DESIGN AND DIAGNOSIS SURVEY OF TREES IN DIFFERENT AGROFORESTRY SYSTEM OF RAMANAGARA TALUK

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DEPARTMENT OF FORESTRY AND ENVIRONMENTAL SCIENCE

UNIVERSITY OF AGRICULTURAL SCIENCES

BANGALORE

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DESIGN AND DIAGNOSIS SURVEY OF TREES IN DIFFERENT AGROFORESTRY SYSTEM OF RAMANAGARA TALUK

Thesis submitted to the

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in

ENVIRONMENTAL SCIENCE

By

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DEPARTMENT OF FORESTRY AND ENVIRONMENTAL SCIENCE
COLLEGE OF AGRICULTURE, GKVK, BENGALURU
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BANGALORE

CERTIFICATE

This is to certify that the thesis entitled **"Design and Diagnosis Survey of Trees in different Agroforestry system of Ramanagara Taluk"** submitted in partial fulfilment of the requirements for the degree of **Master of Science (Agriculture) in Environmental Science** to the University of Agricultural Sciences, Bangalore is a record of *bona fide* research work carried out by **Mr. GAGAN, S. PAMB 0239** during the period of his study in this University under my guidance and supervision. The thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles.

Bengaluru
March, 2023

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(H. B. RAGHU)

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(T. R. KAVITHA)

AFFECTIONATELY DEDICATED

TO MY GUIDE

AND MY FAMILY

ACKNOWLEDGEMENT

Towards the end of this great Voyage in the quest for knowledge and wisdom, whichmakes the beginning of a new horizon, it gives me an insurmountable task to mention all them who planted and nurtured the spirit of faith and helped in accomplishing this task. I take this opportunity to look back on the path traversed during the course of this endeavor and to remember the guiding faces behind the task with a sense of gratitude.

With immense pleasure and deep respect, I express my heartfelt gratitude to my revered teacher, guide and chairman of the advisory committee, ***Dr. C. Nagarajaiah***. ***Dr. M. Mahadeva Murthy*** *Professor and Head, Department of Forestry and Environmental science, UAS, GKVK, Bengaluru for his excellent guidance, constant support, close counsel and valuable suggestions throughout the period of my study. I honestly confess with gratitude that it has been a rare privilege to be under his guidance.*

I am very grateful and obliged to my advisory committee members ***Dr. R. Krishna Murthy****, Professor, Dept. of Soil Science and Agricultural Chemistry,* ***Dr. H.B. Raghu,*** *Assistant Professor, Department of Forestry and Environmental science,* ***Dr. T.R. Kavitha****, Assistant Nematologist, Dept. of Plant Pathology, UAS, GKVK, for their valuable suggestions and advice.*

I express my deep sense of gratitude and heartfelt thanks to the farmers in the studyarea for their kind cooperation rendered during the study.

My parent's aspiration was my soul of inspiration. As a token of love, I dedicate this manuscript to them. My beloved Father ***Mr. Sathish. S.,*** *the person who has inspired me to do the best in my education. My Mother* ***Mrs. Manjula, M.,*** *the one who gaveme strength, her sacrifices, dedicated efforts and sincerely raised me for who I am today with her care and love. A special thanks to my brother* ***Kishan. S.,*** *for being lovable, supportive, caring and for complete moral support. It is my immerse pleasure to acknowledge the support and help to carry out my research by my classmates* ***Vikram patil, Sachin, Jujin, Adarsh,***

Any omission in this brief acknowledgement does not mean lack of gratitude.

Bengaluru

March, 2023 ***(Gagan, S.)***

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Bengaluru

March, 2023 ***(Gagan, S.)***

Design and Diagnosis Survey of Trees in different Agroforestry System of Ramanagara Taluk

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Introduction

- ✓ Agroforestry is a practice of growing of woody tree species along with annual crops *i.e.,* agricultural/horticultural crops. It is necessary to maintain soil health, crop sustainability and environmental stability.
- ✓ Agroforestry Design & Diagnosis is a family of procedures for the diagnosis of land management problems and potentials and the design of agroforestry solutions. The ICRAF has developed an approach to assist agroforestry researchers and development field workers to plan and implement effective research and development projects.
- ✓ In order to maintain environmental sustainability, maintenance of forest area to the tune of 33 per cent is most important, but due to human activities, urbanization and industrialization, the forest land is reducing. At present, the forest area of India is less than 18 per cent. But due to continuous increase in human population, there is huge requirement for area under agriculture.

Objectives

- ✓ Survey to identify different tree species present in Ramanagara Taluk.

Materials and methods

MAP:1Representation of Ramanagara in Karnataka state.

Observations recorded

- ➢ The study was carried out one each in North, South, East and West directions of Ramanagara Taluk.
- **Species identification**: The tree species will be identified by a Transect walk in which one counts records occurrences of the objectives of study.
- The information was obtained from the respondents through personnel interview method having structured questionnaires and by visiting physically to their field for recording observations based on structure and tree components existing.
- The study was conducted in different Agroforestry systems followed by different categories of farmers in Ramanagara taluk.

Results

Table 1: Agroforestry systems followed by different categories of farmers in Ramanagara taluk

Agroforestry systems	Farmers following the agroforestry systems (%) categories of farmers			Average(%)
	Small farmer (35)	Medium farmer (30)	Large farmer (10)	
Bund planting	37.1	17	30	23.33
Boundary planting	17.1	23	20	16.67
Scattered planting	5.71	3	0	3.33
Block planting	0	3	0	1.11
Scattered + Horti-silviculture	2.86	0	10	2.22
Block+ Scattered planting	0	3	0	1.11
Block+ Horti-silviculture	0	0	0	0
Boundary+ Block planting	0	3	0	1.11
Bund + Horti-silviculture	2.86	3	0	2.22
Bund + Scattered planting	2.86	0	0	1.11
Bund + Boundary planting	28.6	43	30	28.89

Table 2: Different number of Trees identified in Ramanagara taluk

SL. No.	Species name	Total No.
1	*Tectona grandis*	224
2	*Grevillea robusta*	125
3	*Azadirachta indica*	127
4	*Melia dubia*	136
5	*Cocos nucifera*	202
6	*Pongamia pinnata*	94
7	*Mangifera indica*	80
8	*Manilkara zapota*	45
9	*Acacia auriculiformis*	3
10	*Artocarpus heterophyllus*	27
11	*Sesbania grandiflora*	21
12	*Gliricidia sepium*	16
13	*Eucalyptus grandis Sm*	104
14	*Dalbergia sissoo*	6
15	*Santalum album*	7
16	*Tamarindus indica*	22
	Total number of trees	**1239**

Discussion

- ✓ Among the agroforestry systems followed by the different categories of farmers, Majority of the farmers following bund planting (23%) followed by Bund+Boundary planting (29%) and Boundary planting (17%) (Table 1).
- ✓ Small farmer are the majority farmers (47%) following bund planting
- ✓ Teak, Silver oak, Neem and Coconut are the tree species found in majority in bund and boundary planting.

