and padauk plantations under natural forests.

Conversely in India, Krishnakumar *et al.* (1991) compared the ecological impacts of *Hevea brasiliensis*, *Tectona grandis* plantations and the natural forest on soil properties, nutrient enrichment, understorey vegetation and biomass recycling.

The study indicated all stand types retained high OM input that helped enrich the soils. Although teak had the highest OM content in the surface layer, depletion of OM with depth was highest for teak and less for natural forests. The depletion pattern for rubber was close to that of natural forests. A study under different climatic conditions in Western Chats, India revealed that sites with very high densities of teak were characterized by higher organic carbon as well as exchangeable Ca and CEC (Singh *et al,* 1986).

Though there may be changes in physical and chemical properties of soils as a result of teak cropping, as the rotation progresses there may be recuperation in some of the properties. That recuperation occurs in some of the soil properties is shown in a study by Jose and Koshy (1972) on the morphological, physical and chemical characteristics of soils as influenced by 1, 15, 30, 60 and 120 years of teak growth. They observe that the natural forest and the 120-year teak plantation have somewhat similar surface horizons rich in organic matter. The surface horizons of younger teak plantations show markedly higher values for bulk density and particle density and relatively lower values for pore space and water-holding capacity than those of natural forests. However, the physical properties of soils from 120-year plantation are similar to those of natural forest although there is considerable compaction in second rotation plantations.

An experiment was conducted where soil samples were collected at depths of 0-15, 16-30 and 31-45 cm from irrigated Teak (*Tectona grandis*) stands aged 6, 8 and 10 years at the forest college and research institute, Mettupalayam, Tamil Nadu to see the effect of teak on farm land and its effect on soil fertility and found that organic matter and available N, P and K were higher in all Teak stands than in the barren site, but, agricultural soil were only greater at 10 years old. Exchangeable Ca and Mg were generally greater at all ages of Teak than in fallow and agricultural soils. It was also reported that the chemical properties showed similar changes with depth in all soils. (Murugesh *et al.*, 1999)

2.6.2 Effect of Teak on soil Physical properties

Pure teak stands have also been associated with physical soil deterioration such as erosion (Centeno, 1997). However, there is limited conclusive evidence in this regard (Brandis, 1921; Centeno, 1997) except when teak is planted on steep slopes where there is limited undergrowth or where excessive burning has taken place (Centeno, 1997; Manning, 1941).

According to Laurie and Griffith (1942) surface soil under teak plantations sometimes hardens, decreasing aeration and increasing soil erosion. Salifu (1997) noted higher surface soil horizon bulk densities (D_b) were observed under teak plantation (1.33g cm^{-3}) than under the native logged forest. However, similar studies by Laurie and Griffiths (1942) under other pure teak plantations in India did not indicate significant soil deterioration. Laurie and Griffith (1942) concluded that poor planting techniques and under-thinning were at least partially responsible for the above changes in soils under pure teak plantations.

Studies by Bell (1973), Chunkao *et al.* (1976), Karanakaran (1984) and Kushalappa (1987) have shown that soil erosion and sediment yields were higher under teak plantations than other cover types due to heavy grazing pressures and repeated fires, soil bulk density has been found to increase under teak plantation management but not under virgin forests (Mongia and Bandayopadhyay, 1992). The high bulk density was attributed to loss of OM under teak as compared to natural forest.

In Kerala, India, Jose and Koshy (1972) studied the morphological, physical and chemical characteristics of soils and influenced by Teak on soil profiles beneath a natural forest and Teak plantations of; 15, 30, 60 and 120 years were compared. Organic matter content in the plantation correlated with the age of the stand. They observed that soils beneath teak plantations less than 30 years old had higher bulk densities, lower amount of pore space and water holding capacity than older plantations and natural forests, indicating that physical condition deteriorated as teak plantation got older.

Aborisade and Aweto (1990), Kadambi (1972), Mongia *et.al* (1992) observed that establishment of large-scale teak plantations leads to soil deterioration through increased erosion, soil compaction and consequent decrease in aeration.

2.7 Economics of teak plantations

An assessment on the productivity and profitability of teak plantations in Nilambur Divisions of Kerela was carried out where the financial cost benefit was analyzed and it was found out that the net present value (NPV) ranged from ₹ 1,91, 000 at 6% discount rate to ₹ 15,000 at 18% discount rate. The benefit cost ratio (BCR) ranged from 7.5 to 2 at 6 and 18% rate of discount. For the mean yield, internal rate of return (IRR) is 31.3% which indicates that the average profitability of teak plantation was 31.3% when land rent has not been taken into account. Even for plantations having low yield, the IRR was found to be 11.7 %. When a land rent of ₹ 1300 ha^{-1} $year^{-1}$ is considered, the profitability of plantations having low yield was found to be 7.8%. And with a higher land rent of ₹ 2500, it was 6.0%. (Chundamannil, 1997).

Shukla (WCA, 2014) studied the economics of some teak- based Agroforestry Systems in Madhya Pradesh. He found out that the benefit cost ratio of teak and paddy was found out to be 3.98 as that of paddy (sole crop) was 2.11in Satpura hills, Katni. In Grid region of *Gwalior/Bhind/ Morena,* the benefit cost ratio of teak and wheat *was 2.38 as that of wheat (sole crop) was 1.92.*

A study on the performance of Sapota- Teak based agroforestry system consisting of arable crops (Paddy, maize, sunhemp), silvicultural trees (*Eucalyptus tereticornis, Casuarina equisetifolia, Albizia molucana, Tectona grandis, Dalbergia sissoo*), horticultural tree (Sapota) and pasture crop (guinea grass) on black clayey soils was done in hill zone of Dharwad, Karnataka and the economic analysis at the end of 17 years (felling all short rotation trees and only adjoining long rotation trees) was done which shows that benefit cost ratio and internal rate of returns were highest in agroforestry system with *T. grandis* (1.67:1 and 23.2% respectively) and were lowest in sapota+ *C. Equisetifolia* (0.99:1 and 12% respectively). The economic analysis at the end of 28 years (felling trees) indicated that benefit cost ratio was higher in sapota+ *T. grandis*+ field crops (3.23:1) followed by sapota+ *Lagerstroemia lanceolata*+ field crops (2.71:1) and sole sapota (2.36:1). It was concluded that sapota- teak based agroforestry model is economically viable for hill and transitional zones of Karnataka. (Patil *et al.*, 2010)

From an assessment on economic viability of teak based agroforestry systems in Main Research Station, Dharwad on red gravelly soil under rainfed conditions where teak was planted at 10m and 20m apart with 2m between plants, it was inferred that marketable timber volume was higher in groundnut+ teak (25.3 m^3 ha^{-1}) and sorghum+ teak (23.147 m^3 ha^{-1}) and was reduced with inclusion of grass or subabul with teak alley. Fodder yield was found to be significantly higher in grass than subabul. Grain/ pod yields were lower in agroforestry systems than their sole cropping. Net return was higher in groundnut+ teak (₹ 26585 ha^{-1} yr^{-1}), sorghum+ teak (₹ 25259 ha^{-1} $year^{-1}$) and sorghum+ teak+ subabul (₹ 21475 ha^{-1} yr^{-1}) as compared to sole crops. Inclusion of sorghum or groundnut with teak was economically viable agroforestry system as compared to inclusion of pastures along teak or sole cropping. (Mutanal *et al.*, 2002)

Singh *et al.* (2011) have conducted a trial to examine the economics of growing teak and cashew nut along with upland paddy in four combinations in Agroforestry model adopted by tribals of Odisha. They worked out the economics at 15^{th} and 45^{th} year (rotation age) at 7% and 15% discounting rate. They found that Net Present Value (NPV) at rotation was highest in land use with Agri-silviculture (teak + paddy) at 7% rate ₹ 7,24,699 ha^{-1} where as at 15% rate of discounting the highest NPV was observed in Agri-horticulture (cashew nut + paddy) ₹ 45,255 ha^{-1}, followed by Silvi-horticulture, Agri-silviculture and lowest in Agri-silvi-horticulture ₹ 27,289 ha^{-1}. The benefit cost ratio (BCR) was found higher 3.64 and 1.98 respectively at the 15th year in case of Silvi-horticulture (teak + cashew nut) at two extreme of discounting (7 and 15%) than that found in the other three agroforestry combinations. At rotation age of 45 years the highest BCR (6.33 and 2.64) was also found in Silvi-horticulture (teak + cashew nut) combination at 7% and 15% discounting respectively and it was found lowest in cashew nut+ paddy (4.42) at 7% and teak + cashew nut + paddy (1.78) at 15%.

An analysis on the financial viability of 20-45 years rainfed teak plantations was done under the sal overwood in Tarai region of Uttarakhand. It was found that the maximum NPV (₹ 19,856) at 12% discount rate and IRR (31.20%) was obtained in 21 years old Barakoli plantation which was due to higher survival rate (43.85 %) and the lowest gestation period (21 years) and a minimum IRR 23.95 % was found in case of Lakhanmandi plantation site due to poor survival rate (23.65 %) and a long gestation period of 45 years. In general, it was opined that all the unirrigated teak plantations on government land (NPV at 12 % rate of interest, ₹ 3,556 to ₹ 19,856 and IRR 23.95 to 31.20 per cent) were financially viable. (Ansari and Singh, 2007)

CHAPTER-III

MATERIALS AND METHODS

MATERIALS AND METHODS

The present investigation entitled "Performance of different Teak-based Agroforestry Systems in Cuttack District of Odisha" was carried out in the Cuttack district of Odisha during July 2015- June 2016. Details about the experimental site, material used and methodology adopted during the course of investigation are discussed in this chapter.

3.1 Experimental site

3.1.1 Location

The headquarter Cuttack city is situated at nearly 30km from state capital, Bhubaneswar. The total geographical area of the district is about 3, 67, 097 ha, out of which 1,88,150 ha (47%) is agricultural land. The district comprises of 1952 villages, out of which 1858 are inhabited and 94 are uninhabited villages. It has 3 sub-divisions namely Cuttack Sadar, Athagarh and Banki, 15 tehsils and 14 blocks.

This district represents two agro-ecological zones, i.e. East and South Eastern coastal plain and mid-central Table Land. It extends from longitudes of 84°58′ to 86°20′ E and latitudes 20°03′ to 20°40′ N. It has varied geographical and geological divisions depending upon the available rock types, vegetation, water bodies and climate. The whole district may be divided into two physiographic divisions namely deltaic plains and lateritic uplands & hilly tracts. The district consist of 14 blocks namely Cuttack Sadar, Baranga, Kantapada, Niali, Tangi- Chowdwar, Salipur, Nischintakoli, Mahanga, Athagarh, Tigria, Baramba, Narasinghpur, Banki, Dampara. The total population of the district is 2,624,470 as per 2011 Census.

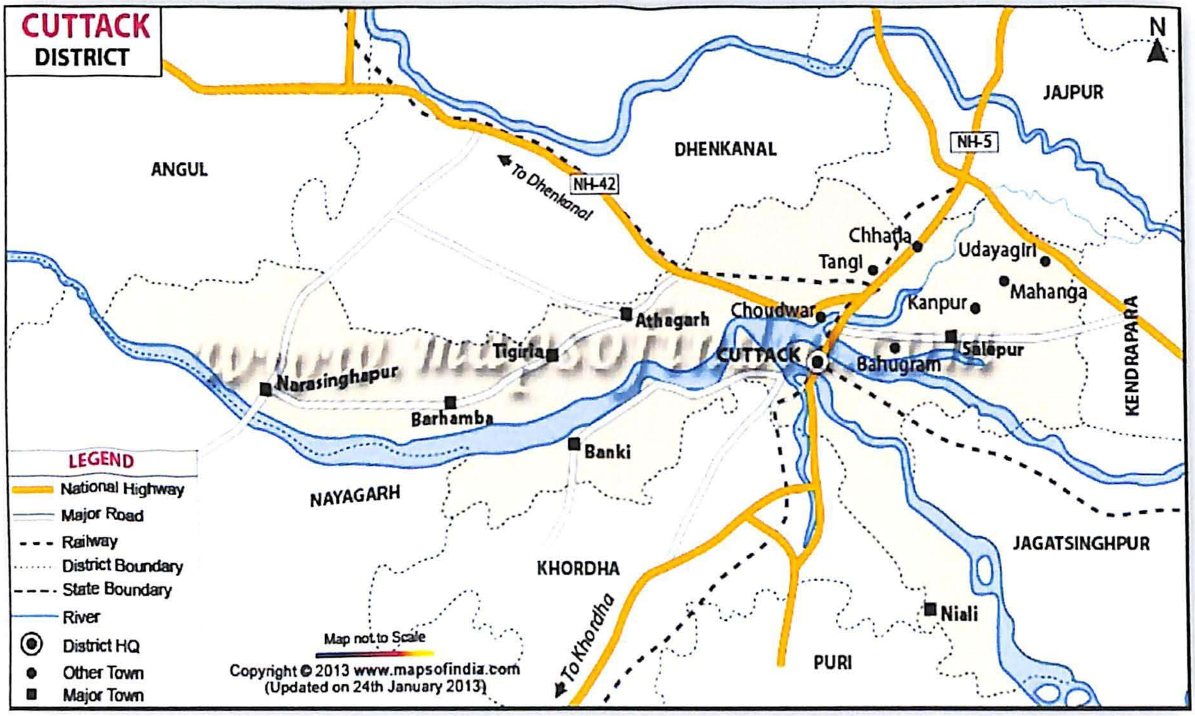

Fig. 3.1 Location map of Cuttack District

3.1.2 Climate and Weather Condition

According to the Koppen–Geiger climate classification system, the climate of Cuttack is classified as Aw (Tropical savanna climate). The city has moderate and tropical climate. Humidity is fairly high throughout the year. The average maximum temperature remains 37 °C during May- June and minimum 16 °C in December. Rainfall is generally heavy during the monsoons, which occur during the month of July- August. The average rainfall received is around 1892.55 mm and average annual temperature is 27.2°C. The weather data is given in the following graph:

The rainfall received during the study period was 1191.5 mm which was contributed both by South-West monsoon and North-East monsoon. This amount of rainfall is distributed over 98 rainy days in a year. The mean maximum and minimum temperature during the experimentation ranged from 27.8 °C to 38.6 °C and 14.7 °C to 26.8 °C, respectively. The temperature begins to rise from the month of March and reaches its maximum in April. April is the hottest month and having mean maximum temperature of 38.6 °C and January being the coldest month having mean minimum temperature of 14.7 °C. The average temperature during the study period ranged from 22.5°C to 32.9 °C.

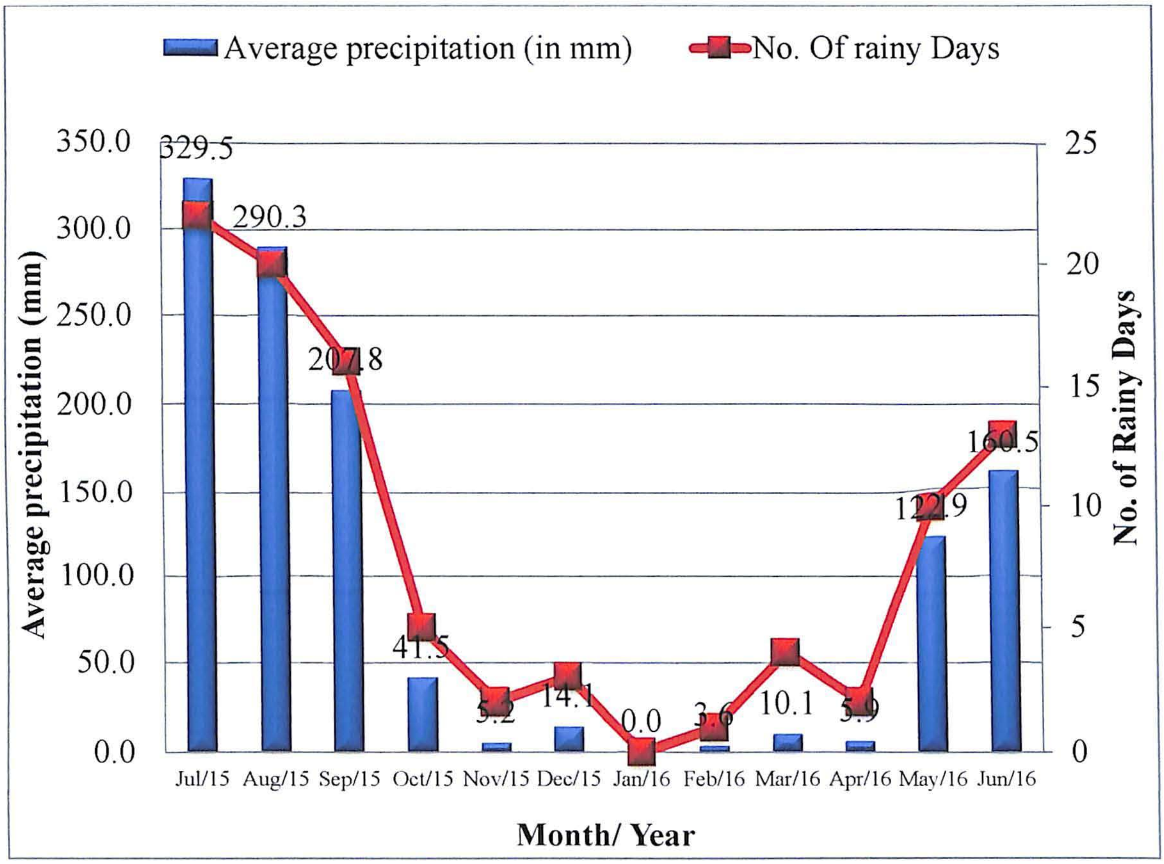

Fig. 3.2 Average rainfall days and Precipitation (mm) of Cuttack District

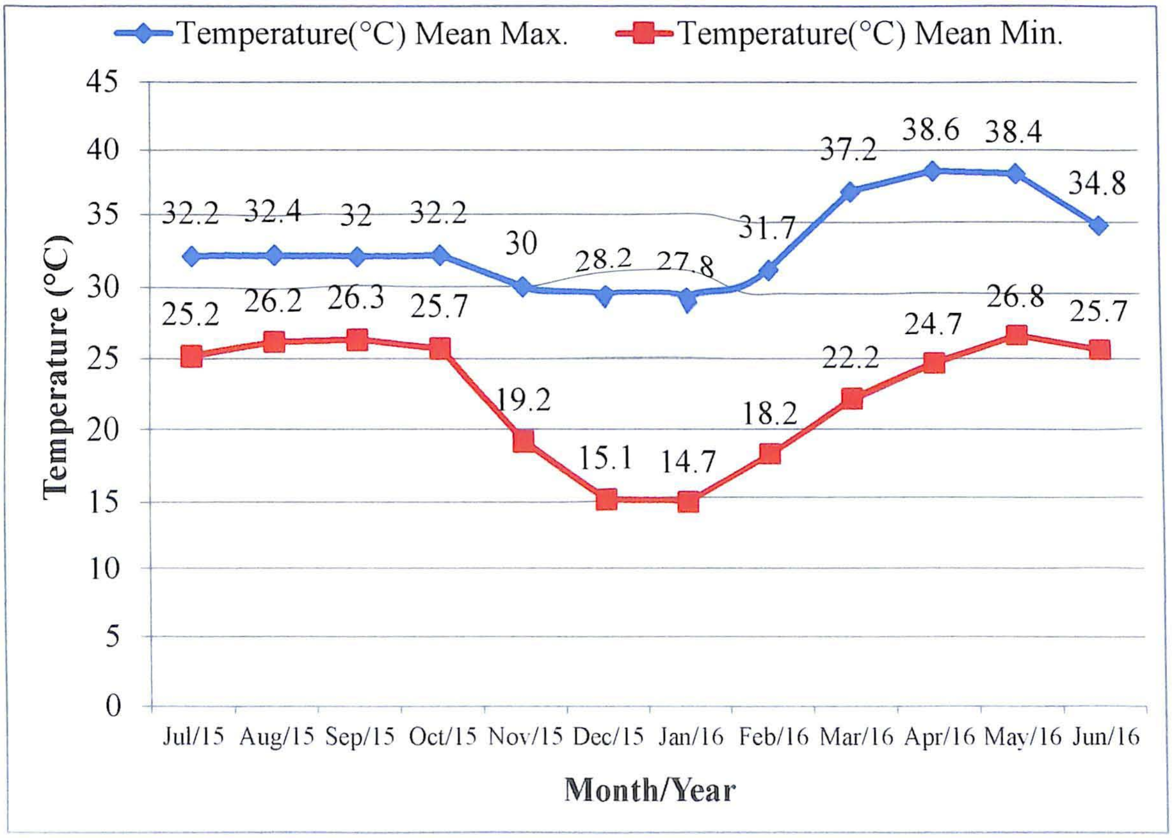

Fig. 3.3 Average temperature (^{0}C) for Cuttack District

Table 3.1 Distribution of rainfall in Cuttack District from July 2015 to June2016