Fig. 1: Number of major Tree species

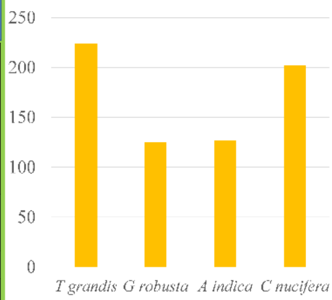
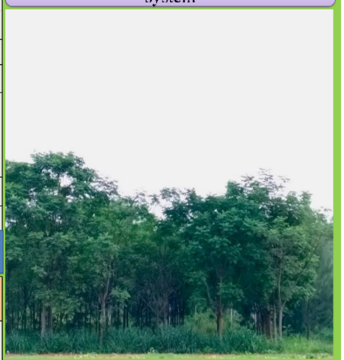


Plate 1: *Melia dubia* based Agroforestry system



Summary

- ✓ Farmers are more concerned with integrating tree species in bund and boundary area of agricultural land.
- ✓ As bund and boundary planting acts as wind breaks, additional source of income, improve the soil fertility and water holding capacity.

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Advisory committee

Chairman : Dr. C. Nagarajaiah

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Dr. T.R. Kavitha

DESIGN AND DIAGNOSIS SURVEY OF TREES IN DIFFERENT AGROFORESTRY SYSTEM OF RAMANAGARA TALUK

GAGAN, S.

ABSTRACT

The study on ‘Design And Diagnosis Survey of Trees In Different Agroforestry System of Ramanagara Taluk’ was conducted during the year 2021-22 district comprising *viz*., Ramanagara, Channapatna, Kanakapura, Magadi Taluks. Bund and boundary plantings were the major traditional agroforestry systems practiced by the farmers whereas Horti-silviculture system was the major agroforestry system followed by large farmers. The crop productivity with respect to grain and straw yields of finger millet under neem and teak based different agroforestry systems were documented lower compared to control. The cost-benefit ratio under agroforestry systems reported to be higher in association with other field crops further Horti-silviculture system recorded higher cost benefit ratio compared to other agroforestry systems. Higher carbon sequestration potential was observed in agroforestry systems than the conventional agriculture. Tree numbers was positively correlated with farm holding size and type of agroforestry systems followed by the farmers. Shannon’s diversity index was higher with large farmer followed by medium and small farmer. 18 tree species belonging to 12 plant families with 66.12 percent of trees being indigenous were recorded in study area. *Tectona grandis* was the most dominant tree species followed by *Grevillea robusta*, *Azadirachta indica* and *Cocos nucifera.* The agroforestry systems following farmers’ integrated trees in their farms based on their preferences such as economic benefit, multipurpose utility of the trees and cultural preference of the locality based.

March, 2023 | C. Nagarajaiah
Dept. of Forestry and Environmental Science | (Major Advisor)
UAS, GKVK, Bengaluru-65

ರಾಮನಗರ ತಾಲೂಕಿನ ವಿವಿಧ ಕೃಷಿ ಅರಣ್ಯ ಪದ್ಧತಿಯಲ್ಲಿನ ಮರಗಳ ವಿನ್ಯಾಸ ಮತ್ತು ರೋಗನಿರ್ಣಯ ಸಮೀಕ್ಷೆ

ಗಗನ್, ಎಸ್.