Rainfall	Normal RF (mm)	Normal Rainy Days (number)	Normal Onset (specify week and month	Normal Cessation (specify week and month)
SW Monsoon (June-Sep)	988.23	71	2nd week of June	Last Week of September
NE Monsoon/ Post Monsoon (Oct- Dec)	60.8	10	Last week of October	2nd week of December
Winter (Jan-Feb)	3.6	1	3rd week of January	Last week of March.
Summer/Pre Monsoon (March-May)	138.9	16	1st week of April	Last week of May
Annual	1191.52	98		

1.1.3 Major soils

Physiographically, the district can be divided into two distinct units viz.,

i. Deltaic plain
ii. Lateritic uplands and hilly tract.

There are mainly three types of soils in the area, which are *Alfisols, Ultisols* and *Entisols*. However, *Vertisols* are found only in Tangi- Choudwar block of the district. *Alfisols* can be further sub-divided in to red loamy soils, red sandy soils, older alluvial soils and deltaic alluvial soils .The red soils are found in the hilly area in the western part of the district and older alluvial soils are found in minor pockets in northern part. The deltaic soil are found in major parts of the district. These deltaic soils are generally deficient in P_2O_5 and N_2. The K_2O are fairly adequate, and pH varies between 4.5 and 6.3. Generally these soils support paddy crops. Ultisols include laterite and lateritic soils, which are found in pockets and characterized by compact to vesicular mass in subsoil horizon composed essentially of a mixture of the hydrated oxide of alumina and iron. These are mainly found in the western part of the district. The soil is gravelly to loamy and rich in iron, aluminium but low in nitrogen, phosphorous, potash and silica. Fertility of the soil is low and it is well drained. Entisols include younger alluvial soils occurring along the course of Mahanadi river mainly in western part and central part of the district. These soils are deficient in nitrogen, phosphoric acid and humus, but not in potash and lime. The pH values are on the acidic side. The texture varies from sandy to loamy sand. These are fertile soils and can produce a wide variety of crops, including paddy, wheat, sugarcane, cotton, banana and tobacco.

Table 3.2 Major soils in Cuttack district

Major Soils	Area(000 ha)	Percent(%) of total
Alluvial Red Laterite	98.82	52.26
Laterite Alluvial	35.60	18.94
Alluvial Laterite	23.88	12.70
Red Laterite alluvial	20.50	10.90
Alluvial	9.20	4.89

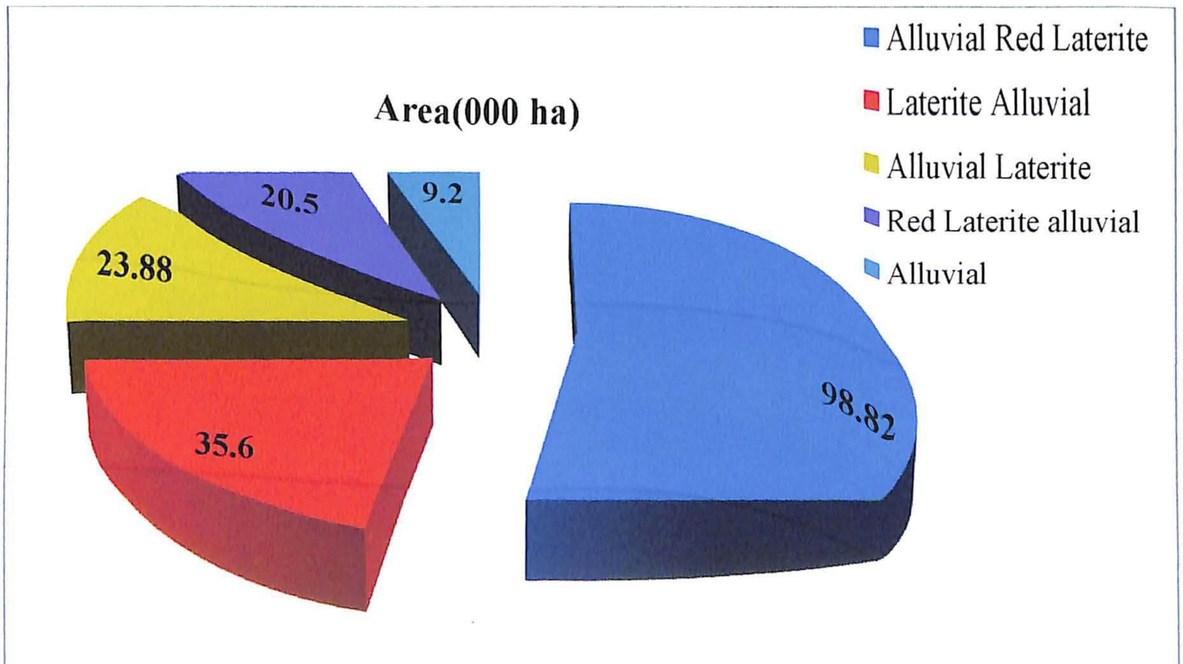

Fig 3.4 Major soils in Cuttack district

Table 3.3 Operational holding of Cuttack district

Size of holding	No. of holdings	Per cent of total land holdings	Area (ha)	Per cent of total area
Less than 1 ha (Marginal)	105525	67.25	48673	33.18
Between 1-2 ha (Small)	38572	24.58	53822	36.68
Between 2-4 ha (Semi-medium)	10846	6.91	28669	19.54
Between 4-10 ha (Medium)	1818	1.16	9981	6.80
Above 10 ha (Large)	155	0.10	5573	3.80

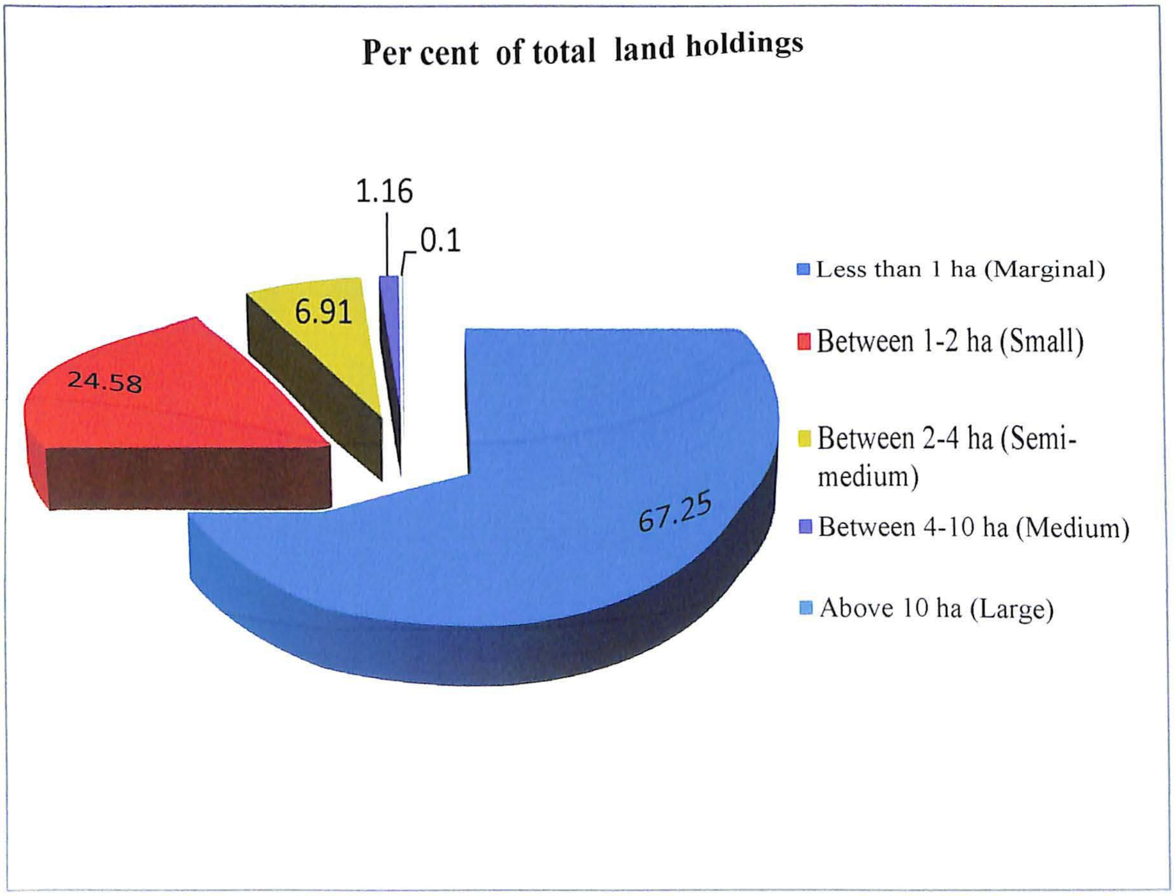

Fig. 3.5 Percentage of land holdings of Cuttack District

3.1.4 Agro-climatic/ecological information

Cuttack district is divided into two agro climatic zones viz. East and South Eastern Coastal plain and Mid Central Table Land. Based on variation in topography, soil type, availability of irrigation and cropping pattern, each agro climatic zone has been divided into several agro ecological situation with a view to generate location specific technologies to cater to the needs of the farming community. The details of such situations of Cuttack district are described in the following table:

Table 3.4 Blocks covered under different agro-ecological situations in Cuttack district

Sl. No	Agro Climatic Zone (ACZ)	Agro Ecological Situation (AES)	Blocks Covered	Area in ha.	% of the Cultivated Area	Soil Type
1	East and South Eastern Coastal Plain	Coastal Irrigated Alluvium	Cuttack Sadar, Niali, Banki- I, Banki- II, Salepur, Baranga, Nischintakoili, Tangi Choudwar, Mahanga, Kantapada	98819	52	Alluvium Lateritic Red Soil
		Raifed Alluvium	Cuttack Sadar, Niali, Nischintakoili, Mahanga, Kantapada	9200	5	Alluvium
		Rainfed Lateritic	Baranga, Tangi-Choudwar	20500	11	Lateritic Red alluvium
2	Mid Central Table Land	River Valley Alluvium Medium Rainfed	Athagarh, Baramba, Narasinghpur, Tigiria	23880	13	Alluvium Lateritic
		Light textured lateritic medium rainfed	Athagarh, Baramba, Narasinghpur, Tigiria	35751	19	Lateritic alluvium

3.1.5 Forest area

The distribution of forests in Odisha is very uneven. The forest coverage of Cuttack district is 11.4% of the total reported area of the district and it contributes 1.9% to Odisha's total forest area. The total forest area of the district is 78369.11 ha and is divided into 6 forest ranges. Northern Tropical Semi Evergreen Forest is found in Athagarh block of Cuttack district. The major forest products of the district are timber firewood, bamboo, etc. Except for the hilly region forming the western territory of the district and the marshy strip stretching along the coast, the entire alluvial plains forming the major portion of the district is practically devoid of forest.

There are 5 types of forests in the Cuttack district. The details of the same are as follows:

Sl.No.	Type of Forest	Area in Sq. Kms.
1	Reserve Forests	522.39
2	Demarcated Protected Forest	101.41
3	Un-demarcated Protected Forest	Nil
4	Un-Classified Forest	0.45
5	Other Forests	163.65
	Total	**787.90**

3.1.6 Thrust Areas in Cuttack District

- Promoting diversified cropping patterns with emphasis on the area expansion of pulses, vegetables and high yielding varieties of rice.
- Technological intensification in rice farming.
- Promoting Integrated farming system approach through judicious integration of suitable on-farm and off-farm enterprises.
- Integrated crop management in flood prone areas.
- Promoting pond based integrated farming system and scientific pisciculture.
- Promoting INM and IPDM approach in field and horticultural crops.
- Soil health management and management of problematic soil.
- Promoting alternate livelihood options for resource poor farm families.
- Gender mainstreaming in agriculture and allied sector.
- Promotion of agro-forestry models in the district.

3.2 Experimental details

3.2.1 Experimental Design

The experiment was carried out in a Randomized Block Design (RBD) with four replications. Seven crops (paddy, arhar, colocasia, mango ginger, okra, brinjal and chilli) were identified in the study area where *Tectona grandis* were planted at 4m plant to plant spacing in the field bunds. Two hundred numbers of plants were present per hectare.

3.2.2 Treatments

There were 7 treatments as shown below:

Treatments	Details
Tl	Paddy planted with teak as intercrop
T2	Arhar planted with teak as intercrop
T3	Colocasia planted with teak as intercrop
T4	Mango ginger planted with teak as intercrop
T5	Okra planted with teak as intercrop
T6	Brinjal planted with teak as intercrop
T7	Chilli planted with teak as intercrop

3.2.3 Experimental Procedure:

A preliminary survey was done in four villages of Cuttack district viz. Bada Munduli, Patenigan, Mahakalabasta and Govindpur in the month of August 2015 to demarcate the suitable teak based agroforestry systems containing various agricultural crop species as intercrops with teak. Subsequently seven fields from each of four different villages were taken into consideration to obtain required data from field related to the research work. The agricultural fields selected for research work were mainly subjected to teak based system since the last few years. The tree components present in the field were 10 years old plantations.

Data related to growth and performance of different teak tree present on the field bunds such as tree height, D.B.H.(O.B.), G.B.H.(O.B.) etc. were duly recorded to access their relative growth as compared to their growth outside the field bund. In order to study various soil characteristics related to the teak based agroforestry systems, the soil samples were taken from 1 meter distance from the tree base in three depth slots, i.e. 0-15, 15-30 and 30-45 cm depth respectively for each treatment from each of four different replications and composite soil samples were prepared for each depth for different agroforestry systems. Successive processing of soil samples were done and final findings were recorded for further discussions. Initial soil samples collected from 0-15 cm, 15-30 and 30-45 cm depth for different agroforestry system before the experiment were collected from different villages of the district under study and analyzed for organic carbon, nitrogen, phosphorus and potassium. The data are presented in the table below:

Table 3.5 Initial Soil parameters related to teak based agroforestry systems

Sl. No.	Agroforestry System	Soil depth (cm)	OC (%)	Available Nutrients (kg ha^{-1})		
				N	P_2O_5	K_2O
1	Teak + Paddy	0-15	0.44	186.5	49.8	205.6
		15-30	0.21	172.3	40.6	156.8
		30-45	0.33	187.1	21.2	130.7
2	Teak + Arhar	0-15	0.36	187.1	39.8	164.2
		15-30	0.18	162.3	27.9	119.6
		30-45	0.31	185.2	16.8	110.8
3	Teak + Colocasia	0-15	0.49	199.6	78.6	305.8
		15-30	0.28	174.3	54.7	251.6
		30-45	0.37	188.2	30.8	203.8
4	Teak + Mangoginger	0-15	0.46	199.4	64.9	222.4
		15-30	0.26	174.1	44.7	212.6
		30-45	0.34	186.3	26.8	177.2
5	Teak + Okra	0-15	0.51	211.3	80.5	316.8
		15-30	0.34	174.3	58.7	283.6
		30-45	0.41	199.2	35.9	255.7
6	Teak + Brinjal	0-15	0.52	224.8	88.4	327.8
		15-30	0.34	186.8	75.6	289.5
		30-45	0.43	199.4	49.6	268.3
7	Teak + Chilli	0-15	0.58	249.5	97.4	347.8
		15-30	0.43	199.7	83.8	332.7
		30-45	0.50	201.3	68.3	275.2

Fig. 3.6 ***Tectona grandis*** **with paddy**

Fig. 3.7 ***Tectona grandis*** **with arhar**

Fig. 3.8 ***Tectona grandis*** **with colocasia**

Fig. 3.9 ***Tectona grandis*** **with mango ginger**

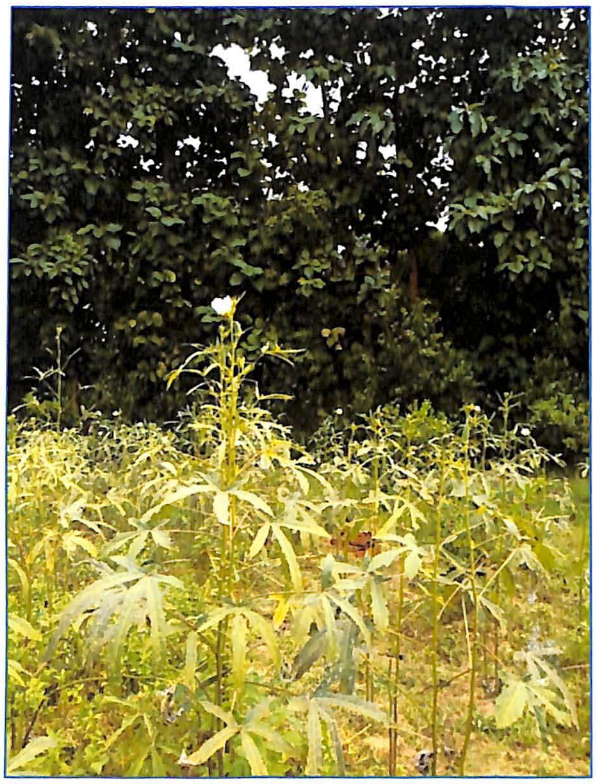

Fig. 3.10 *Tectona grandis* with okra

Fig. 3.11 *Tectona grandis* with brinjal

Fig. 3.12 *Tectona grandis* with chilli

3.2.4 Observations recorded

The observations were recorded on the growth and yield parameters related to teak present in the crop fields. Significant observations were also recorded for accessing various soil nutrient parameters and economics related to teak based agroforestry system was also brought under consideration. The parameters recorded are described as below.