ಪ್ರಬಂಧ ಸಾರಾಂಶ

'ರಾಮನಗರ ತಾಲ್ಲೂಕಿನ ವಿವಿಧ ಕೃಷಿ ಅರಣ್ಯ ಪದ್ಧತಿಯಲ್ಲಿನ ಮರಗಳ ವಿನ್ಯಾಸ ಮತ್ತು ರೋಗನಿರ್ಣಯ ಸಮೀಕ್ಷೆ' ಕುರಿತು ಅಧ್ಯಯನವನ್ನು ೨೦೨೧–೨೨ ರಲ್ಲಿ ರಾಮನಗರ, ಚನ್ನಪಟ್ಟಣ, ಕನಕಪುರ, ಮಾಗಡಿ ತಾಲ್ಲೂಕುಗಳನ್ನು ಒಳಗೊಂಡಿರುವ ಜಿಲ್ಲೆಯಲ್ಲಿ ನಡೆಸಲಾಯಿತು. ಬದು ಮತ್ತು ಗಡಿಗಳಲ್ಲಿ ಕೃಷಿ ಅರಣ್ಯ ಮರಗಳನ್ನು ಬೆಳೆಯುವುದು ರೈತರು ಅಭ್ಯಾಸ ಮಾಡುವ ಪ್ರಮುಖ ಸಾಂಪ್ರದಾಯಿಕ ಕೃಷಿ ಅರಣ್ಯ ಪದ್ಧತಿಗಳಾಗಿವೆ. ದೊಡ್ಡ ಹಿಡುವಳಿ ರೈತರಲ್ಲಿ ತೋಟಗಾರಿಕೆ–ಅರಣ್ಯ ಪದ್ಧತಿಯು ಪ್ರಮುಖ ಕೃಷಿ ಅರಣ್ಯ ಪದ್ಧತಿಯಾಗಿದೆ. ಬೇವು ಮತ್ತು ಸಾಗುವಾನಿ ಮರಗಳ ಆಧಾರಿತ ವಿವಿಧ ಕೃಷಿ ಅರಣ್ಯ ಪದ್ಧತಿಗಳ ಅಡಿಯಲ್ಲಿ ರಾಗಿ ಧಾನ್ಯ ಮತ್ತು ಒಣಹುಲ್ಲಿನ ಇಳುವರಿಗೆ ಸಂಬಂಧಿಸಿದಂತೆ ಬೆಳೆ ಉತ್ಪಾದಕತೆಯನ್ನು ಸಾಂಪ್ರದಾಯಿಕ ಕೃಷಿಗೆ ಹೋಲಿಸಿದರೆ ಕಡಿಮೆ ದಾಖಲಿಸಲಾಗಿದೆ. ಕೃಷಿ ಅರಣ್ಯ ಪದ್ಧತಿಗಳ ಆಡಿಯಲ್ಲಿನ ವೆಚ್ಚ–ಲಾಭದ ಅನುಪಾತವು ಇತರ ಕೇತ್ರ ಬೆಳೆಗಳ ಸಹಯೋಗದೊಂದಿಗೆ ಹೆಚ್ಚಿನದಾಗಿದೆ ಎಂದು ವರದಿಯಾಗಿದೆ ಮತ್ತು ತೋಟಗಾರಿಕೆ–ಅರಣ್ಯ ಪದ್ಧತಿಯು ಇತರ ಕೃಷಿ ಅರಣ್ಯ ಪದ್ಧತಿಗಳಿಗೆ ಹೋಲಿಸಿದರೆ ಹೆಚ್ಚಿನ ವೆಚ್ಚ–ಲಾಭದ ಅನುಪಾತವನ್ನು ದಾಖಲಿಸಿದೆ. ಸಾಂಪ್ರದಾಯಿಕ ಕೃಷಿಗಿಂತ ಕೃಷಿ ಅರಣ್ಯ ಪದ್ಧತಿಗಳಲ್ಲಿ ಹೆಚ್ಚಿನ ಇಂಗಾಲದ ಅನುಕ್ರಮ ಸಾಮರ್ಥ್ಯವನ್ನು ಗಮನಿಸಲಾಗಿದೆ. ಮರಗಳ ಸಂಖ್ಯೆ ಕೃಷಿ ಹಿಡುವಳಿ ಗಾತ್ರ ಮತ್ತು ರೈತರು ಅನುಸರಿಸುವ ಕೃಷಿ ಅರಣ್ಯ ಪದ್ಧತಿಗಳೊಂದಿಗೆ ಧನಾತ್ಮಕವಾಗಿ ಸಂಬಂಧ ಹೊಂದಿವೆ. ಮಧ್ಯಮ ಮತ್ತು ಸಣ್ಣ ಹಿಡುವಳಿ ರೈತರಿಗಿಂತ ದೊಡ್ಡ ಹಿಡುವಳಿ ರೈತರಲ್ಲಿ ಶಾನನ್‌ನ ವೈವಿಧತೆಯ ಸೂಚ್ಯಂಕ ಹೆಚ್ಚಾಗಿ ಕಂಡುಬಂದಿದೆ. ೧೨ ಸಸ್ಯ ಕುಟುಂಬಗಳಿಗೆ ಸೇರಿದ ೧೮ ಮರ ಪ್ರಭೇದಗಳು ಶೇಕಡಾ ೬೬.೧೨ ರಷ್ಟು ಮರಗಳು ಸ್ಥಳೀಯವಾಗಿವೆ ಎಂದು ಅಧ್ಯಯನ ಪ್ರದೇಶದಲ್ಲಿ ದಾಖಲಿಸಲಾಗಿದೆ. ಸಾಗುವಾನಿ ಪ್ರಬಲವಾದ ಮರ ಪ್ರಭೇದವಾಗಿದ್ದು, ಸಿಲ್ವರ್ ಓಕ್, ಬೇವು ಮತ್ತು ತೆಂಗಿನ ಮರ ನಂತರದ ಪ್ರಭೇದಗಳಾಗಿವೆ. ಆರ್ಥಿಕ ಲಾಭ, ಮರಗಳ ವಿವಿದೋದ್ದೇಶ ಉಪಯುಕ್ತತೆ ಮತ್ತು ಪ್ರದೇಶದ ಸಾಂಸ್ಕೃತಿಕ ಆದ್ಯತೆಗಳು ರೈತರು ಸಮಗ್ರ ಮರಗಳನ್ನು ಕೃಷಿ ಅರಣ್ಯ ಪದ್ಧತಿಗಳಲ್ಲಿ ಅನುಸರಿಸಲು ಕಾರಣಗಳಾಗಿವೆ.

ಮಾರ್ಚ್, 2023

ಅರಣ್ಯ ಮತ್ತು ಪರಿಸರ ವಿಜ್ಞಾನ ವಿಭಾಗ — ಸಿ. ನಾಗರಾಜಯ್ಯ

ಕೃವಿವಿ, ಜಿಕೆವಿಕೆ, ಬೆಂಗಳೂರು — (ಪ್ರಮುಖ ಸಲಹೆಗಾರರು)

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ABBREVIATIONS AND SYMBOLS

Abbreviations and Symbols	Expansions
%	Per cent
@	At the rate
BC	Biochar
BD	Bulk Density
c mol kg^{-1}	Centimol per Kilogram
Ca	Calcium
CD	Critical difference
Cm	Centi meter
cm^{-2} g	Centimeter square per gram
CO_2	Carbon dioxide
Cu	Copper
DAS	Days after sowing
dS m^{-1}	Deci Siemen per metre
EC	Electrical Conductivity
et al.	Co workers
Fe	Iron
Fig.	Figure
FYM	Farm yard manure
G	Gram
g ha^{-1}	gram per hectare
g cm^{-2}	Gram per centimeter square
GJ	Ghanjeevamruth
GKVK	Gandhi Krishi Vigyana Kendra
ha^{-1}	Per hectare
K	Potassium
K_2O	Potassium oxide
Kg	Kilogram
kg ha^{-1}	Kilogram per hectare
LMR	Leaf mass ratio
Mg	Magnesium

mg kg^{-1}	Milligram per kilogram
Mg m^{-3}	Mega gram per cubic meter
Mn	Manganese
N	Nitrogen
NaOH	Sodium hydroxide
NAR	Net assimilation rate
NS	Non-significant
OC	Organic Carbon
$^{\circ}C$	Degree Celsius
P	Phosphorus
P_2O_5	Phosphorus pentoxide
ppm	Parts per million
q ha^{-1}	Quintal per hectare
S.Em±	Standard Error mean
SLA	Specific leaf area
SLW	Specific leaf weight
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
t ha^{-1}	Tons per hectare
UAS	University of Agricultural Sciences
VC	Vermicompost
ZARS	Zonal Agricultural Research Station
Zn	Zinc

INTRODUCTION

I INTRODUCTION

India is an agrarian nation, with over 70 per cent of its people living in villages and depending primarily on agriculture, animal husbandry *etc.,* for living. In addition, it has been expected that India will surpass China as the world's most populated nation within a few decades. However, the area under cultivation (140 million ha) is static or even declining, placing significant pressure on our arable land in order to feed the growing population and supplement industrial needs at the same time. This necessarily requires crop intensification and adoption of alternative land use systems (Chavan *et al*., 2015).