3.2.4.1 Height of trees present in the field bunds.

Height of the trees growing in the field bunds of crop fields was measured from ground level to the tip of main shoot with the help of Ravi Altimeter. Trees were categorized under different height classes of 5m-10m,10m-15m,>15m. The height of individual trees present in the field bunds were expressed in tabular format and simultaneous average height and standard deviation was respectively cited.

3.2.4.2 Numbers of trees

Number of trees in present in the field bunds was recorded by counting number of trees of individual species.

3.2.4.3 Diameter at Breast Height (D.B.H.)

The over bark diameter of tress; D.B.H (O.B.) present in the field bunds were measured by using 75 cm. Vernier Calliper. Trees were categorized under different diameter classes of 5cm-10cm,10cm-15cm, >15cm.The diameter of individual trees present in the field bunds were expressed in tabular format and simultaneous average D.B.H. and standard deviation was respectively cited.

3.2.4.4 Girth at Breast Height (G.B.H.):

The over bark girth of individual trees, G.B.H. (O.B.) present in the field bunds were also measures with the help of tape and its average value and its subsequent standard deviation was also calculated.

3.2.4.5 Age of trees:

Age of the tree species present on the rice field bunds were calculated by using Pressler's increment borer. On the contrary, a general questionnaire was also done to acknowledge the age of standing trees present on the field bunds.

3.2.4.6 Volume of trees

The stem volume was calculated by applying Hubers's formula.

$$V = S_m \times L$$

Where, V= Stem volume in m^3

S_m= cross sectional area at the breast height in m^2.

L= Height of the tree in m.

The volume was then converted to m^3 ha^{-1}.

3.2.4.7 Role played by trees present in the Crop fields

Role played by Indigenous and planted tree species present in the field bunds were accessed in terms of tangible and intangible benefits obtained by interacting with the household members (based on a questionnaire), PRA studies, KVK, Cuttack annual reports.

3.2.4.8 Chemical analysis of soil

Soil samples of 500gm weight from each crop fields were collected from 1 meter distance from the tree base in three different slots, i.e. from 0-15cm, 15-30 cm and 30-45cm depth in the month of September-October, 2015. Collected samples were air dried under shade, finely dusted and passed through a 2 mm sieve and finally 250 gm. of such soil were taken from each treatment plots in polythene bag with proper label for analysis of pH, organic carbon, Nitrogen, Phosphorus and Potash and value of electrical conductivity. The methods used were mentioned below:

a) pH: Soil pH was determined in 1:2 soil and water suspension by using glass electrode pH meter (Jackson,1967).

b) Organic Carbon: Organic Carbon content of the soil sample was determined by Walkley and Black's rapid titration method (Piper, 1950).

c) Available Nitrogen: Available nitrogen was determined by the method described by Subbiah and Asija (1956). Nitrogen released as ammonia during distillation of 20 gram soil with 100 ml 0.32% of $KMnO4$ and 100 ml of 2.5% $NaOH$ was received in 2% boric acid containing mixed indicator and ammonia was titrated against standard 0.02 NH_2SO_4.

d) Available phosphorous: It was determined by Bray's-I method with shaking 2 gram soil in 20 ml of extracting solution (0.03N NH_4AF in 0.025N HCl) for 5 minutes. The filtrate was estimated by spectrophotometer for phosphorous after development of colour by $SnCl_2$ and measured at 660nm (Jackson, 1973).

e) Available Potassium: It was determined by equilibrating 5 gram of soil in 25 ml neutral ammonium acetate (Jackson, 1973) and reading of extract was taken in flame photometer.

f) Electrical Conductivity: It was determined by using an EC probe meter. The probe or sensor consists of two metal electrodes and a constant voltage is applied across the electrodes resulting in an electrical current flowing through the sample. Since the current flowing through the water is proportional to the concentration of dissolved ions in the water, the electrical conductivity can be measured in terms of dSm^{-1}.

3.2.4.9 Economics of the teak based agroforestry systems

Economics of different teak based agroforestry system were worked out on hectare basis considering the cost of cultivation of sole crop and the gross return associated with the tree component. Yield of sole crop and with tree component was duly recorded in tonnes per hectare basis. Simultaneously percentage change or percentage yield reduction was calculated by considering the crop yield of sole crop as the base value. Net return for different teak based agroforestry system was also calculated by deducting the cost of cultivation from the gross return. The benefit-cost ratio (BCR) related to various teak based agrisilvicultural system was calculated by dividing the gross return with the cost of cultivation.

3.5 Statistical Analysis

The quantitative data on various observations were analyzed as per the procedure described, i.e. SEm (±) and Critical Difference (C.D.) were calculated at 5 % level of significance for comparing the treatment means where 'F' test was found significant. The following formulae were used for estimation of SEm and CD.

Mathematically,

$SE_m(\pm) = \sqrt{(EMS/R)}$

$CD_{(0.05)} = SE_m(\pm) \times \sqrt{2} \times t_{(0.05)}$ at error degree of freedom.

Where EMS = Error Mean sum of square.

R = Number of replication.

CHAPTER-IV

RESULTS

RESULTS

The experimental results of the present investigation "Performance of different Teak-based Agroforestry Systems in Cuttack District of Odisha" are presented in this chapter under following head:

4.1 Study of growth performance of teak with various agricultural crops.

4.2 Study of soil characters related to different teak based agroforestry system.

4.3 Study of economics related to different teak based agroforestry system.

The relevant data pertaining to different attributes have been presented in Table 4.1 to 4.8 and Figure 4.1 to 4.16.

4.1 Study of growth performance of Teak in association with various agricultural crops

4.1.1 Tree height

The data presented in Table 4.1 and illustrated in Figure 4.1 revealed that height of teak vary significantly when grown with different field crops. The maximum height of 15.98 m was recorded in Teak planted with chilli. When arhar, colocasia, mangoginger, and brinjal were intercropped with teak, a reduction in height of tree species to the extent of 5.57%, 3.19%, 4.44% and 1.50%, respectively was observed. But when teak was grown with okra, the height (15.82 m) was found to be at par with teak + chilli agrisilvicultural system. The minimum height of teak was observed in teak + arhar agroforestry system (15.09 m).

4.1.2 Diameter at Breast Height (D.B.H.)

The data on DBH of teak intercropped with different agricultural crops varied significantly. Maximum DBH of 17.28 cm was recorded in teak when grown with chilli. The DBH of teak in teak + okra agrisilvicultural system was at par with the DBH recorded under teak + chilli system. When mangoginger, colocasia, paddy and brinjal were grown in the interspaces of teak, almost same DBH varying from a minimum of 16.01 cm in teak + mangoginger to a maximum of 16.63 cm in teak +brinjal was observed. The minimum DBH of 15.81 cm was observed in teak when grown with arhar (Table 4.1 and Figure 4.2).

4.1.3 Girth at Breast Height (G.B.H.)

The circumferential girth at the breast height (G.B.H) was presented at table 4.1 and figure 4.3. It was observed that the GBH of teak was significantly superior when grown with chilli (0.72 m) followed by teak + okra (0.70 m). The trend was almost similar to the plant height recorded in different teak based agroforestry system. The GBH with teak +brinjal, teak + paddy and teak + colocasia were almost same in the present study. The teak planted with arhar was significantly found to have the lowest G.B.H. of 0.54 m.

4.1.4 Volume

There was a significant variation in the volume of the tree when grown in association with different field crops. (Table 4.1 and Figure 4.4). However, the trend was similar to that of the other growth parameters like height, DBH and GBH. Maximum volume of 0.38 m^3 was recorded in teak + chilli system followed by that of teak + okra (0.37 m^3). The minimum tree volume of 0.28 m^3 was recorded teak + arhar agrisilvicultural system.

Table 4.1 Growth performance of teak in association with different agricultural crop

Sl. No.	Agroforestry Systems	Average Growth parameters			
		Height (in m)	**DBH (in cm)**	**GBH (in m)**	**Volume (in m^3)**
1	Teak + Paddy	15.66	16.25	0.65	0.33
2	Teak+ Arhar	15.09	15.81	0.54	0.29
3	Teak+ Colocasia	15.47	16.12	0.62	0.32
4	Teak+ Mango ginger	15.27	16.01	0.60	0.31
5	Teak+ Okra	15.82	17.17	0.70	0.37
6	Teak+ Brinjal	15.74	16.64	0.67	0.34
7	Teak+ Chilli	15.98	17.29	0.72	0.38
	SEm (±)	**0.10**	**0.25**	**0.01**	**0.01**
	CD (5%)	**0.21**	**0.52**	**0.03**	**0.03**