Agriculture is a major economic activity and a primary source of income for approximately 58% of India's population. Thousands of hectares of forest and agricultural land have been degraded, and biodiversity has been lost in the name of modern agriculture and development with no long-term management. In recent few years, there has been a growing concern about the rising population and the massive gap between demand and supply, as well as the exploitation of forests to meet the rising demand for fuel, fodder, and timber. Furthermore, the concentration of carbon dioxide (CO_2) and other Green House Gases (GHGs) in the atmosphere has rised significantly over the last century and is expected to rise further. The majority of this is because of the use of fossil fuels and the conversion of tropical forests to agricultural land. Since 1750, the concentration of CO_2 in atmosphere has increased by 30%, with a sharp increase detected in the last 50 years (IPCC 2001).

To overcome this massive burden on our existing ecosystem and population in the future, it is more important to take some alternative steps to meet population demand while reducing the threat to the ecosystem and biodiversity. As a result, the idea of using land for different purposes and planting multipurpose trees has gained importance in recent years.

Agroforestry is multi-use land management system where agricultural crops and woody perennials coexist on an identical land management unit (Owunubi and Otegbeye, 2002). Agroforestry practices cover a wide range of land use systems in which woody perennials are purposefully associated with agricultural crops and animals in a part of the spatial or temporal arrangement (Lundgren and Raintree, 1982). One of the primary benefits of agroforestry is soil conservation; the existence of woody perennials in agroforestry systems may affect some bio-physical and bio-chemical processes that determine the health of the soil substrate (Nair, 1993). Some bio-physical and bio-chemical processes may get affected by the existence of woody perennials in agroforestry systems which influence the health of soil substrate.

Through the integration of trees on farms and in the agricultural landscape, agroforestry is a dynamic, ecologically oriented system for managing natural resources that diversifies and sustains production for an increased social, economic, and environmental benefit for land users at all levels (ICRAF 2001). Through its concrete and intangible advantages, agroforestry is extremely important to the Indian economy. In fact, agroforestry has a significant potential for simultaneously achieving three key goals, including the protection and stabilization of ecosystems, the production of a high level of commercial commodities, and the expansion of the rural population's sources of income and basic supplies (Dhyani *et al*., 2009).

For the purpose of assisting in the management of natural resources and sustainable land use, agroforestry is primarily centred on the planting of trees on and off farms. At the site level, the system is more stable and adaptable due to the above- and below-ground diversity, but at the landscape and watershed levels, the system is connected to forests and other natural elements (Nair *et al*., 2008; Garrett, 2009).

In particular, arid and semi-arid regions are benefiting greatly from alternative land use strategies in terms of maintaining the resource base and boosting overall productivity. Utilizing land for agroforestry decreases vulnerability to climate and environmental change and improves livelihood security. There is ample proof that an agroforestry system has a more capability for carbon sequestration than an annual production system does in terms of improving soil fertility, soil moisture and conservation, nutrient cycling, microclimate, reclaiming troublesome soils, and total biomass productivity (Dhyani *et al*., 2009).

The most significant effects of an increase in atmospheric CO_2 concentration are frequently cause negative changes in the global climate (increasing temperatures, more frequent droughts and floods) (USDA NRCS, 2000). The rise in the amount of sedimentation in water bodies and drainage systems results of change in the frequency of extreme events which cause soil and water resource degradation. The need for low-cost carbon sequestration strategies is now becoming a crucial issue in the context of global climate change. The addition of trees to crop and grazing lands increases both net above and below-ground carbon sequestration (Palm *et al*. 2004; Haile *et al*. 2008). It is presently thought that sequestering net carbon via tree-based systems could be a lucrative business for carbon trading. Tree-based systems in India offer a long-term strategy to harness carbon emissions while still enabling the establishment of food crops, where the bulk of the population relies on agriculture. According to International Center for Research in Agroforestry projections, the carbon market may reach US$1 trillion by 2025, meaning that a sizeable amount of money may be made available to support climate change adaptation and sustainable rural development (Anonymous, 2009).

The significant role that forestry and agroforestry systems play in sequestering carbon has raised attention worldwide in reducing greenhouse gas emissions. According to reports, agroforestry would have access to 630 million hectares of land, with the ability to store 586 Mt of carbon annually by 2040. (Watson *et al*. 2000). (Singh and Lal, 2000) estimated that short rotation plantations on 40 million hectares will mitigate carbon emissions by around 0.072 Gt year with a cautious productivity of 5.5 tons per hectare per year.

Competition, complexity, sustainability and profitability are the four main objectives of the science of agroforestry systems, and each of these elements needs to be balanced in order to yield successful results. Depending on the resources available, the density of trees or shrubs changed from one agroforestry system to another (Singh *et al*., 2007). The only effective option to deal with these circumstances is agroforestry, and it is critical to investigate and record indigenous and traditional knowledge of agroforestry methods for its advancement.

It has been established that the only alternative to achieving the aim of raising forest cover from its current level of less than 21% to 33 per cent is possible only by agroforestry. Agroforestry is consequently starting to play a big part in the industry of environmental system services. However, there is no reliable information on the amount of agroforestry land in the nation. According to estimates from 2013, 8.2% of India's total geographical area, or 13% million hectares (Mha), is covered with agroforestry. 53.32 Mha, or around 17.57% of India's stated total geographic area, could potentially be covered by agroforestry in the near future, making it the third-largest land use activity, behind agriculture and forestry (Dhyani *et al*., 2013). In Southern India, Karnataka is the region best suited for tree-based farming practices.

Ramanagara has significant agricultural, horticultural, animal husbandry, sericulture, and industrial potential. The main draw back here is a diverse investment portfolio in urban infrastructure, textiles and apparel, food processing, media, tourism development, and export promotion.

In this context, the present work is an attempt to study the evaluation of agroforestry systems in the Ramanagara with the following objectives.

Objectives:

1. Survey to identify different tree species present in Ramanagara Taluk.

2. To categorize the tree species to identify the dominated species in that region.

3. To study the carbon sequestration of tree species in agroforestry system.

REVIEW OF LITERATURE

II REVIEW OF LITERATURE

Present study was conducted on ‘Design and Diagnosis Survey of Trees in different Agroforestry System of Ramanagara Taluk’ in the year 2022. The related accessible research information is presented in this chapter.

Agroforestry is a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land-management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence (FAO). In which the practices are ecologically sustainable in nature, having varied benefits such as maintaining and increase of total yieldby the combination of annuals with perennial trees and also including livestock on the same unit of land (Chavan *et al*., 2015). Agroforestry systems practices can be adopted under a large hectare area which is available in the form of alleys, boundaries, bunds, wastelands. Many farmers retain trees such as *Acacia nilotica, Acacia catechu, Dalbergia sissoo, Mangifera indica, Zizyphus mauritiana,* and *Gmelina arborea,* etc. in their farmland. Which plays an important role in climate change mitigation especially due to its tree component by accumulating CO_2 in the form of biomass (Dhillon *et al*., 2012).

Agroforestry, not only involved in climate change mitigation but also in adaptation to climate change condition and improvement of overall farm productivity, maintaining soil fertility through litter fall, maintaining environmental services such as carbon sequestration, phytoremediation, watershed protection and biodiversity conservation. Realizing the scope and importance of Agroforestry the people should involve in the implementation and development of agroforestry in India (Ranjan *et al*., 2016).

It has also been well revealed that agroforestry can serve to bridge the conflict and the distinction existing between the need for conservation of biodiversity and the provisionof needs of human society (McNeely and Scherr, 2003).

2.1 Identification of different existing agroforestry systems

Rana (1995) conducted a survey to identify four existing agroforestry systems in mid-hill zone of Himachal Pradesh *viz;* agri-silviculture system, agri-silvihortipastoral system, agri-silvipastoral system and pasture were the most promising agroforestry systems. While Kachru (1997) carried out a diagnostic survey and assessed productivity of the agroforestry systems in sub humid and sub temperate region of Himachal Pradesh and recognized seven different agroforestry system types viz, agri-horticulture, agri- silviculture, agri-silvi-horticulture, agri-horti-silviculture, pastoral-silviculture, and pasture.

Vishwanath *et al*. (2000) conducted study on the *Acacia nilotica* based traditional agroforestry systems in central India and he reported that there were two major *Acacia nilotica* based agroforestry systems practiced by the farmers in the form of bund planting and scattered planting in the upland rice field. Further, they observed higher density in bundplanting followed by scattered planting.

Rasul and Thapa (2006) made an attempt to evaluate the agroforestry system with other competitive land use systems practiced in the Chittagong hill tracts, a hilly region of Bangladesh, from both the financial and economic perspectives. The study concluded that financial analysis was more important for the farmers to adopt new land use system.

Devaranavadgi *et al*. (2010) carried out survey to study existing traditional agroforestry systems in northern dry tract of Karnataka, where eight different types of agroforestry systems *viz.,* Bund planting, Boundary planting, Agri-silviculture, Horti- silviculture, scattered planting, Block plantation, Avenue plantation, planting along irrigation were prominent systems of region. The bund planting was found to be most prominent agroforestry practice both in rainfed and irrigated situations. Nearly 88.4 per cent of the respondents followed bund planting in rainfed situation, whereas it was 86.1 per cent in irrigated situation. The other potential agroforestry practices followed were boundary planting and scattered planting. Neem and Babul (*Acacia nilotica*) are frequently occurring tree species under both rainfed (82.9% and 46.2%) and irrigated ecosystems (74.4% and 35.4 %,).

Nair (2011) studied the importance and value of the perceived environmental benefits of agroforestry systems based originally on long experience and observations are now being supported and substantiated by rigorous scientific research. To fully exploit the potential benefits, more broad-based and rigorous investigations are needed. This special collection of papers will go a long way in creating awareness about the importance of these issues and promoting much-needed research investments in this seriously under-researched area with seemingly high value and applicability.

Naresh *et al*. (2011) carried survey to identify the existing different agroforestry systems practiced by the farmers in sub-tropical region of Himachal Pradesh. It was revealedthat there were seven different kinds of agroforestry systems practiced and they were Agri-silviculture, Agri-horticulture, Agri-silvi-horticulture, Agri-horti-silviculture, Pastoral- silviculture, Pastoral-silvi-horticulture, Pastoral-horticulture-silviculture existed. Among these, Agri-silviculture and Pastoral-silviculture were the most prevalent agroforestry systems of the region.

Bhoyar *et al.* (2016) studied seven different types of agroforestry systems practicedby farmers in four villages of lower plateau of Melghat region, Amravati district, Maharashtra. He recorded that the boundary plantation was most prominent agroforestry practice in rainfed agro-ecosystem of Melghat region. Nearly 60.1 per cent of the respondents followed the boundary plantation in rainfed situation followed by agri-silviculture with scattered (15.27%) and bund plantation (14.25%) and lowest was foundin poultry based agroforestry (1.74%).

Sabastian *et al*. (2017) studied on farm and household factors affecting the adoptionof timber and non-timber forest product management practices by farmers and how understanding those factors can facilitate the adoption of silvicultural practices for enhancing timber and NTFPs production. The study confirmed that farmers who have access to extension services, farmers' groups and knowledge of government policy aremore likely to adopt timber and NTFPs production technologies. These findings suggest that while designing extension programs farm and household factors should be considered by policymakers, researchers and extension providers.

Tewari *et al.* (2018) made an attempt to know the importance of incorporation of minor fruit trees in an agroforestry system for multiple uses and conservation of biological diversity. The results showed that the minor fruit trees help in reaching self-sufficiency in fruit, timber and top feed and also in meeting the nutritional requirement of rural poor people. Further, suggested that the minor fruit trees have more than one utility; hence, theyshould be preferred under agroforestry.

Toppo and Raj (2018) suggested that Agroforestry is an ecologically sustainable land use system that plays a crucial role in the mitigation of climate change due to the adaptation of tree components in agriculture and also helps in climate adaptation. He revealed that the agroforestry systems also help in overall farm productivity, enrichmentof soil through litter fall, providing environmental services such as climate change mitigation (carbon sequestration), phytoremediation, watershed protection, and biodiversity conservation.

Amare *et al*. (2019) investigated on the under-rated and not widely recognized traditional agroforestry practice followed by smallholders in the highlands of Ethiopia. It was revealed that farmers cultivate indigenous trees for a variety of benefits, including livelihoods, ecosystem services and the existence of scenic and economically valued birds.

Chittapur, and Murthy (2019) carried out structural analysis and mapping of agroforestry systems under irrigated ecosystem in north-eastern part of Karnataka, India covering six districts. Six prominent agroforestry systems were *in vogue* predominated by bund planting (43.06%) followed by boundary planting (19.44%), silvihorti systems (12.50%), scattered planting (4.17%) and silvipasture system (2.78%), while block plantation system was part of integrated farming systems on the farm. Among the tree species *Tectona grandis*, *Azadirachta indica*, and *Cocos nucifera* were the preferred perennials. Farmers preferred the planting of trees on bund and boundary of the farm.