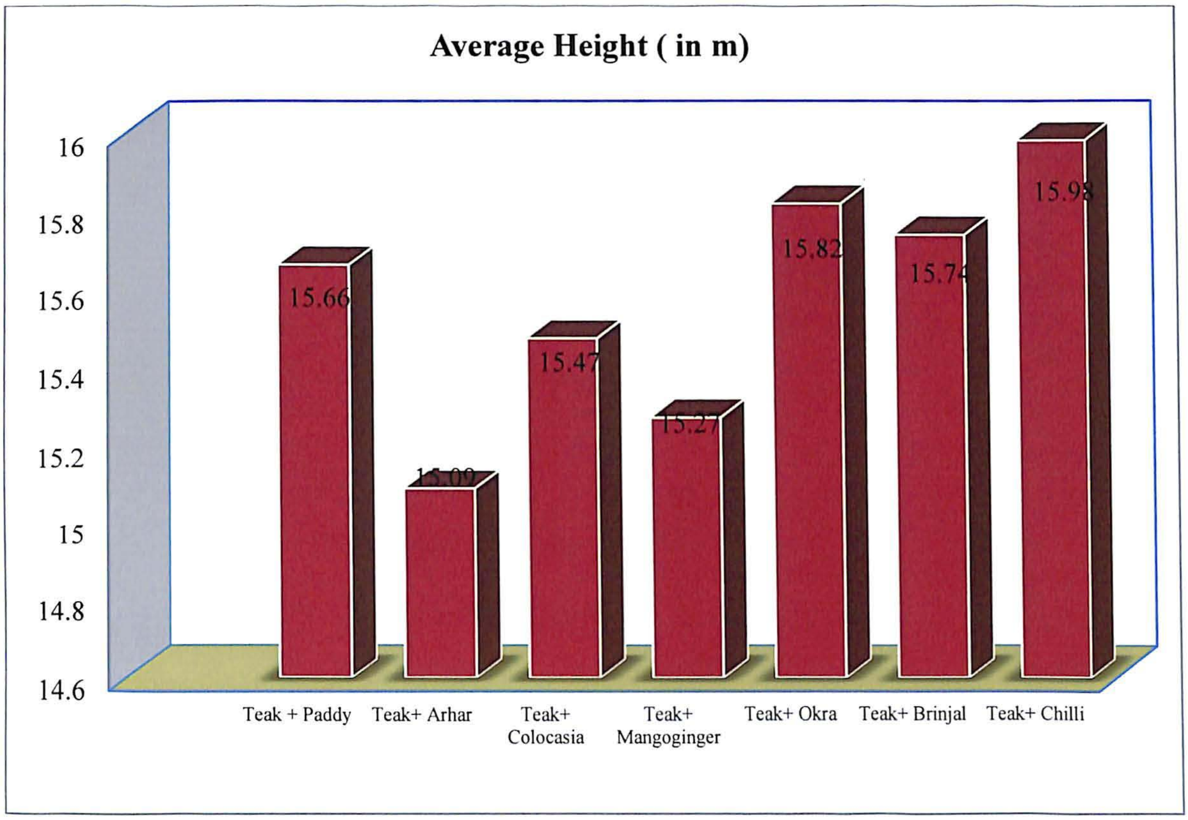

Fig. 4.1 Average Height of teak in the crop field bunds

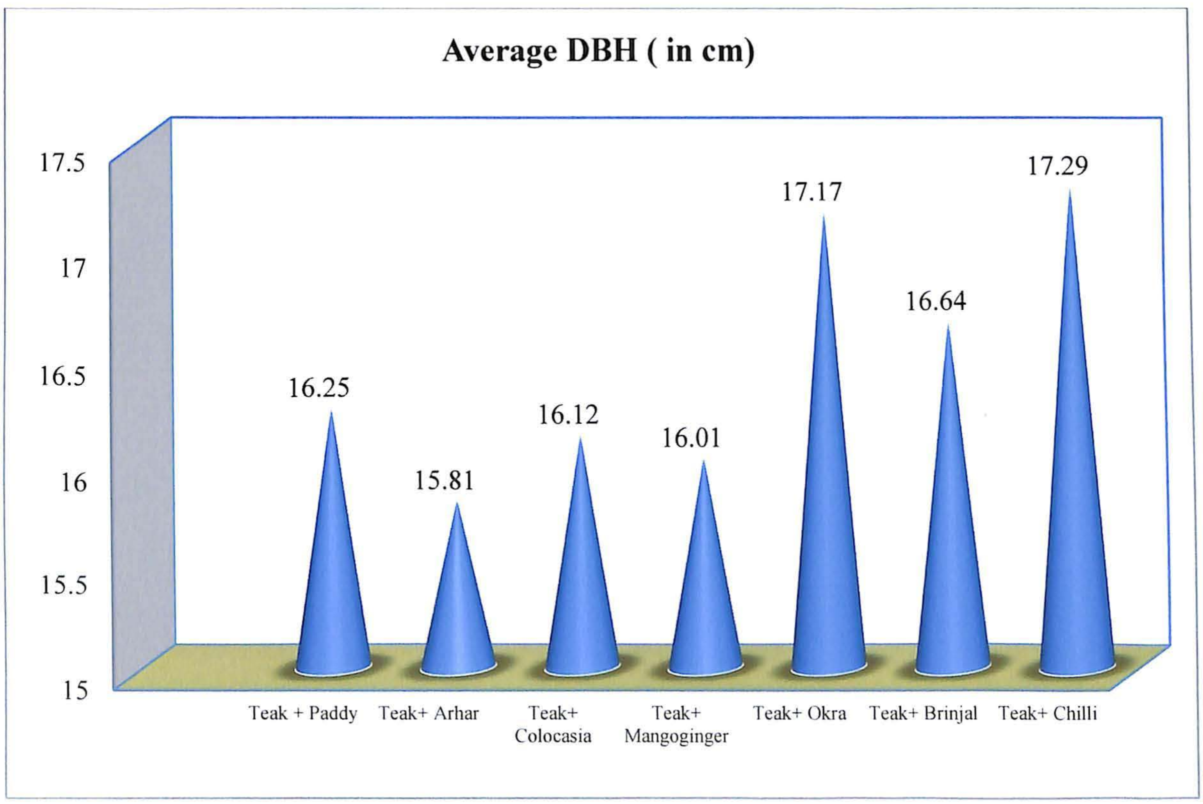

Fig. 4.2 Average DBH of teak in the crop field bunds

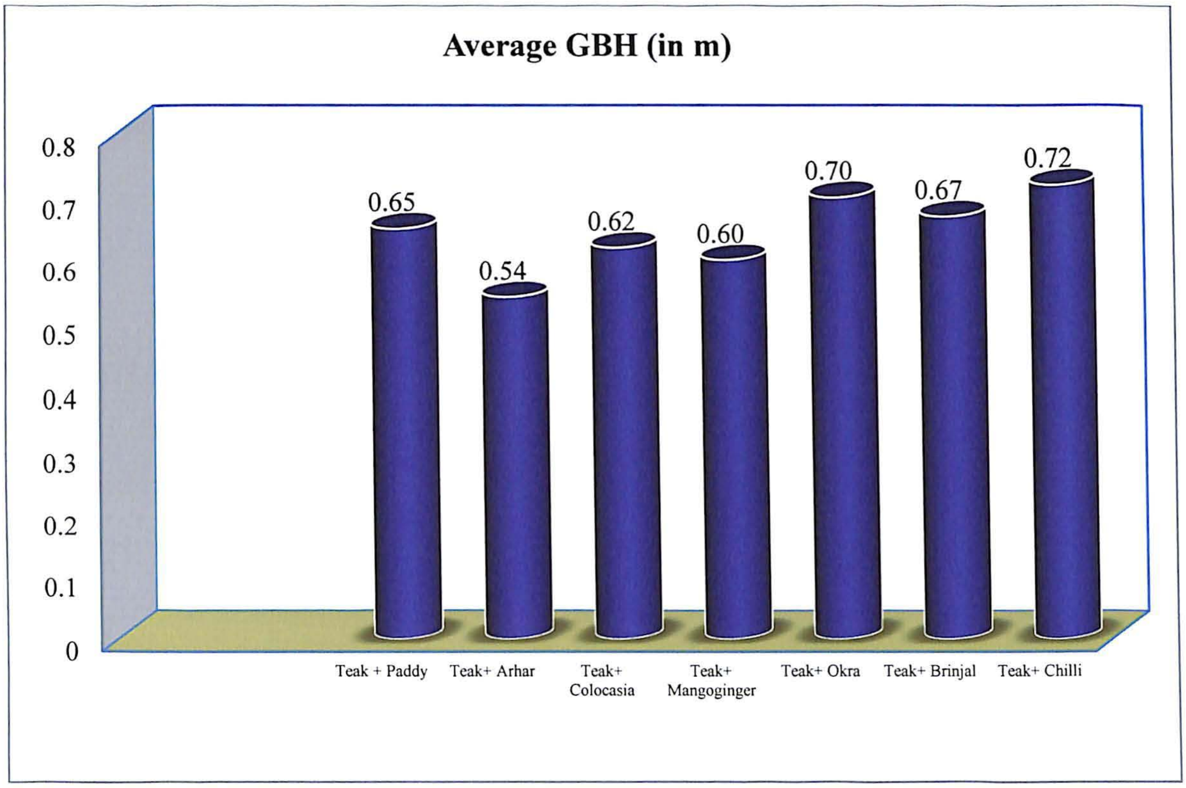

Fig. 4.3 Average GBH of teak in the crop field bunds

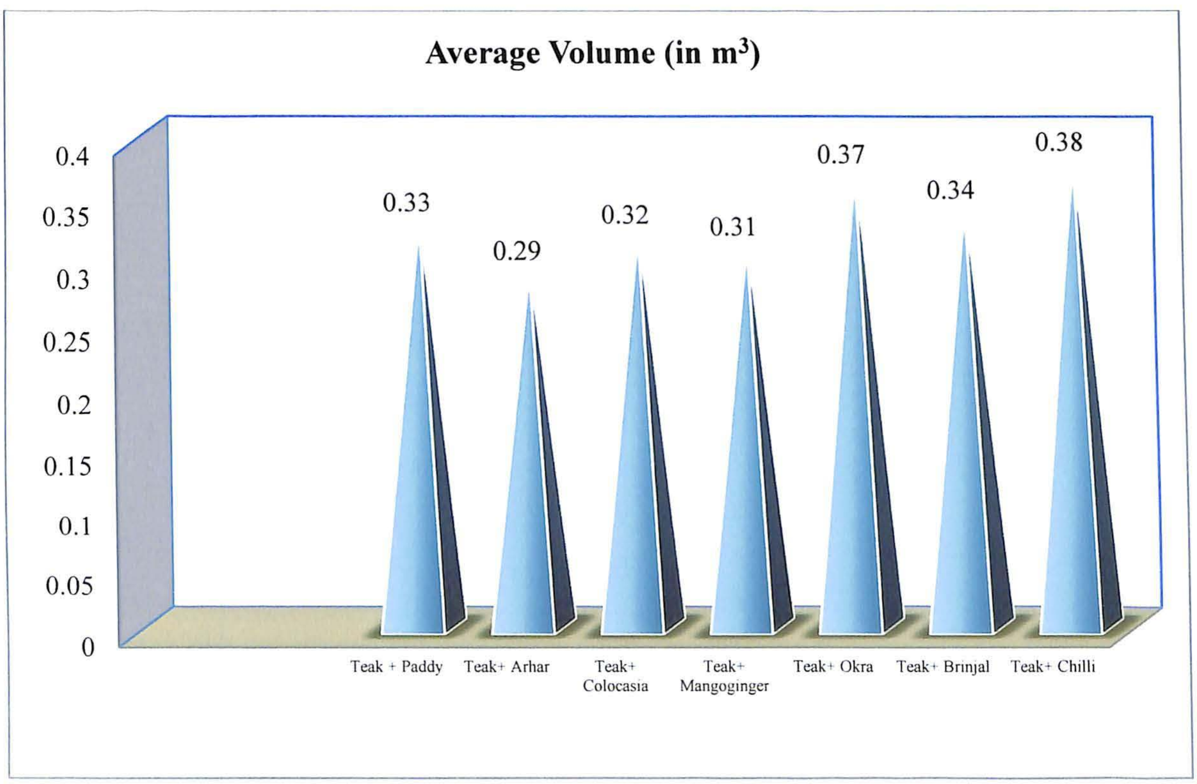

Fig. 4.4 Average Volume of teak in the crop field bunds

4.1.5 Yield of associated crops in teak based agroforestry system

Data presented on Table 4.2 and illustrated in Fig 4.5 and Fig 4.6 revealed that yield of associated crops in control system (without tree component) was higher as compared to those obtained in agroforestry system. Among the crops grown, while Brinjal recorded the maximum fruit yield of 14.25 t ha^{-1} in control with à yield reduction of 8.91 %, paddy recorded 4.35 t ha^{-1} in control and the yield reduction was to the extent of 7.36 % in agroforestry system. Arhar had the lowest yield of 0.85 t ha^{-1} in control and the yield reduction was to the extent of 12.94 % in agroforestry system. Colocasia and Mango ginger were found more compatible with a marginal yield reduction of 6.78 and 6.56 %, respectively.

Table 4.2 Yield of associated crops with teak in agroforestry systems

Sl. No.	Intercrops with Teak	Yield of associated crops (in t ha^{-1})		Percentage reduction in agroforestry systems with respect to control (%)
		Controlled Condition	Agroforestry System	
1	Paddy	4.35	4.03	7.36
2	Arhar	0.85	0.74	12.94
3	Colocasia	8.55	7.97	6.78
4	Mangoginger	6.10	5.70	6.56
5	Okra	6.65	6.10	8.27
6	Brinjal	14.25	12.98	8.91
7	Chilli	2.98	2.63	11.74
	SEm (+/-)	0.14	0.17	-
	CD (5%)	0.30	0.36	-

4.2 Study of soil characters related to different tree based agroforestry system

Data on available nutrient status of soil (organic carbon, available nitrogen, available phosphorous, available potassium, electrical conductivity of soil, pH of soil and electrical conductivity of soil) were brought under consideration pertaining to the existence of different teak based agroforestry systems. Related data were presented in Table 4.3 and figure 4.7 to 4.12.

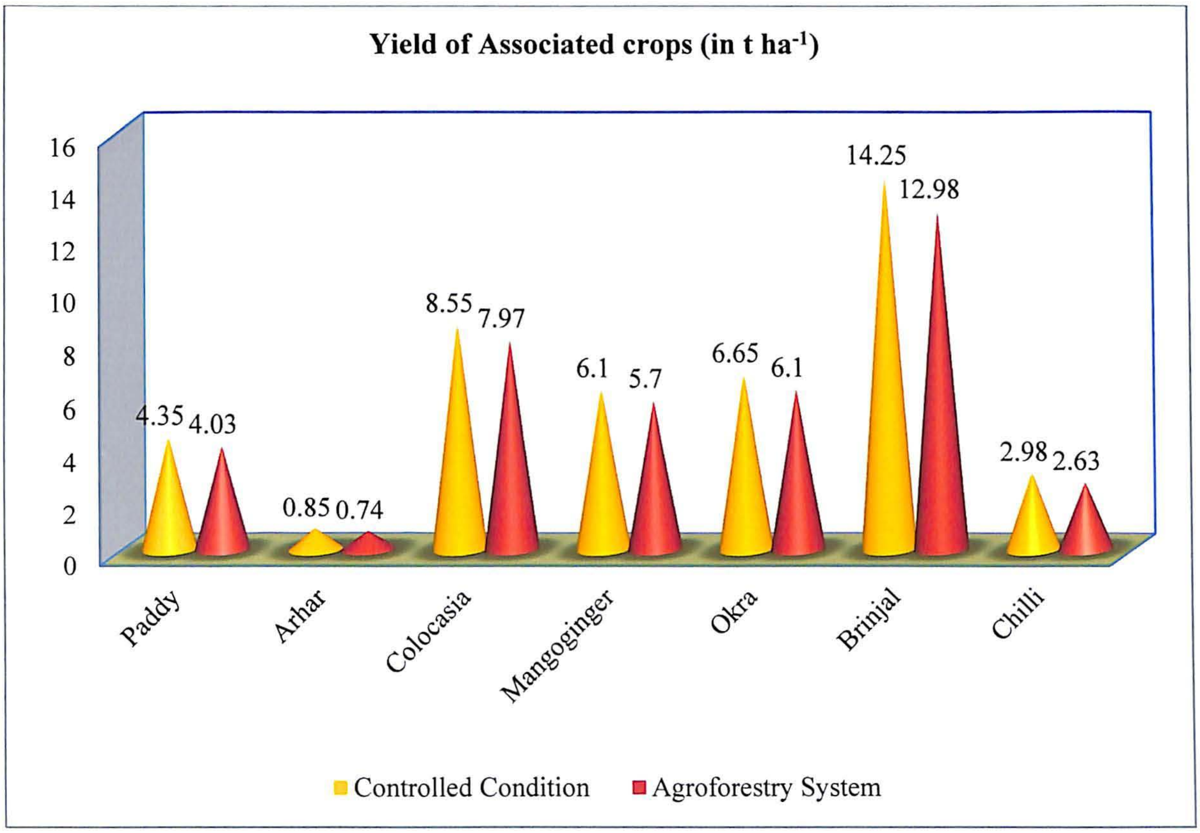

Fig. 4.5 Yield of associated crops with teak in Agroforestry Systems

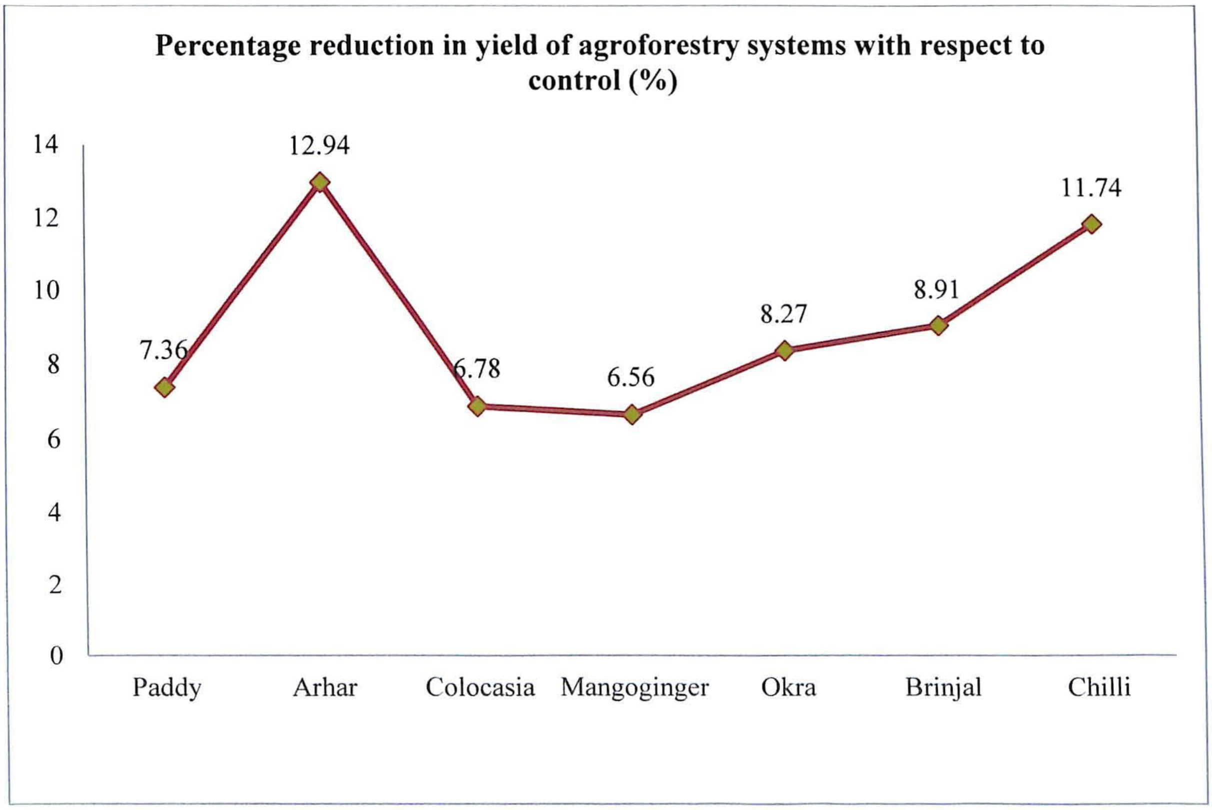

Fig. 4.6 Percentage reduction in yield of crops in teak based agroforestry systems with respect to control

4.2.1 Organic carbon

Organic carbon content of soil was found to decrease and then increase with increase in soil depth (Table 4.3 and Figure 4.7). It varied significantly among various crop species present with teak in agroforestry systems as compared to the organic carbon content of the soil present in the controlled condition where only sole crop was grown. The value ranged from 0.19-0.59 % in the controlled condition while it ranged between 0.22-0.63% in the teak based system respectively. In the teak based agroforestry system, maximum organic carbon content of 0.63 % was found under teak + chilli system in 0-15 cm soil depth. It was followed by teak + brinjal agroforestry systems (0.57%) in the top layer (0-15 cm). Lowest organic carbon content was significantly found in the teak + arhar system (0.22%) in the 15-30 cm layer. On overall basis the organic carbon content of teak based agroforestry system was found to be significantly more as compared to the controlled condition.

4.2.2 Available nitrogen

The available nitrogen of the soil present in various teak based agroforestry system was found to be significantly higher as compared to its controlled condition (Table 4.3 and Fig 4.8). However, the trend of variation was similar to that of organic carbon with respect to soil depth. The value of available nitrogen varied from 129.40 kg ha^{-1} to 162.90 kg ha^{-1} in controlled condition where as in the tree based agroforestry system it varied from 162.5 kg ha^{-1} to 250.0 kg ha^{-1}. In the teak based agroforestry system, maximum available nitrogen of 252.5 kg ha^{-1} was found under teak + chilli system in 0-15 cm soil depth, followed by teak + brinjal agroforestry systems (227.5 kg ha^{-1}) in the same layer. Lowest available nitrogen of 163.1 kg ha^{-1} was found in the teak + arhar system in the 15-30 cm layer.

4.2.3 Available phosphorous

Available phosphorus of soil was found to decrease with increase in soil depth (Table 4.3 and Figure 4.9).Phosphorous availability (Table 4.3 and figure) varied from 17.9 kg ha^{-1} to 98.9 kg ha^{-1} in controlled condition where as in teak based agroforestry system it ranged from 24.5 kg ha^{-1} to 108.0 kg ha^{-1}. In the teak based agroforestry system, the available phosphorous in the soil was significantly higher as compared to its controlled condition. Maximum available phosphorus of 108.0 kg ha^{-1} was found under teak + chilli system in 0-15 cm soil depth, followed by teak + brinjal agroforestry systems (98.9 kg ha^{-1}) in the top layer. Lowest available phosphorus content of 24.5 kg ha^{-1} was found in the teak + arhar system in the 30-45 cm layer.

4.2.4 Available Potassium

Significant variation was observed in the available potassium status of soil present in the crop fields with teak in the field bunds as compared to its controlled condition (Table 4.2 and Figure 4.10). Available potassium under no tree control condition varied from 111.5 kg ha^{-1} to 348.1 kg ha^{-1} where as in teak based agroforestry system it varied from 119.2 kg ha^{-1} to 359.3 kg ha^{-1} respectively. In general potassium content was found to be significantly higher under tree crop combination than no tree condition. Highest available potassium was found in teak + chilli system (348.1 kg ha^{-1}) followed by teak + brinjal system (329.3 kg ha^{-1}) in top layer (0-15 cm soil depth). Lowest available potassium was recorded in teak + arhar system (119.2 kg ha^{-1}) in 30-45 cm soil depth. However, the trend of variation was similar to that of available phosphorus with respect to soil depth.

4.2.5 pH

The pH value for all teak based agroforestry system was significantly more as compared to its controlled condition value. The pH in controlled condition varied from 5.10 to 6.56 where as in teak based agroforestry system it varied from 5.16 to 6.64 (Table 4.3 and Figure 4.11).The pH of teak + arhar system was found to be lowest (5.16 at 0-15 cm soil depth). On the contrary the pH of teak + chilli system was found to be significantly highest (6.64 at 30-45cm soil depth). The pH of both agroforestry system as well as controlled condition was found to increase with increase in soil depth.

4.2.6 Electrical conductivity

The electrical conductivity of soil present in the teak based agroforestry system was significantly more as compared to its controlled condition (Table 4.3 and Figure 4.12). It varied from 0.013 dS m^{-1} to 0.056 dS m^{-1} in controlled condition where as in teak based agroforestry system it varied from 0.016 dS m^{-1} to 0.059 dS m^{-1}. Further the value of electrical conductivity in various teak based agroforestry systems was found to be following a decreasing trend with increase in soil depth. Highest electrical conductivity was recorded in teak + chilli system (0.059 dS m^{-1}) in top layer (0-15 cm depth) where as the lowest was recorded in teak + arhar system (0.016 dS m^{-1}) in the 30-45 cm soil depth.

Table 4.3 Soil chemical parameters related to different teak based agroforestry system

Sl. No.	Intercrops with teak	Soil depth (cm.)	Control						Agroforestry system					
			pH (1:2)	EC (dS m^{-1})	OC (%)	Available N (kg ha^{-1})	Available P_2O_5 (kg ha^{-1})	Available K_2O (kg ha^{-1})	pH (1:2)	EC (dS m^{-1})	OC (%)	Available N (kg ha^{-1})	Available P_2O_5 (kg ha^{-1})	Available K_2O (kg ha^{-1})
1	Paddy	0-15	5.27	0.026	0.45	187.5	50.7	206.9	5.31	0.029	0.47	190.0	59.8	218.1
		15-30	5.56	0.022	0.21	172.8	41.9	157.2	5.63	0.024	0.25	173.4	49.4	166.8
		30-45	5.70	0.014	0.34	187.4	21.8	131.8	5.80	0.017	0.37	189.9	28.4	140.8
2	Arhar	0-15	5.10	0.024	0.38	187.3	40.6	165.3	5.16	0.027	0.42	189.9	75.0	176.5
		15-30	5.29	0.021	0.19	162.5	28.6	120.9	5.36	0.023	0.22	163.1	37.1	130.5
		30-45	5.34	0.013	0.32	186.4	17.9	111.5	5.42	0.016	0.34	187.6	24.5	119.2
3	Colocasia	0-15	5.96	0.035	0.50	200.0	79.4	306.7	6.00	0.038	0.54	203.7	88.5	317.9
		15-30	6.26	0.024	0.28	175.0	55.2	252.9	6.33	0.026	0.32	175.6	63.7	262.5
		30-45	6.34	0.017	0.38	189.5	31.2	204.3	6.42	0.020	0.41	191.2	37.8	212.3
4	Mango-ginger	0-15	5.91	0.029	0.47	200.0	65.9	223.1	5.95	0.032	0.49	202.5	75.0	234.3
		15-30	6.06	0.023	0.27	174.6	45.9	213.7	6.13	0.025	0.31	175.4	54.4	223.3
		30-45	6.19	0.016	0.35	187.5	27.5	178.7	6.27	0.019	0.38	190.3	34.1	186.7
5	Okra	0-15	6.35	0.037	0.52	212.5	81.7	317.4	6.39	0.040	0.56	215.0	90.9	328.7
		15-30	6.49	0.031	0.34	175.2	59.3	284.9	6.56	0.033	0.36	175.7	77.8	294.5
		30-45	6.50	0.021	0.41	199.9	36.6	256.2	6.58	0.024	0.45	201.3	43.2	264.2
6	Brinjal	0-15	6.40	0.046	0.53	225.0	89.9	329.3	6.45	0.049	0.57	227.5	98.9	340.4
		15-30	6.50	0.041	0.35	187.5	76.7	290.6	6.57	0.043	0.38	188.1	89.2	300.2
		30-45	6.56	0.039	0.44	200.0	50.0	269.1	6.63	0.042	0.47	201.5	56.6	277.1
7	Chilli	0-15	6.41	0.056	0.59	250.0	98.9	348.1	6.46	0.059	0.63	252.5	108.0	359.3
		15-30	6.54	0.050	0.43	200.0	84.9	333.5	6.61	0.052	0.46	202.6	93.4	343.1
		30-45	6.56	0.040	0.51	202.6	69.9	276.8	6.64	0.043	0.54	203.8	76.5	284.8

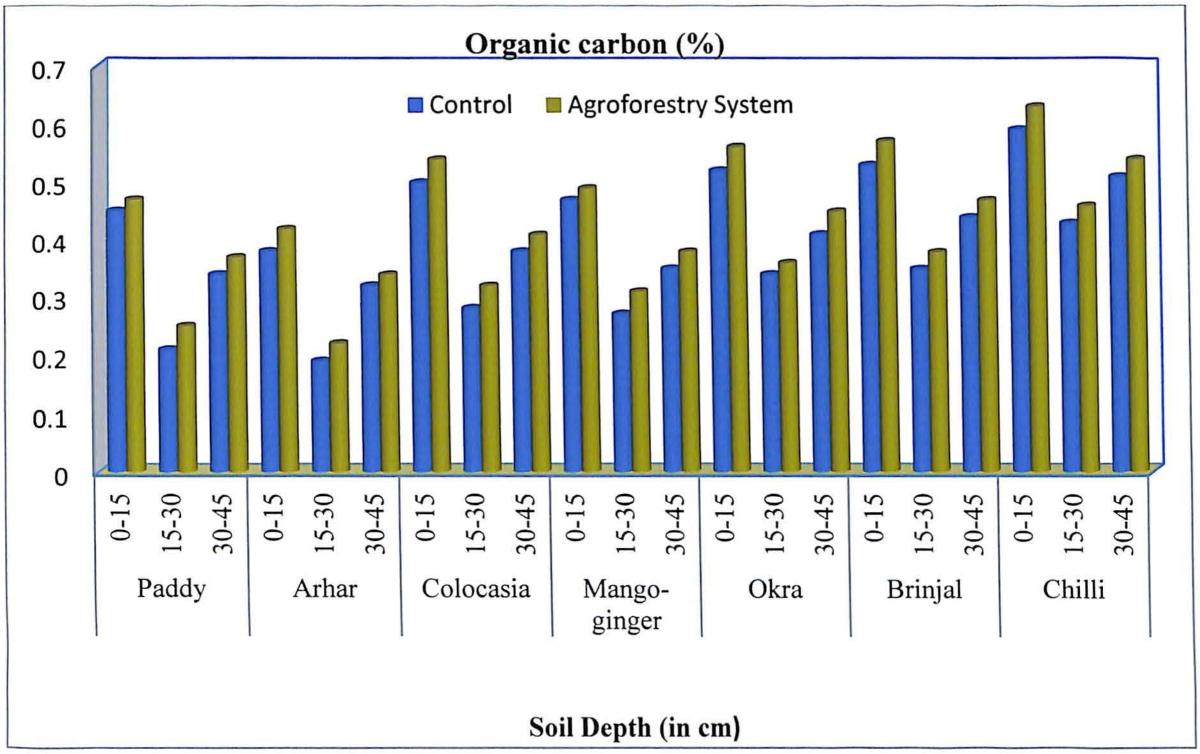

Fig. 4.7 Organic carbon content in teak based Agroforestry Systems and its respective controlled condition

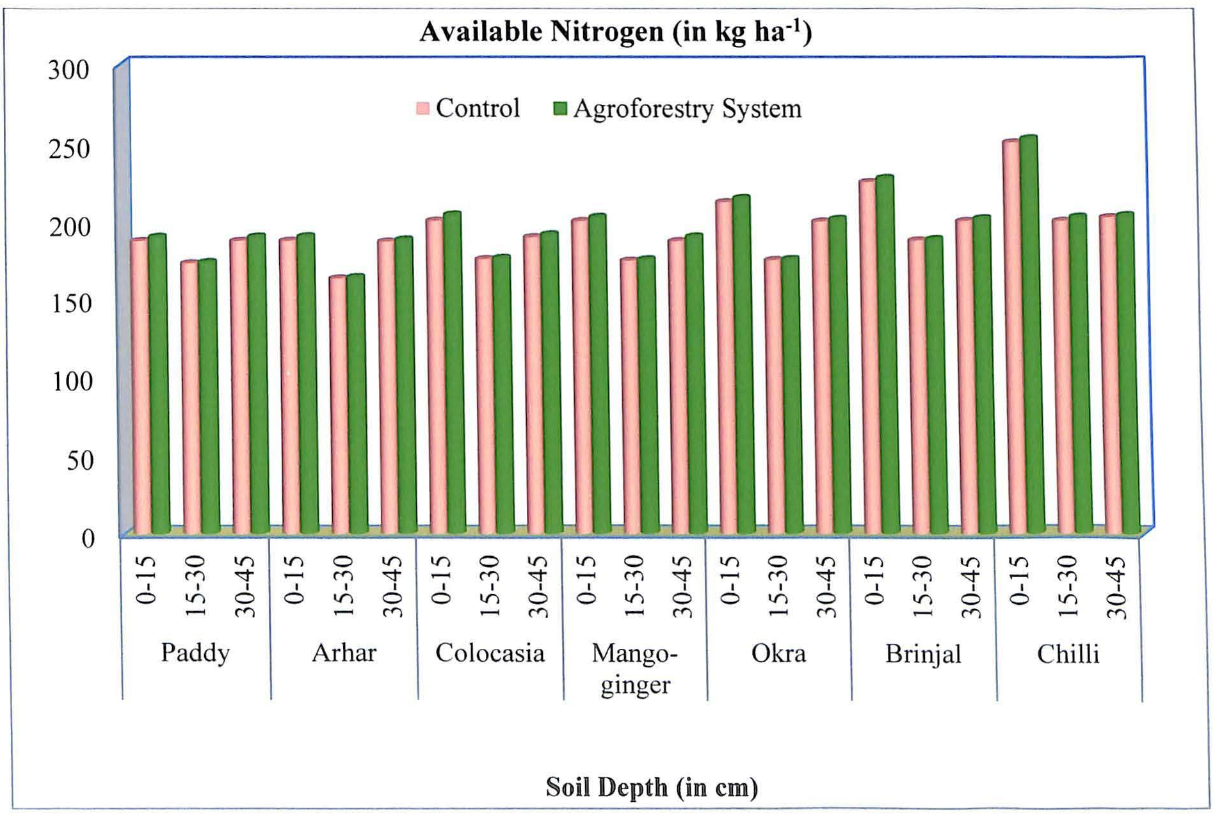

Fig. 4.8 Available Nitrogen Status in teak based Agroforestry Systems and its respective controlled condition

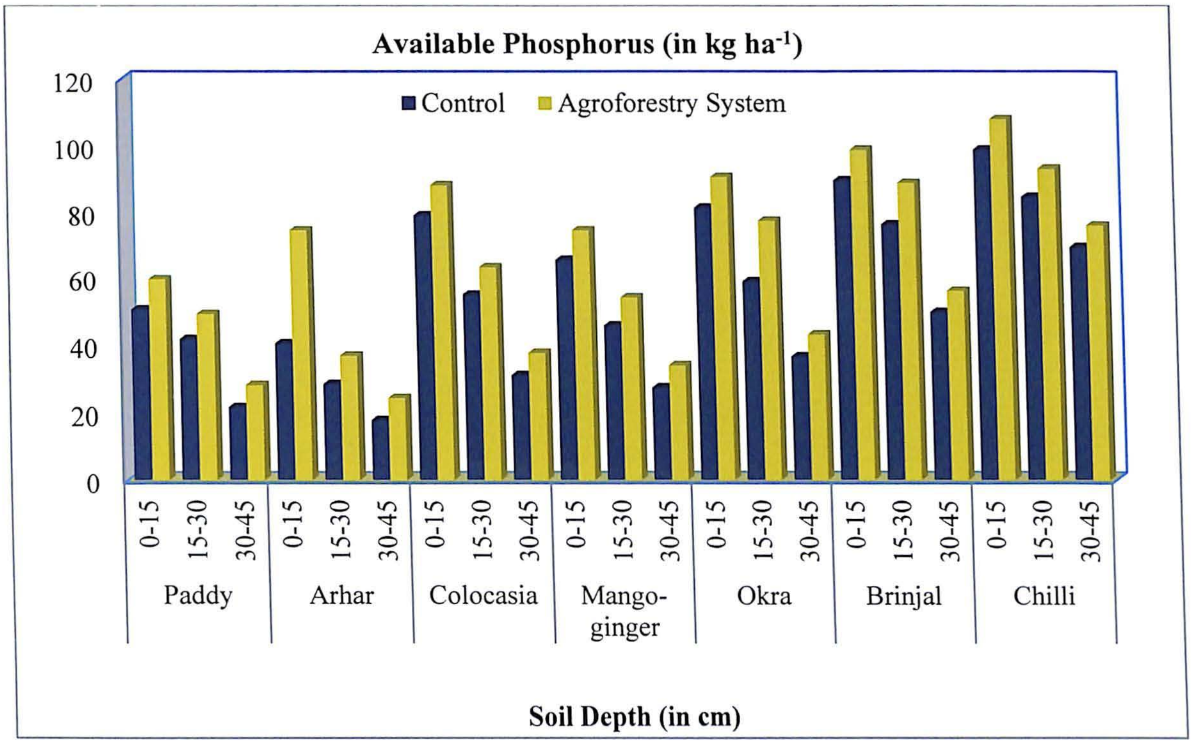

Fig. 4.9 **Available phosphorus status in teak based agroforestry systems and its respective controlled condition**

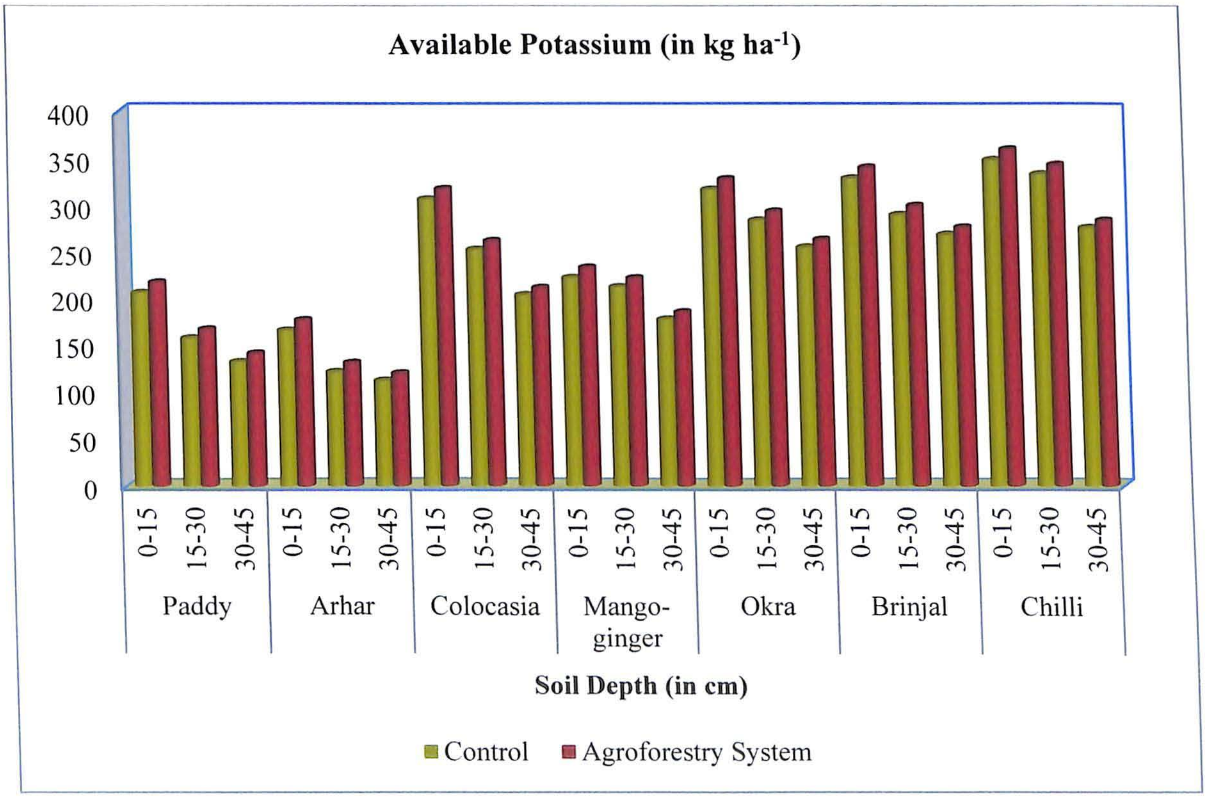

Fig. 4.10 **Available potassium status in teak based agroforestry systems and its respective controlled condition**

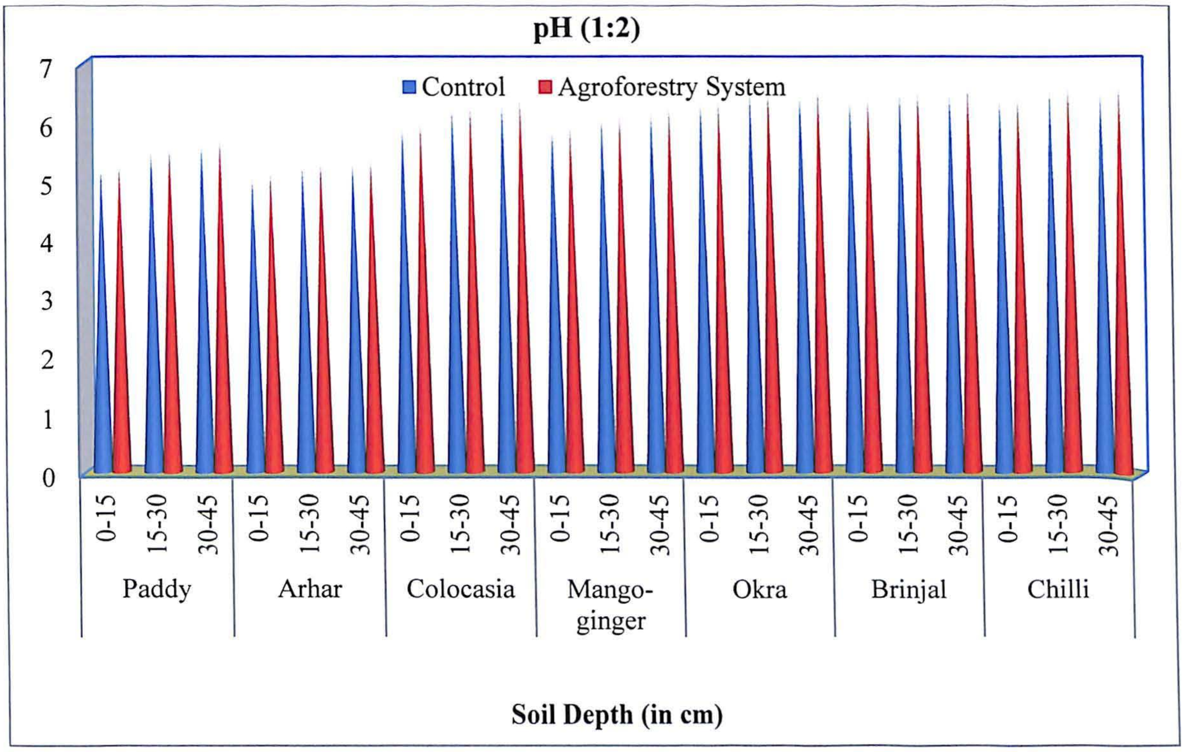

Fig. 4.11 pH in teak based agroforestry systems and its respective controlled condition

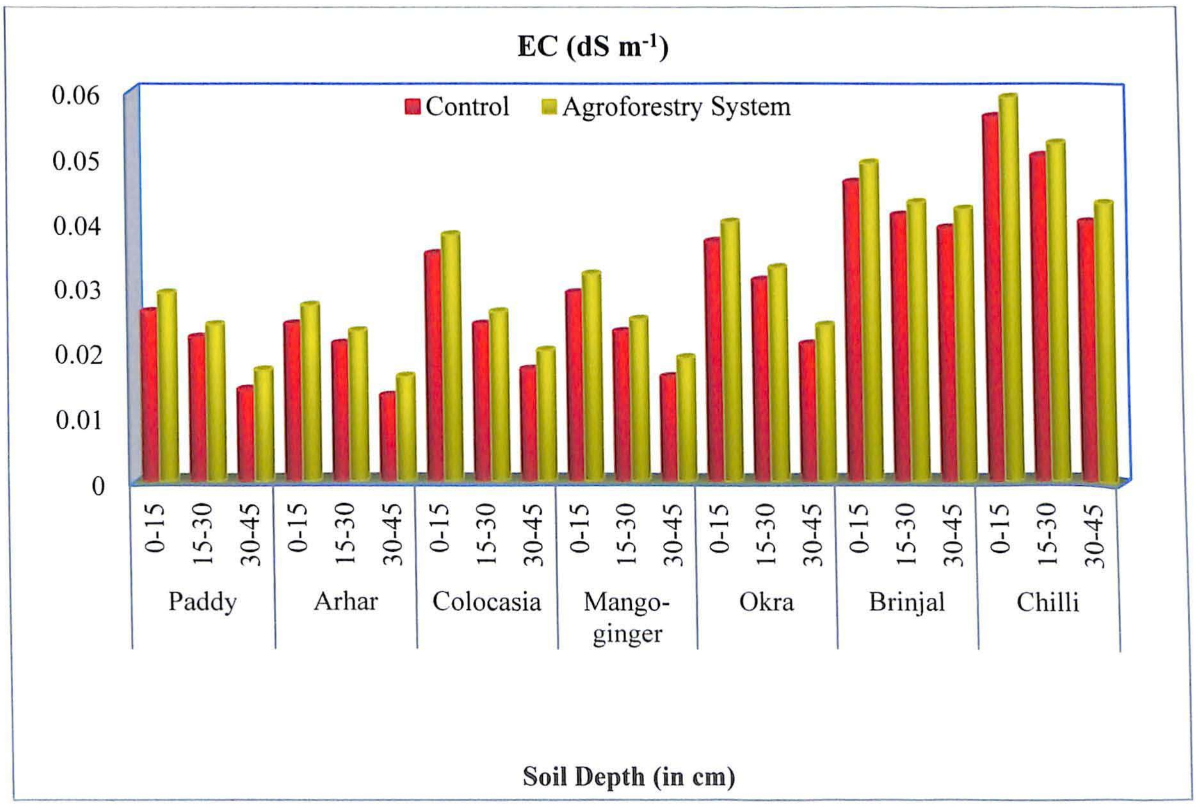

Fig. 4.12 EC in teak based agroforestry systems and its respective controlled condition

4.3 Study of economics related to different tree based agroforestry system

The data in Table 4.4 and figure revealed that the economic parameters such as gross return, net return, B:C ratio of different teak based agroforestry systems varied significantly among the different treatments.