Deka *et al.* (2021) conducted study in the Papum Pare district of Arunachal Pradesh to document the prevalent traditional agroforestry systems of the region. Agri-silviculture, agri-horticulture, horti-silviculture, silvi-pasture, homegardens, boundary plantations and block plantations were among the various AFS models reported from the study area. Among the different traditional agroforestry used the most prominent was home-gardens and the least practiced was silvi-pasture. On management regime, home-gardens followed by agri-silviculture, boundary plantation were highly managed while horti-silviculture, block plantations and silvi-pasture were very little managed.

2.2 Evaluation of existing agroforestry systems

2.2.1 Economics of agroforestry systems

Akbar *et al.* (1990) studied on effect of four different species: *Eucalyptus camaldulensis, Albizia proeera, Morus alba* and *Leucaena leucocephala* on wheat crop along the boundary of fields at different distance from trees. He reported that there was no significant difference in the wheat yield among different tree species. However, the wheat yield was numerically lowest at 2 m distance in case of all the four tree species and control.

Kho *et al.* (2001) evaluated on effects of *Faidherbia albida* trees on niger and millet crops reported that the production Niger and millet in on-farm field experiment under the *F. albida* canopy was about 36 per cent higher than in the open field. The nitrogen availability under trees was estimated to be more than 200 per cent higher than in the open causing 26 per cent production increase. The phosphorus availability was estimated to be almost 30 per cent higher and because of its high limitation causing a production increase of 13 per cent. The net effect through other resources (notably light and water) was negligible (3% production reduction) and not significant.

Dwivedi *et al*. (2007) studied on the socio-economic outcome between traditional and commercial agroforestry practices followed by farmers in western Uttar Pradesh. Studyrevealed that *Azadirachta indica*, *Acacia nilotica*, *Dalbergia sissoo*, and *Eucalyptus species* were dominant tree species in traditional agroforestry system whereas, *Populus deltoides* and *Eucalyptus spp*. were the major species of commercial agroforestry, furtherit was found that fuelwood (50.6 %) was major driving force for adoption agroforestry in traditional agroforestry area while additional income (71.3 %) was the major factor in commercial agroforestry area. Even though net return from traditional agroforestry is lowerthan commercial agroforestry system per hectare, but traditional agroforestry plays a majorrole in farmer's livelihood.

Rahman *et al*. (2007) evaluated on multistrata agroforestry system comparing with the monoculture showed the positive and much higher net present value (NPV) in multistrata agroforestry than traditional monoculture in both the conditions with or without inclusion of labour costs and also revealed that it is more profitable and less risky compared to other agricultural options.

Nagarajaiah *et al.* (2012) evaluated on the medicinal and aromatic crops under teak based agroforestry system, it was recorded that among different medicinal and aromatic crops grown with teak significantly higher herbage yield was obtained in aloevera than in othercrops. There was a marginal reduction in herbage yield of all the medicinal and aromatic crops (except *Coleus*). The highest collar diameter was recorded in aloevera. Thus, among medicinal and aromatic plants grown with teak, aloe, lemon grass, and coleus are found to be superior in terms of herbage yield.

Patil *et al.* (2012) conducted research on *Melia azedarach* based Agroforestry system at main Agricultural Research Station, University of Agricultural Sciences, Dharwad on medium black clay soil under different spacing viz, 5m x 1m, 5m x 2m, 5m x 3m, and 5m x 4m. Soybean (JS - 335) crop was grown in the interspace of *Melia azedarach* rows. The yield of soybean in 10-year-old *Melia azedarach* agroforestry system wasassessed and it was found that the yield was significantly decreased in 5m x 1m and 5m x2 m spacing as compared to 5 x 4m spacing.

The diameter of the tree at breast height was found significantly higher in wider row spacing of 5m x 4m as compared to 5m x 1m spacing. The net returns and B:C ratio was also found significantly higher in *Melia azedarach* at 5m x 4m spaced agroforestry system followed by at 5m x 3m system as spaced compared to the other treatments. This result reflect the importance of spacing between trees for integrating with the crop in the agroforestry system.

Bali *et al*. (2013) conducted field experiment to evaluate the growth and yield of Okra in association with Lemon and Guava tree based Agroforestry system. The results revealed that, Okra yield was found better in Guava-Okra based Agroforestry system; however, the performance of the Lemon-Okra agroforestry system was also found better result. Further, it revealed that the tree growth was better in open field condition but in the total crop and tree yield showed that agroforestry system is more profitable compared to the monoculture of agriculture or forestry production system.

Bijarpas *et al.* (2015) made an attempt on socioeconomic evaluation of agroforestry systems in Northern Iran revealed that there is a significant difference between Net present value (NPV) gained from the monoculture system and different agroforestry systems as it showed that NPV of mixed crop is higher than single crop in study area, which also suggested that there are many advantages in environmental, social and economic perspectives.

Rani *et al*. (2016) studied on economic evaluation of agroforestry systems in the northwestern region of Punjab state results revealed that tree-based land use systems are economically viable and more profitable compared to pure agricultural crops. In pure *Eucalyptus tereticornis* plantations recorded the Highest B:C ratio of 3.30 after 5 years. Simultaneously in *Populus deltoids* + *Triticum aestivum* crop-based land use system was recorded higher B:C ratio 2.02 followed by *Tectona grandis* plantations (2.06), *Triticum aestivum*+ *Oryza sativa* (1.89), *Triticum aestivum*+ *Pennisetum glaucum* +fruit crop (1.72), *Brassica napus*+fruit crop (1.56) and *Brassica napus* + *Oryza sativa* (1.27). Further, it was found that *Eucalyptus tereticornis* and *Populus deltoids* based land use systems are more profitable and economically viable than other land use systems in this study area of Punjab.

Chouhan *et al.* (2017) made a socioeconomic survey on the selected farmers whose primary source of income is agriculture and adopting agroforestry in their farmland. Even though the village farmers are educated only up to the primary school level, they are cultivating horticulture crops with agriculture crops or pasture crops for commercial purpose. In addition to this they also grown forest tree species on bunds in scattered manner. Whereas large scale farmers grown teak, silver oak plantation in their farmlands to increase efficiency of use of resources and sustainable land use practice.