4.3.1 Gross Return

It was observed that the gross return from various teak based agroforestry systems was significantly more as compared to the gross return obtained from the controlled conditions (Table 4.4 and Figure 4.13). In teak based agroforestry system, highest return was obtained from teak + chilli system (₹ 2,52,449 ha^{-1}) while the return from the controlled condition of same area was found to be ₹ 1,49,000 ha^{-1}. Gross return of crops from teak based agroforestry system was found to be significantly different from each other and from its controlled condition. Lowest gross return was found in teak + paddy system (₹ 1,61,443 ha^{-1}) and the gross return from its controlled condition was found to be ₹ 52,200 ha^{-1}.

4.3.2 Net Return

It was revealed that net return obtained from various teak based agroforestry system was higher from the net return obtained from the respective controlled conditions which favoured no trees on the field bunds (Table 4.4 and Figure 4.14). It was observed that maximum net return was obtained from the teak + chilli agroforestry system (₹ 1,80,348 ha^{-1}) whereas the net return from its controlled condition was found to be ₹ 99,000 ha^{-1}. The net return obtained from other teak based agroforestry systems was considerably lower than teak + chilli system. The lowest net return was obtained from teak + paddy system (₹ 1,16,003 ha^{-1}). On the contrary, the net return from its controlled condition was found to be ₹ 28,500 ha^{-1}.

4.3.3 B:C Ratio

The B:C Ratio of the teak based agroforestry system was found to be higher as compared to its controlled condition (Table 4.4 and Figure 4.15). In the teak based system, the value of B:C varied from 2.32 to 3.50 while in the controlled condition it varied from 1.43 to 2.98. In the teak + chilli based agroforestry system, the B:C ratio was found to be highest (3.50) with respect to its controlled condition (2.63). On the contrary, it was lowest in teak + colocasia system (2.32) and B: C ratio in its controlled condition was found to be 1.43.

Table 4.4 Economics of teak based Agroforestry System

Sl. No.	Intercrops with teak	Controlled System			Agroforestry Systems						Contribution of income to total income (%) in Agroforestry Systems	
		Gross return (₹ ha^{-1})	Net return (₹ ha^{-1})	B:C ratio	Income from crop (₹ ha^{-1})	Income from tree (₹ ha^{-1})	Income from tree per year (₹ ha^{-1})	Gross return per year (₹ ha^{-1})	Net return per year (₹ ha^{-1})	B:C ratio	Crops	Teak
1	Paddy	52200	28500	2.20	48360	4537730	113443	161803	116003	3.53	29.89	70.11
2	Arhar	68000	40000	2.43	59200	4337520	108438	167638	117538	3.35	35.31	64.69
3	Colocasia	85500	25500	1.43	79700	4437660	110942	190642	108542	2.32	41.81	58.19
4	Mangoginger	91500	31500	1.53	85500	4437590	110940	196440	114340	2.39	43.52	56.48
5	Okra	99750	64750	2.85	91500	4737870	118447	209947	152847	3.68	43.58	56.42
6	Brinjal	142500	82500	2.38	129800	4637800	115945	245745	163645	2.99	52.82	47.18
7	Chilli	149000	99000	2.98	131500	4837940	120949	252449	180349	3.50	52.09	47.91

* Return from firewood is included.

+ Selling price of crops by farmers includes paddy @ ₹ 12000, arhar @ ₹ 80000, colocasia @ ₹ 10000, mangoginger @ ₹ 15000, okra @ ₹ 15000, brinjal @ ₹ 10000 and chilli @ ₹ 50000 per tonne.

+ Cost of cultivation of teak based agroforestry systems with intercrops includes paddy @ ₹ 45800, arhar @ ₹ 50100 , colocasia @ ₹ 82100, mangoginger @ ₹ 82100 , okra @ ₹ 57100, brinjal @ ₹ 82100 and chilli @ ₹ 72100 per year and its respective controlled system includes ₹ 23700, ₹ 28000, ₹ 60000, ₹ 60000, ₹ 35000, ₹ 60000 and ₹ 50000.

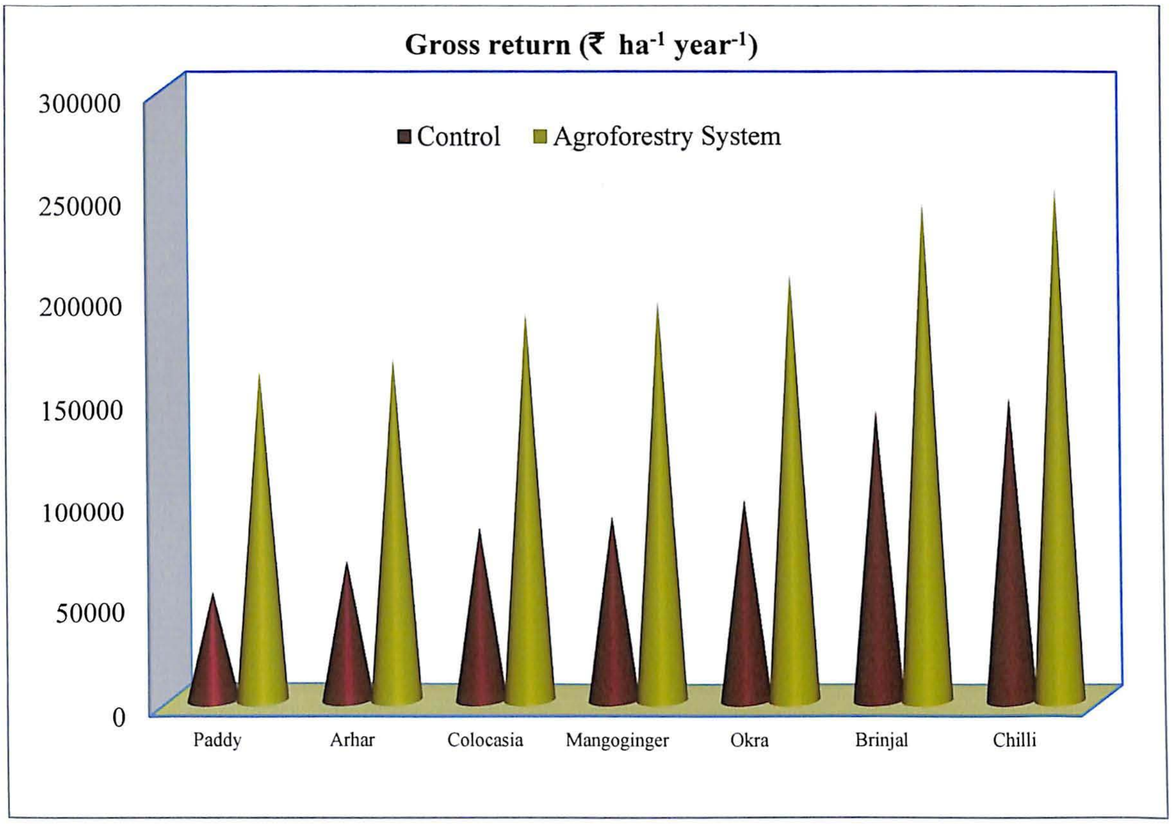

Fig. 4.13 Gross return from different teak based agroforestry system and from controlled condition

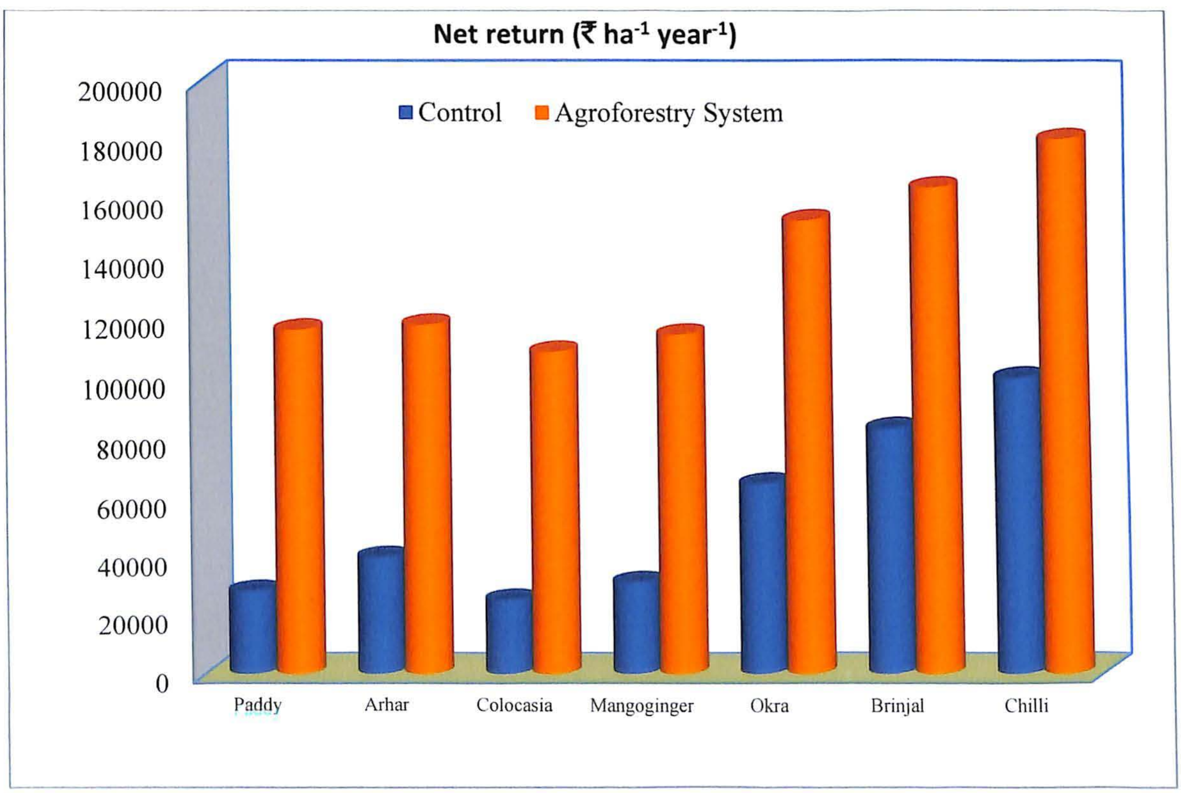

Fig. 4.14 Net return from different teak based agroforestry system and from controlled condition

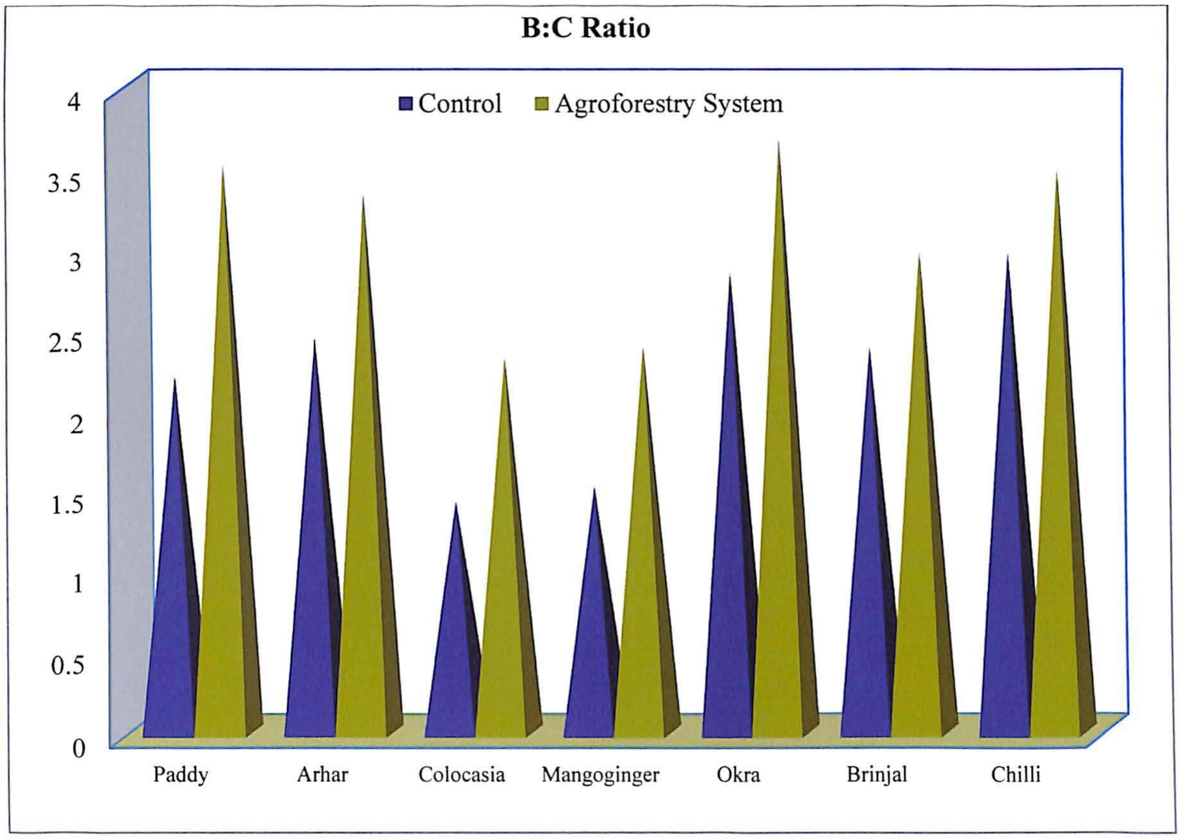

Fig.4.15 BCR Analysis of teak based agroforestry system with controlled condition

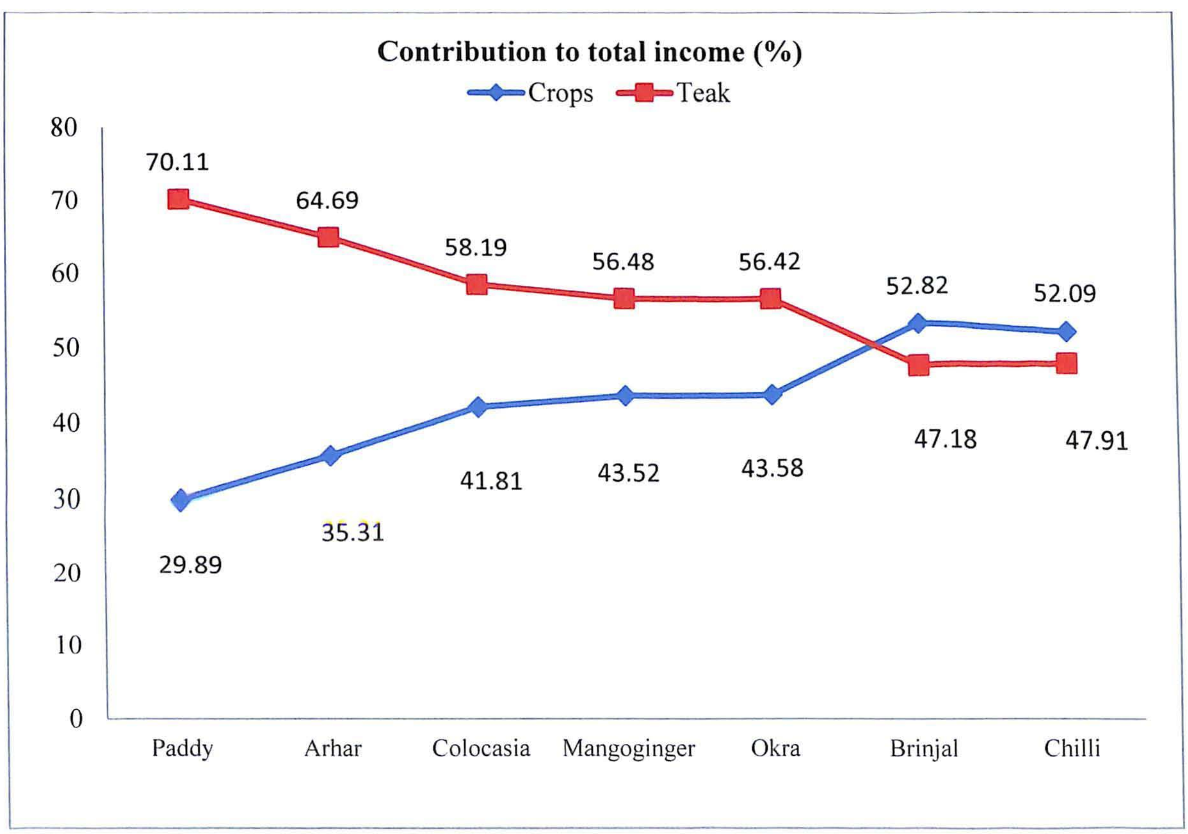

Fig.4.16 Contribution of income to total income (%) in agroforestry systems

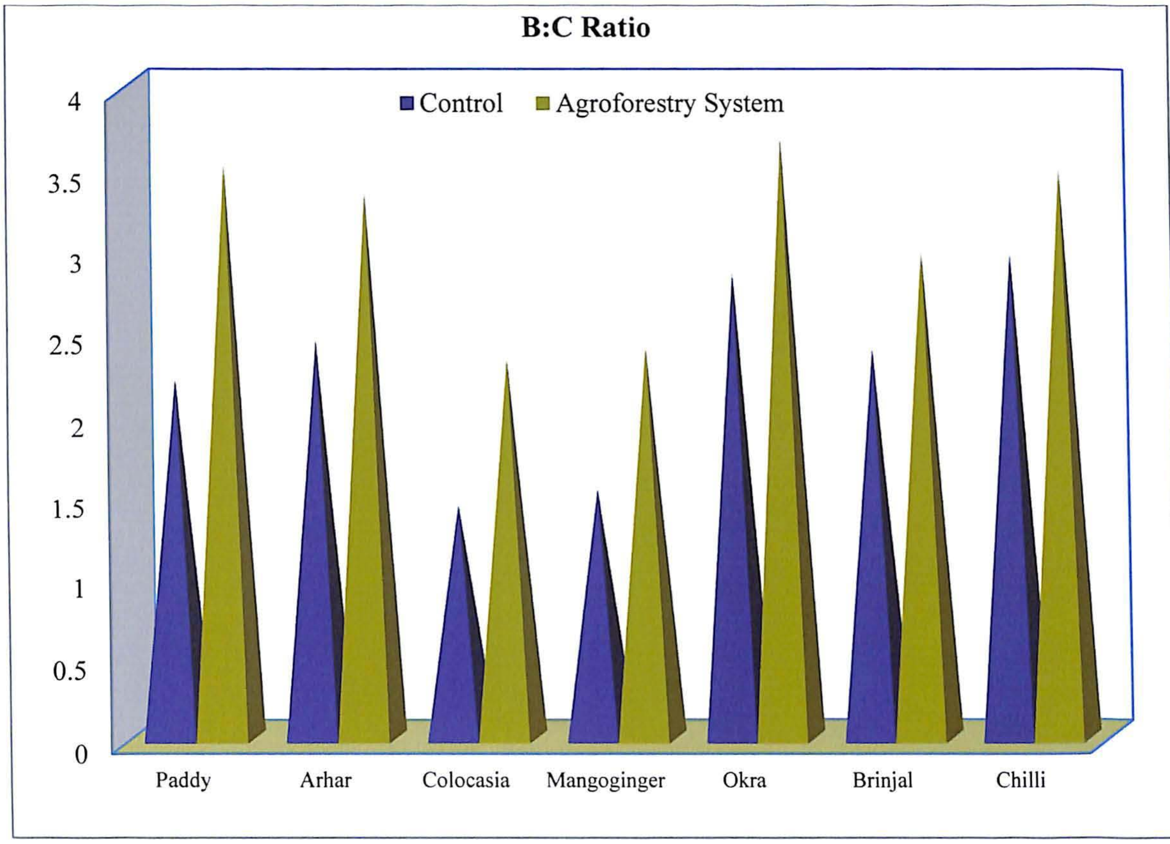

Fig.4.15 BCR Analysis of teak based agroforestry system with controlled condition