Coulibalya *et al*. (2017) analyzed the impacts of adopting fertilizer trees in additionto field crops such as *Gliricidia sepium* and *Faidherbia albida* on household food security. Studying by dividingthe land by ownership further, revealed that farmers with smaller farms of up to 2 acres realized the highest gains. Further the use of fertilizer tree in combination with improved maize seed also significantly increased the value of food crops. Hence, he concluded that Agroforestry is gaining importance as it plays a vital role in adaptation and mitigation strategy against the adverse effects of climate change and the use of fertilizer trees promoted as an agroforestry practice, contributes to improved soil fertility by fixing nitrogen into the soil thereby increasing the supply of nutrients, resulting in better food crop yields.

Singh and Oraon (2017) studied to know the importance of different land use systems. It was revealed that among the different agroforestry systems such as Agri- silviculture, Agri-horticulture, Silvi-pastural and home garden systems, the production of wood by *Leucaena leucocephala* under Agri-silviculture was found highest (112.00 cu.m.ha^{-1}), under Agri-horticulture in the tree *Syzygium cumini* (52.00 cu.m.ha^{-1}), in Silvi- pastoral system it was found that in *Dalbergia sissoo* (37.50 cu.m.ha^{-1}), whereas in home garden, the tree species *Gmelina arborea* produced maximum wood volume (100.00 cu.m.ha^{-1}). Further the yield performances were also found additional benefits from the same land in agricultural, vegetables and grasses. Therefore, it suggested that rural people should adopt and implement of the agroforestry model with a suitable strategy in combination of trees and field crops, and this combination should concern the ecological and environmental stability on a sustainable basis in addition to socioeconomic upliftment of rural people.

Sneh (2019) studied the effect of different spacings (3 m x 3 m, 4 m x 3 m, 5 m x 3 m, 6 m x 3 m, 7 m x 3 m and 8 m x 3 m) of poplar on the growth and production of fodder crops *viz.*, cowpea, sorghum, berseem and oat. They reported that the population based cropping system (3 m x 3 m) with oat was found more economical, gave maximum net returns (Rs. 151767/-) and B:C ratio (2.44) followed by poplar + sorghum net returns (Rs. 137264/-) B:C ratio (2.31) at 3 m x 3 m spacing.

2.2.2 Carbon sequestration in agroforestry systems

Schroeder (1993) conducted studies on perspective of climate change issues and the global carbon cycle, suggested agroforestry practices are attractive because of two reasons: Agroforestry systems directly involved in storage of carbon in tree components and they have potential to bring down the deforestation by reducing the clear of forest landfor agriculture purpose. Surveyed literature showed that median carbon storage by agroforestry practices was 9 t C ha^{-1} in semi-arid, 21 t C ha^{-1} in sub-humid, 50 t C ha^{-1} in humid, and 63 t C ha^{-1} in temperate Eco regions.

Jose (2009) examined four major ecosystem services and environmental benefits from practicing agroforestry: (1) carbon sequestration, (2) biodiversity conservation, (3) soil enrichment and (4) air and water quality. Past and present evidence indicated that agroforestry, as part of a multifunctional working land use system, also can be a viable land-use option. This realization should help to promote agroforestry and its role as an integral part of a multifunctional working landscape.

Mohammed *et al.* (2011) assessed the biomass production in an agroforestry systemand natural forest. It was recorded higher total tree biomass in the natural forest (3078.6 kg^{-1} 100 m^{-2}) and among the agroforestry system pineapple based agroforestry had the highest tree biomass (1022.4kg^{-1} 100m^{-2}) followed by lemon agroforestry (76.8kg^{-1} 100 m^{-2}) and Banana agroforestry (135.9kg^{-1} 100m^{-2}) and the banana agroforestry is moreprofitable than other two systems.

Kanime *et al*. (2013) assessed on the biomass, carbon storage and carbon dioxide mitigation potential of plantations of *Populus deltoides*, *Eucalyptus tereticornis*, *Dalbergia sissoo*, *Mangifera indica*, *Litchi chinensis* and *Prunus salicina*. The maximum total biomass (94.8 Mg ha^{-1}) was observed in a 10-year-old *Dalbergia sissoo* monoculture plantation, followed by an eight-year-old *Populus deltoides* block plantation (63.0 Mg ha^{-1}). Carbon stocks ranged from 4.51 Mg ha^{-1} in an 8-year-old *Populus deltoides* boundaryplantation to 43.39 Mg ha^{-1} in *Dalbergia sissoo* plantation. The carbon sequestration rate for *Populus deltoides* block and boundary plantations were estimated to be 2.75 and 0.43 Mg ha^{-1} $year^{-1}$, respectively. Eucalyptus boundary plantation sequestered 0.84 Mg $ha^{-1}year^{-1}$ while *Dalbergia sissoo* plantation sequestered 2.73 Mg ha^{-1} $year^{-1}$. Among fruit trees, the highest sequestration rate was recorded in *Mangifera indica* (mango) plantation, with 1.43 Mg ha^{-1} $year^{-1}$.

Murthy *et al.* (2013) assessed on carbon sequestration potential of Agroforestry Systems in India. As a result, Agroforestry systems shown significant carbon accumulation in living biomass, as well as soil carbon, demonstrating the potential to offer the ecosystemservice of carbon sequestration in addition to this agroforestry systems can also contribute to reducing CO_2 emissions by avoiding use of forest-based fuel wood and conserving soil. Meanwhile reducing deforestation rates in tropical zones by providing a wide variety of products and services to rural communities.

The study conducted on quantitative analysis on carbon storage of 25 valuable tree species concluded that, the maximum carbon storage in *Tamarindus indica* was 55.95 tC followed by 44.81 tC in *Terminalia arjuna* and lowest carbon storage value estimated in *Emblica officinalis* 1.77 tC. Finally reported that as the diameter of species increases its biomass and carbon storage capacity increases and also sequester more carbon, i.e., removesmore carbon dioxide from atmosphere (Pandya *et al*., 2013).

Mangalassery *et al*. (2014) evaluated on the carbon sequestration quantification in both biomass and soil in two pasture systems (*Cenchrus ciliaris* and *Cenchrus setegerus*), two tree systems (*Acacia tortilis* and *Azadirachta indica*) and four silvi-pastoral system (combination of one tree and on grass) in arid northwestern India. It was found that silvi- pastoral system sequestered 36.3% to 60.0% more total soil organic carbon stock comparedto the tree system and 27.1–70.8% more in comparison to the pasture system and also foundthat soil organic carbon and net carbon sequestered were greater in the silvi-pastoral system. Thus, it finally revealed that silvi-pastoral system having components like trees and grasses can help in better sequestration of atmospheric carbon compared with systems containing only trees or pasture.