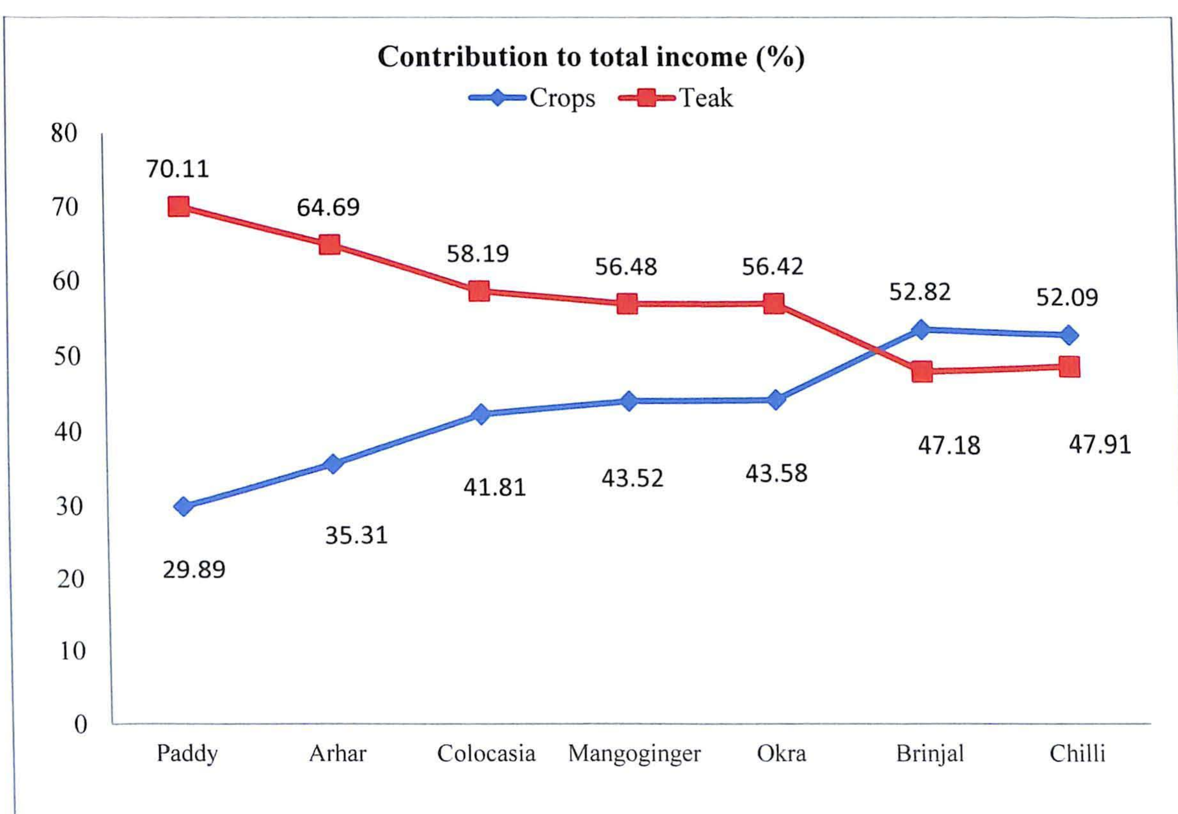

Fig.4.16 Contribution of income to total income (%) in agroforestry systems

4.3.4 Contribution of income to total income

Data presented on Table 4.4 and illustrated in Figure 4.16 revealed that contribution of income from field crops ranges from a minimum of 29.89 % in paddy to a maximum of 52.82 % in brinjal. From silvicultural component, contribution of income ranges from 47.18 % in brinjal to 70.11 % in paddy. Except for the case of teak + brinjal (47.18 %) and teak + chilli (47.91 %) system, contribution of silvicultural component to total income is greater than 50%.

CHAPTER-V

DISCUSSION

DISCUSSION

A field experiment was carried out in the four villages of Cuttack district of Odisha state *viz.* Bada Munduli, Patenigan, Mahakalabasta and Govindpur respectively during 2015-16 to study the performance of teak based agroforestry systems on the crop field bunds. Data on growth and performance of teak on the crop field bunds, the effect of teak on the soil characters and economics related to various teak based agroforestry systems have been presented in the preceding chapter. An attempt has been made in this chapter to analyze the results and interprete the findings in the line of research concluded.

5.1 Weather condition during the study period

The study was undertaken during the *kharif* season of 2015-16 under the agroclimatic condition prevailing at Cuttack district under East and South-Eastern Coastal Plain zone. The agroforestry systems require a specific range of temperature, precipitation and sunshine hours during different stages of growth for fullest expression of their yield potential because of the shade effect of the tree species (10 years old). Any imbalance in the requirements of the above environmental factors leads to depression in both the crop yield as well as the growth of tree component. The optimum temperature requirement for good yield of rice was found to be 26.9° C during critical period of growth stages. Other intercrops grown require more or less temperature range of 25-29°C which was more or less congenial during the growth period of the crops. The total rainfall received during the experiment was 1191.5 mm. Sunshine hours had significant correlation with growth and yield performance of all the crop because of the presence of tree crop on the rice field bunds.

Mutanal *et al.* (2004) reported variation in growth of teak species and associated crops in agroforestry system as compared to sole crop due to low level light transmission ratio, soil moisture and other environmental disorders. Environmental factors like temperature, rainfall and relative humidity also affect the growth and yield of both rice and other crops chilli, mango ginger, brinjal and okra (Annual report, AICRP on Agroforestry, OUAT, Bhubaneswar,2008). The prevailing mean temperature and sunshine hours during the growth stages of rice and other crops and the associated teak species present in the adjoining field bunds during *kharif* season were more or less conducive for growth and development of the field crops and the associated tree in the system.

5.2 Growth and performance of Teak tree species on the crop field bunds

Teak planted on crop field bunds recorded the maximum plant height of 15.95 m when grown with chilli which was 1.00 and 1.50 % higher than the height obtained with teak species grown in association with okra and brinjal, respectively. Teak+ Arhar and Teak+ mango ginger system had the minimum height (15.09 and 15.26 m) and other growth characters. Variations in tree height and other growth characters might be attributed to faster rate of growth, higher uptake of nutrients and better utilization of soil moisture of the tree species under different types of crops grown. Differential uptake of nutrients and moisture by the associated crops with the same tree component by many workers in agri silvicultural systems. Similar findings have been reported by Zahabu *et al.* 2015 and Patil *et al*, 2000.

With regard to D.B.H. of Teak, it was noted that Teak in association with chilli and okra had higher DBH values as compared to Teak + brinjal and other tree and crop combination. Minimum values of DBH was observed in Teak+ mango ginger combination. In this bund planted situation balanced fertilizer application to associated field crops might have helped in growth of tree species as well (Gantayat *et al*, 2008). Heque and Osman (1993) also observed similar trend in DBH in 26 year old teak plantations.

The G.B.H. of Teak showed the same trend as that of tree height and D.B.H. Teak+ chilli and teak + okra combination recorded the maximum values over other tree+ crop systems during the period under report. Sharma *et al.* (2011) reported better growth performance of teak in agroforestry system with wheat as compared to sole cropping.

As regards to volume of teak present in the field bunds, almost the same trend was noticed. Teak with chilli and okra had the maximum volume over other agrisilvicultural systems. This could be attributed to better manifestation of growth which resulted in increased tree volume. This is in conformity with the findings of Mutanal *et al.*, 2002 and Zahabu *et al.*, 2015.

5.3 Yield of field crops

Agroforestry system allows for positive and negative interactions among tree and crop. The productivity of agroforestry system is often attributed to mixture of species as they make better use of growth resources than the same species grown separately. The negative interactions viz., annual crop yield reducing up to 25% per cent were observed (Dagar *et al.*, 1995). Many authors have reported positive interaction effect of trees on crops. Growing of crops in the interspaces in teak is reported to be more economical and assure regular income from agroforestry system (Mutanal *et al.*, 2002 and Shukla, 2014). The competitive effects of trees on crop are not consistent due to various reasons. These effects may be complimentary or competitive depending upon the level of competition for growth resources between woody component and crops and also due to site conditions. Under some conditions productivity of agricultural crop is reported to be lower (Mutanal *et al.*, 2009 and Patil *et al.*, 2011), whereas several workers (Purwanto *et al.*, 2003, Pujar *et al*, 2007 and Rajendran *et al.*, 2003) reported higher productivity of crops in different trees.

Here in this present investigation, yield of all crops grown with 10 years old teak declined and the decrease was found maximum with arhar and chilli while in other field crops, the decrease was not that significant when compared to the age of the tree component. At Bhubaneswar, yield of intercrops with teak also declined significantly and the decrease increased with age of the tree component (Annual report, AICRP on agroforestry, OUAT, 2008).

5.3 Soil characters related to different agroforestry system in the rice field

Agroforestry systems are known to improve the soil physical condition and fertility status of the soil through nitrogen fixation and addition of leaf litter (Mohapatra *et al.*, 2008). In this present investigation, organic carbon status of soil showed remarkable improvement over the initial values (Table 3.5). In this investigation, organic carbon, available N, P and K values were influenced by tree-crop combination over no tree control. Irrespective of the crop grown in the system, all the values were higher when a tree component was found in the system. Organic carbon values increased from 0.45 to 0.47% in teak + paddy system with marginal increase in P and K. This might be due to higher leaf fall and faster decomposition leaf litter of teak tree species planted in the rice field bunds. Gantayat *et al.*, 2008 reported that *Acacia mangium* could add 6 to 7 tonnes of leaf litter ha^{-1} per annum under optimum management conditions as compared to *Dalbergia sissoo* and *Tectona grandis*. Similar findings have also been reported by many authors and have proved that the inclusion of teak can improve the soil physical and chemical conditions (Shukla, 2009, Sharma *et al.*, 2011, Mongia and Bandopadhyay, 1992).

Available nitrogen, phosphorus and Potassium values followed the similar trend as that of organic carbon. All the values were higher than the initial values which suggested that agroforestry systems did not deplete the soil of the native soil fertility rather helped in building of the nutrient status of the soil (Mohapatra *et al*, 2008).

5.4 Study of economics related to the tree based agroforestry system

Gross and net return in no tree control and in agrisilvicultural system is governed by their respective yield and corresponding market price. In control condition, gross and net return and B: C ratio was higher with chilli, brinjal and okra followed by other crops. But in teak+ chilli and teak+ okra agroforestry system all the values were much higher. The gross , net return and B:C ratio were ₹ 2,52,449 and ₹2,45,745 ha^{-1} , ₹ 1,80,349 and ₹ 1,63,645 ha^{-1} and 3.50 and 3.68 with teak + chilli and teak + okra agroforestry system, respectively.

As regards to contribution of income to total income (%) in agroforestry systems , teak contributed 70.11% in teak+ paddy system while its contribution decreased with other crops viz. teak+ arhar (64.7%), teak + colocassia(64.7 %). Minimum contribution was evident in teak+ brinjal (47.2 %) and teak+ chilli (47.9%) system. This clearly suggested that although the contribution from tree component was lower in teak+ brinjal and teak+ chilli system but overall income from the system was much higher due to the inclusion of the vegetable crop component. Many workers working with tree and vegetable agri- horticultural system are of the same opinion.

Similar findings have been reported by Shukla, 2014, Patil *et al.*, 2010, Mutanal *et al.*, 2002, Singh *et al.*, 2011.

CHAPTER-VI

SUMMARY AND CONCLUSION

SUMMARY AND CONCLUSION

An experiment entitled "Performance of different Teak-based Agroforestry Systems in Cuttack District of Odisha" was conducted at four different villages of Cuttack district during 2015-16. The experiment was laid out in randomized block design with seven treatments and replicated four times. The results have been discussed in the preceding chapter. The salient findings of the experiment are as follows:

- Teak trees planted with chilli were the tallest ones as compared to teak planted with other crops in the agroforestry system.
- Teak trees in the arhar field bunds were the shortest trees amongst the trees in other systems.
- Highest D.B.H and G.B.H amongst different teak based systems was found to be in teak-chilli agrisilvicultural system.
- Teak trees were found to have minimum D.B.H. and G.B.H. in teak-arhar system as compared to other systems.
- Volume was found maximum in teak trees present in the teak + chilli agri silvi system. On the other hand, teak trees present in the arhar field bunds were found to have minimum volume.
- The crop yield in the field planted with teak was lower than its respective control condition. The highest crop yield was obtained in brinjal planted with teak and the lowest was found to be in teak-arhar combination. The maximum yield reduction was found in arhar and minimum in mango ginger.
- The pH of soil in the tree based agroforestry system was found to be more as compared to the pH of soil present in the controlled condition where no tree crop was incorporated.

- Agroforestry system with teak and chilli had the maximum pH and minimum pH was found to be in teak-arhar system. The pH showed an increasing trend with the increase in soil depth.
- Teak + chilli system had highest electrical conductivity where as teak field planted with arhar had lowest one.
- The electrical conductivity of soil was found to be significantly more in tree based system as compared to controlled condition. Additionally, electrical conductivity of soil showed a decreasing trend with the increase in soil depth.
- Available nutrient status of soil in the crop field containing teak trees in its field bunds were found to be significantly higher as compared to the crop field where no trees were present.
- Status of organic carbon in the crop fields with teak as field bund plantation was found to be significantly more as compared to the organic carbon content of controlled field condition where no trees were present in the field bunds.
- The organic carbon content of soil in the 0-15cm soil depth was found to be significantly more as compared to that of soil in the 15-30cm and 30-45 cm depth. The organic carbon content showed a decreasing trend with respect to 0-15 cm depth and then increasing trend with the increase in soil depth
- Amongst various teak-crop combinations, the status of nitrogen was highest in chilli planted with teak whereas it was the lowest in arhar. The available nitrogen showed a similar trend as organic carbon with increase in soil depth.
- The phosphorus and potassium status of soil present in different teak based agroforestry system was found to be significantly more as compared to the controlled condition.

- Amongst various crop species planted with teak, the status of phosphorus and potassium was highest in teak- chilli combination whereas it was lowest in teak-arhar combination. The phosphorus and potassium status of other teak based agroforestry system were found to be following a decreasing trend with soil depth.

- The gross return obtained from different teak based agroforestry system was significantly more than those obtained from controlled condition.

- Amongst the various crops grown with teak, the maximum gross return was obtained from teak-chilli agrisilvicultural system which yielded ₹2,52,449 ha^{-1}. On the other hand gross return from teak-paddy agroforestry system was found to be minimum amongst all treatments (₹ 1,61,803 ha^{-1}).

- The return from tree components in the crop field bunds was maximum from teak trees with chilli (₹ 1,20,949 ha^{-1}) and minimum values was obtained from arhar with teak (₹ 1,08,438 ha^{-1}) .

- The net return obtained from various tree based agroforestry system was found to be significantly more as compared to its controlled condition.

- Teak based agroforestry system with chilli gave maximum net return amongst all other agroforestry system (₹ 1,80,349 ha^{-1}). On the other hand lowest net return was obtained from teak-paddy agroforestry system (₹ 1,16,003 ha^{-1}).

- The B: C ratio of various tree based agroforestry system was found to be significantly more as compared to the B:C ratio of the controlled condition.

- Amongst various treatments, teak based agroforestry system with okra as intercrop exhibited highest B:C ratio (3.68).On the other hand, teak-colocasia agroforestry system exhibited minimum B:C ratio (2.32) in comparison to all other treatments.

CONCLUSION

Teak trees present in the chilli field bunds recorded maximum growth parameters in terms of tree height (15.98 m), D.B.H. (17.29 cm), G.B.H. (0.72 m^3) and volume (0.38 m^3). The nutrient status of soil such as soil pH, Organic carbon, available N, P and K was also found significantly higher in tree based agroforestry system as compared to the controlled condition. Net return (₹ 1,80,349 ha^{-1}) were found highest in teak and chilli based agroforestry system but the B: C ratio was found highest in teak and okra based agroforestry system (3.68). Soil fertility was either maintained or improved in tree based system indicating sustainability of the tree based agroforestry system. Overall, tree based agroforestry system seems to be more beneficial (both in qualitative and economic aspect) in comparison to conventional controlled method of crop cultivation.

FUTURE LINE OF WORK

The same set of experiment may be repeated for further confirmation and with more number of crop species planted with teak. More nitrogen fixing trees can be included as field bund plantations for ameliorating soil health to a greater extent. Multipurpose trees exhibiting massive growth and crown spread can be tried for more productivity of both tree component and crop at various locations of Odisha.

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APPENDICES

APPENDICES

APPENDIX-1 Height, DBH, GBH and volume obtained in agroforestry Systems

Sl. No	Agroforestry system	Bada Munduli				Patenigan				Mahakalabasta				Govindpur			
		Height (m)	**DBH (cm)**	**GBH (m)**	**Volume (m^3)**	**Height (m)**	**DBH (cm)**	**GBH (m)**	**Volume (m^3)**	**Height (m)**	**DBH (cm)**	**GBH (m)**	**Volume (m^3)**	**Height (m)**	**DBH (cm)**	**GBH (m)**	**Volume (m^3)**
1	Teak+ Paddy	16.6	17.4	0.76	0.39	16.2	16.4	0.69	0.34	15.6	15.6	0.66	0.30	15.2	16.4	0.63	0.32
		16.3	17.4	0.75	0.39	15.6	16.4	0.72	0.33	15.4	15.4	0.62	0.29	15.6	16.6	0.67	0.34
		16.2	17.0	0.70	0.37	15.7	16.2	0.66	0.32	15.2	16.0	0.67	0.31	16	15.2	0.61	0.29
		16.3	16.2	0.68	0.34	15.3	16.6	0.74	0.33	15.8	15.4	0.61	0.29	14.8	16.6	0.69	0.32
		15.8	16.4	0.69	0.33	15.2	17.4	0.78	0.36	15.9	15.6	0.58	0.30	14.5	16.4	0.61	0.31
		16.4	16.2	0.64	0.34	15.7	17.0	0.68	0.36	16	16.2	0.67	0.33	14.9	15.2	0.60	0.27
		16.5	16.0	0.60	0.33	16.2	16.8	0.62	0.36	15.3	16.4	0.65	0.32	14.5	16	0.57	0.29
		16.6	16.8	0.68	0.37	16.6	16.4	0.67	0.35	15.6	16.4	0.69	0.33	15.1	15.6	0.52	0.29
		16.2	16.2	0.61	0.33	15.3	16.9	0.70	0.34	15.2	15.4	0.63	0.28	15.7	15.8	0.54	0.31
		16.3	16.2	0.66	0.34	15.1	16.7	0.65	0.33	15.7	15.4	0.67	0.29	14.4	15.6	0.58	0.28
	Replication Mean	**16.32**	**16.58**	**0.68**	**0.35**	**15.69**	**16.68**	**0.69**	**0.34**	**15.57**	**15.78**	**0.65**	**0.31**	**15.07**	**15.94**	**0.60**	**0.30**
	Total Mean	Height (m)				DBH (cm)				GBH (m)				Volume (m^3)			
		15.66				**16.25**				**0.65**				**0.33**			
2	Teak+Arhar	15.4	16.4	0.63	0.33	15.6	16.2	0.59	0.32	14.9	15.6	0.56	0.29	14.6	15.6	0.48	0.28
		15.4	15.8	0.54	0.30	15.4	16.0	0.57	0.31	15.2	16.0	0.58	0.31	13.7	15.6	0.47	0.26
		15.6	16.6	0.61	0.34	15.0	16.4	0.62	0.32	14.8	15.4	0.48	0.28	14.8	16.2	0.48	0.31
		15.9	16.4	0.62	0.34	14.9	15.6	0.55	0.28	15.2	15.8	0.52	0.30	15.4	15.2	0.52	0.28
		15.1	15.8	0.53	0.30	14.7	15.8	0.52	0.29	14.7	15.2	0.49	0.27	15.2	15.8	0.51	0.30
		15.7	16	0.55	0.32	15.2	16.4	0.55	0.32	14.3	15.4	0.53	0.27	15.7	15.4	0.53	0.29
		14.6	15.2	0.49	0.26	15.1	15.8	0.50	0.30	14.2	15.2	0.45	0.26	14.9	16	0.47	0.30
		15.8	16	0.52	0.32	15.7	15.6	0.53	0.30	14.9	15.4	0.52	0.28	15.6	15.8	0.52	0.31
		15.1	16.2	0.59	0.31	15.1	16.0	0.58	0.30	15.3	15.6	0.57	0.29	14.8	15.4	0.51	0.28
		15.7	16.8	0.65	0.35	14.6	15.4	0.53	0.27	15.6	15.6	0.58	0.30	14.2	15.8	0.59	0.28
	Replication Mean	**15.43**	**16.1**	**0.57**	**0.32**	**15.13**	**15.92**	**0.55**	**0.30**	**14.91**	**15.52**	**0.53**	**0.28**	**14.89**	**15.68**	**0.51**	**0.29**
	Total Mean	Height(m)				DBH (cm)				GBH(m)				Volume (m^3)			
		15.09				**15.81**				**0.54**				**0.29**			

Sl. No	Agroforestry system	Bada Munduli				Patenigan				Mahakalabasta				Govindpur			
		Height (m)	DBH (cm)	GBH (m)	Volume (m^3)	Height (m)	DBH (cm)	GBH (m)	Volume (m^3)	Height (m)	DBH (cm)	GBH (m)	Volume (m^3)	Height (m)	DBH (cm)	GBH (m)	Volume (m^3)
3	Teak+ Colocasia	16.7	17.2	0.68	0.39	15.7	16.2	0.65	0.32	15.2	15.8	0.63	0.30	14.8	15.6	0.57	0.28
		16.5	16.8	0.63	0.37	15.8	16.4	0.61	0.33	14.9	15.2	0.56	0.27	15.2	15.0	0.55	0.27
		16.1	16.4	0.61	0.34	15.2	16.6	0.68	0.33	15.4	15.4	0.59	0.29	15.7	15.4	0.58	0.29
		15.7	16.8	0.65	0.35	15.7	16.0	0.61	0.32	14.7	16.2	0.67	0.30	14.5	16.6	0.6	0.31
		15.6	16.2	0.6	0.32	16.0	15.8	0.58	0.31	15.4	16	0.65	0.31	15.1	16.2	0.55	0.31
		16.2	16.8	0.66	0.36	16.1	16.8	0.71	0.36	16.2	15.4	0.58	0.30	14.6	16.8	0.58	0.32
		15.7	16.2	0.58	0.32	15.9	16.4	0.68	0.34	15.5	15.8	0.61	0.30	15.4	15.4	0.59	0.29
		15.4	16.4	0.62	0.33	15.3	16.2	0.68	0.32	14.7	15.2	0.58	0.27	15.1	16.8	0.64	0.34
		15.2	16.6	0.66	0.33	15.6	16	0.64	0.31	15.6	16.2	0.68	0.32	14.7	15.6	0.56	0.28
		15.4	16.2	0.61	0.32	15.2	16.8	0.75	0.34	15.7	16	0.66	0.32	15.4	15.2	0.59	0.28
	Replication Mean	**15.85**	**16.56**	**0.63**	**0.34**	**15.65**	**16.32**	**0.66**	**0.33**	**15.33**	**15.72**	**0.62**	**0.30**	**15.05**	**15.86**	**0.58**	**0.30**
	Total Mean	Height(m)				DBH (cm)				GBH(m)				Volume (m^3)			
		15.47				**16.12**				**0.62**				**0.32**			
4	Teak+ Mango-ginger	15.6	16.8	0.64	0.35	15.1	16.4	0.69	0.32	14.8	16.2	0.63	0.31	14.8	16.2	0.61	0.31
		14.9	16.2	0.63	0.31	15.7	16.8	0.71	0.35	14.7	15.8	0.58	0.29	15.2	16.4	0.63	0.32
		15.8	16.4	0.61	0.33	15.4	16.2	0.65	0.32	15.6	15.4	0.58	0.29	15.7	15.2	0.50	0.29
		15.6	16.8	0.62	0.35	14.5	15.4	0.58	0.27	14.8	15.6	0.61	0.28	14.5	15.4	0.55	0.27
		15.2	16.7	0.58	0.33	14.8	15.6	0.59	0.28	15.0	15.8	0.63	0.29	15.1	15.6	0.56	0.29
		15.7	16.5	0.63	0.34	15.7	16.6	0.74	0.34	15.7	15.2	0.58	0.29	14.6	15.2	0.49	0.265
		15.1	16.2	0.55	0.31	15.9	16.6	0.62	0.34	15.9	15.8	0.60	0.31	15.4	15.8	0.54	0.30
		15.8	16.4	0.65	0.33	15.4	16.2	0.56	0.32	15.7	15	0.57	0.28	15.1	16.2	0.6	0.31
		15.7	15.8	0.62	0.31	15.6	16.2	0.54	0.32	14.2	15.6	0.61	0.27	14.7	16.0	0.57	0.30
		16.2	16.6	0.58	0.35	15.3	16.0	0.59	0.31	14.8	15.3	0.59	0.27	15.4	16.2	0.59	0.32
	Replication Mean	**15.56**	**16.44**	**0.61**	**0.33**	**15.34**	**16.20**	**0.63**	**0.32**	**15.12**	**15.57**	**0.60**	**0.29**	**15.05**	**15.82**	**0.56**	**0.30**
	Mean	Height(m)				DBH (cm)				GBH(m)				Volume (m^3)			
		15.27				**16.01**				**0.60**				**0.31**			

Sl. No	Agroforestry system	Bada Munduli				Patenigan				Mahakalabasta				Govindpur			
		Height (m)	**DBH (cm)**	**GBH (m)**	**Volume (m^3)**	**Height (m)**	**DBH (cm)**	**GBH (m)**	**Volume (m^3)**	**Height (m)**	**DBH (cm)**	**GBH (m)**	**Volume (m^3)**	**Height (m)**	**DBH (cm)**	**GBH (m)**	**Volume (m^3)**
5	Teak+Okra	16.7	18.6	0.82	0.45	16.4	17.4	0.71	0.39	16.1	17.0	0.73	0.37	14.8	15.6	0.69	0.28
		16.9	18.2	0.77	0.44	16.1	17.0	0.64	0.37	16.0	16.4	0.75	0.34	15.4	16.2	0.72	0.32
		16.5	18.6	0.59	0.45	16.6	17.6	0.75	0.40	16.4	17.6	0.75	0.40	14.9	15.8	0.64	0.29
		15.8	18.2	0.81	0.41	15.3	17.0	0.73	0.35	15.2	16.8	0.68	0.34	15.8	16.6	0.76	0.34
		17.0	18.6	0.78	0.46	16.0	17.4	0.75	0.38	15.6	16.4	0.61	0.33	15.2	16.0	0.69	0.31
		16.9	18	0.76	0.43	15.3	18.2	0.67	0.4	15.8	17.6	0.65	0.384	14.2	15.2	0.68	0.258
		15.8	17.6	0.79	0.38	15.7	17.8	0.61	0.39	15.3	16	0.62	0.307	15.8	16.2	0.69	0.326
		16.4	17.6	0.85	0.4	15.4	17.2	0.64	0.36	15.9	17.6	0.59	0.387	15.7	16.4	0.71	0.331
		15.9	17.2	0.74	0.37	16.2	18.4	0.77	0.43	15.8	17.8	0.74	0.393	14.6	15.2	0.57	0.265
		16	18.6	0.68	0.43	16	17.4	0.65	0.38	15.4	17.2	0.78	0.358	16.0	16.4	0.61	0.338
	Replication Mean	**16.39**	**18.12**	**0.76**	**0.42**	**15.90**	**17.54**	**0.69**	**0.38**	**15.75**	**17.04**	**0.69**	**0.36**	**15.24**	**15.96**	**0.68**	**0.31**
	Mean	Height(m)				DBH (cm)				GBH(m)				Volume (m^3)			
		15.82				**17.17**				**0.70**				**0.37**			
6	Teak+ Brinjal	16.2	18.8	0.74	0.45	16.3	17.6	0.69	0.4	15.6	15.8	0.74	0.31	15.6	16.0	0.63	0.31
		16.7	18.2	0.75	0.43	15.4	17.2	0.72	0.36	15.2	15.2	0.67	0.28	15.4	16.8	0.69	0.34
		16.2	18.4	0.79	0.43	16.2	17.3	0.76	0.38	15.9	15.8	0.61	0.31	14.7	17.2	0.74	0.34
		15.9	17.8	0.70	0.40	16.0	17.4	0.74	0.38	15.6	15.4	0.68	0.29	16.2	15.6	0.6	0.31
		15.4	16.2	0.69	0.32	15.9	17.0	0.69	0.36	15.8	16.0	0.69	0.32	15.8	15.6	0.65	0.30
		16.9	16.8	0.68	0.37	15.6	16.4	0.63	0.33	15.6	16.4	0.62	0.33	14.4	15.8	0.68	0.28
		16.2	16.2	0.71	0.33	15.3	17.2	0.73	0.36	15.8	15.8	0.67	0.31	15.3	15.2	0.58	0.278
		17.1	17.6	0.65	0.42	16.2	17.4	0.68	0.39	15.3	15.4	0.61	0.29	14.9	15.8	0.67	0.29
		16.2	17.2	0.62	0.38	15.6	16.8	0.62	0.35	15.5	16.4	0.69	0.33	15.1	16.8	0.68	0.34
		16.5	18.2	0.67	0.43	15.2	17.0	0.7	0.34	15.6	16.2	0.68	0.32	15.3	15.6	0.61	0.29
	Replication Mean	**16.33**	**17.54**	**0.70**	**0.40**	**15.77**	**17.13**	**0.70**	**0.36**	**15.59**	**15.84**	**0.67**	**0.31**	**15.27**	**16.04**	**0.65**	**0.31**
	Mean	Height(m)				DBH (cm)				GBH (m)				Volum(m^3)			
		15.74				**16.64**				**0.67**				**0.34**			
7	Teak+Chilli	16.3	18.2	0.82	0.42	16.5	17.4	0.71	0.39	15.8	17.0	0.69	0.36	15.7	16.6	0.78	0.34
		16.5	17.4	0.85	0.39	16.3	17.6	0.75	0.40	15.6	17.2	0.74	0.36	15.6	16.4	0.66	0.33
		16.3	18.4	0.79	0.43	16.5	17.2	0.71	0.38	15.8	17.5	0.78	0.38	15.6	16.2	0.79	0.32
		16.7	18.0	0.72	0.42	16.9	17.6	0.64	0.41	15.2	17.4	0.79	0.36	14.8	15.4	0.72	0.28
		16.8	17.6	0.69	0.41	16.2	17.0	0.67	0.37	15.6	16.8	0.63	0.35	14.9	15.6	0.67	0.29
		16.5	18.4	0.72	0.44	16.3	17.6	0.72	0.40	16.2	17.6	0.75	0.39	15.7	16.2	0.7	0.32
		16.5	18.6	0.68	0.45	16.5	18.2	0.74	0.43	16.3	17.2	0.64	0.38	14.8	15.4	0.62	0.28
		16.1	18.4	0.71	0.43	15.8	18.0	0.68	0.40	15.7	17.0	0.76	0.36	15.2	16.0	0.75	0.31
		16.6	18.3	0.75	0.44	15.9	17.6	0.69	0.39	15.5	17.6	0.75	0.38	16.3	17.4	0.69	0.39
		16.0	18.4	0.68	0.43	15.6	17.6	0.77	0.38	16.4	17.5	0.72	0.39	15.5	16.4	0.74	0.33
	Replication Mean	**16.43**	**18.17**	**0.74**	**0.43**	**16.25**	**17.58**	**0.71**	**0.39**	**15.81**	**17.28**	**0.73**	**0.37**	**15.41**	**16.16**	**0.71**	**0.32**
	Mean	Height(m)				DBH (cm)				GBH(m)				Volume (m^3)			
		15.98				**17.29**				**0.72**				**0.38**			

APPENDIX-2 Yield of different crops obtained in agroforestry Systems

Sl. No.	Associated crops with teak	Yield of associated crops (t/ha)									
		Control					Agroforestry System				
		Bada Munduli	Patenigan	Mahakala-basta	Govindpur	Average	Bada Munduli	Patenigan	Mahakala-basta	Govindpur	Average
1	Paddy	4.20	4.50	4.10	4.60	4.35	4.10	3.90	3.80	4.30	4.03
2	Arhar	1.01	0.90	0.80	0.70	0.85	0.83	0.77	0.71	0.63	0.74
3	Colocasia	8.70	8.40	8.60	8.50	8.55	8.30	8.10	7.90	7.60	7.97
4	Mango-ginger	6.20	5.90	6.30	6.00	6.10	5.90	5.40	5.90	5.60	5.70
5	Okra	6.70	6.80	6.60	6.50	6.65	6.40	6.30	6.01	5.70	6.10
6	Brinjal	14.20	14.50	13.90	14.4	14.25	12.80	13.30	12.6	13.2	12.98
7	Chilli	3.20	2.90	3.10	2.70	2.98	2.80	2.70	2.60	2.40	2.63

APPENDIX-3 Economic return from teak in teak based agroforestry system:

Sl. No	Intercrops with teak	Volume			Income from teak (₹ ha^{-1})			Gross income per year (₹ ha^{-1} year^{-1})	Cost of cultivation of tree (₹ ha^{-1})				Total Cost of cultivation of tree (₹ ha^{-1} year^{-1})	Net return from tree (₹ ha^{-1})
		Marketable timber (m^3 plant^{-1})	Marketable timber (m^3 ha^{-1})	Firewood (stack volume (m^3 ha^{-1})	Timber	Firewood	Total		Planting material	Land preparation and planting	Maintenance	Total cost		
1	Paddy	0.45	90	5.39	4500000	37730	4537730	113443	1000	20000	200000	221000	22100	91343
2	Arhar	0.43	86	5.36	4300000	37520	4337520	108438	1000	20000	200000	221000	22100	86338
3	Colocasia	0.44	88	5.38	4400000	37660	4437660	110942	1000	20000	200000	221000	22100	88842
4	Mangoginger	0.44	88	5.37	4400000	37590	4437590	110940	1000	20000	200000	221000	22100	88840
5	Okra	0.47	94	5.41	4700000	37870	4737870	118447	1000	20000	200000	221000	22100	96347
6	Brinjal	0.46	92	5.4	4600000	37800	4637800	115945	1000	20000	200000	221000	22100	93845
7	Chilli	0.48	96	5.42	4800000	37940	4837940	120949	1000	20000	200000	221000	22100	98849

* Economics for tree is considered for 40 years old teak and worked out on per year old basis

*Cost of teak timber is ₹50000 per m^3 and firewood is ₹ 7000 per m^3