Shukla and Viswanath (2014) conducted studies on growth, wood quality parameters and estimations of productivity of 12-year-old teak trees (*Tectona grandis* L.f.) grown under three different agroforestry systems such as unmanaged block (Bum), unmanaged line on the farm boundary (Lum) and intensively managed block (Bim) plantations. Mean annual increment (MAI) of 0.020, 0.006 and 0.016 m^3 $tree^{-1}$ $year^{-1}$ were recorded in Lum, Bum and Bim, respectively. Teak raised in Lum plantation appeared to be better than two block plantations (Bum and Bim) in overall growth performance. In the evaluation of various wood quality parameters, the wood quality of Bum was found to be comparatively superior to Bim and much better than those of Lum. The 12-year-old farm teak trees from three systems exhibited lower average values of different wood quality parameters compared to mature forest teak.

Suryawanshi *et al*. (2014) investigated on aboveground and belowground biomass carbon sequestration potential of selected tree species Results showed that *Moringa olifera* species was dominant and sequestrated 15.775 tons of carbon and having 14 trees followedby *Azadirachta indica* i.e., 12.272 tons and *Eucalyptus citriodora* has found to be the lowest carbon sequestration potential that is 1.814 tones.

The studies carried on the estimation of tree biomass and carbon storage and sequestration in the Solapur University, accounted about 30 species including 1230 individuals of trees. The maximum carbon storage was found in the *Azardirachta indica* for both the above and below components. However, in the saplings of these trees, *Ploythialongifolia* has shown good potential for the sequestration of carbon. Although *Tamarindus indica* has highest wood density (900.2 kg/m^3) among the tree's species found in the study area, it has lower abundance in comparison to other species. Therefore, it can be concludedthat the older trees have higher carbon content than younger trees. However, it is also observed that saplings have more capacity of absorbing carbon than old trees as they are growing and require more carbon to grow. Moreover, old trees are the reservoirs of carbon.It is noticed that Neem (*Azardirichta indica*) tree act as the best carbon absorbing agent in the study area. (Gavali and Shaikh, 2015).

Uthappa *et al*. (2015) conducted studies on soil physico-bio-chemical properties under a ten-year-old poplar based agri-silviculture system. The poplar based system showed a significant effect on soil physico- chemical and biological properties. The soil bulk density was significantly lower under trees when compared to sole crop, most of the soil chemical properties viz., organic carbon, available nitrogen, available phosphorus, exchangeable calcium, DTPA extractable zinc, copper and manganese were significantly higher under trees than the sole crop. It was recorded that soil properties were significantly improved under the poplar based agroforestry system in comparison to the sole crop.

Bijalwan *et al.* (2016) revealed that the agroforestry systems have the diverse potential for carbon sequestration but there is a need of using the precise methodology for calculation of carbon sequestration potential of every component in the system. It also overthrown the importance of more role on agroforestry trees rather than the agroforestry system as young trees association in agroforestry systems can serve not only as carbon sinkbut they have more potential to sequester carbon at a faster rate. Therefore, the developmentof new agroforestry models with the objective of wider adaptations and cash environment benefits seems to be more purposeful in the years to come.

Dhyani *et al*. (2016) studied on carbon sequestration potential of agroforestry in India, In India, the potential of carbon sequestration in agroforestry systems is estimated between 0.25 to 19.14 and 0.01 to 0.60 Mg C/ha/yr. for tree and crop components, respectively. The contribution of agroforestry in soil carbon sequestration varied between 0.003 to 3.98 Mg C/ha/yr. The total Carbon sequestered in each component differs depending on region, types of species, system, site quality, and previous land-use. The review indicates that agroforestry systems, besides, to accumulate and sequester carbon, provide an excellent opportunity to increase the tree cover to a level of 33% of the total geographical area of the country as desired by the National Forest Policy.

Newaj *et al.* (2016) suggested that integrating agroforestry components may provide a means for diversifying production systems and reaching sustainability in smallholder farming system. In addition to that the agroforestry systems involved in enhancing the uptake and sequester of CO2 from the atmosphere.

Shahapurmath *et al.* (2016) evaluated the growth performance and productivity potential of *Tectona grandis* grown in the plantation as well as in the farmlands at the coastal zone of Karnataka. The results showed that the growth of teak tree in farmland was significantly higher compared to tree grown in pure plantation, that is indicated by the overall height (11.95 m), diameter (23.69 cm), clear bole height (6.20 m), tree volume (0.61 m^3) and timber volume (0.33 m^3) was higher in farmland than trees grown in pure plantation (11.60 m, 20.33 cm, 4.90 m, 0.42 m^3 and 0.18 m^3, respectively). However, crownparameters did not show a significant difference among trees grown in pure plantations andfarmlands. It was concluded that teak grown in farmland may produce higher growth and volume as compared to the pure plantation because of better management by the farming community.

Swamy *et al*. (2017) studied the agrisilviculture system with six different tree species *viz.*, *Pongamia pinnata*, *Dalbergia sissoo*, *Acacia auriculiformis*, *Tectona grandis*, *Casuarina equisitifolia* and *Azadirachta indica* in shelterbelt of agroforestry systemin arid region of Karnataka. The maximum above ground biomass was observed in *A. auriculiformis* (59.75 t ha^{-1}) followed by *T. grandis* (56.62 t ha^{-1}), respectively. Whereas, below ground biomass was highest in *T. grandis* (20.25 t ha^{-1}) followed by *A. auriculiformis* (14.75 t ha^{-1}).

Gupta *et al.* (2019) studied on impact of tree density (D_1 = 333 tree ha^{-1} and D_2 = 666 tree ha^{-1}) on carbon sequestration potential of 30-year-old *Hardwickia binata* Roxb. + *Cenchrus* *setigerus* silvipasture system in hot semiarid region of Rajasthan. They reported that carbon sequestration for a hectare land was significantly more (40.8 per cent) in high density system (31.6 ± 12.6 Mg C ha^{-1}) and carbon sequestered in soil organic matter varied from 19.93 ± 0.31 Mg C ha^{-1} in control to 22.94 ± 0.65 Mg C ha^{-1} and 23.25 ± 0.78 Mg C ha^{-1} in D_1 and D_2 respectively. The total carbon sequestered (below and above ground tree biomass and soil organic carbon) was in the order $D_2 > D_1 >$ control.

Rizvi *et al.* (2019) reported that in Central Plateau and Hill region of India total carbon sequestered at zone level was 17.81 Tg C and equivalent CO_2 absorption was at 65.36 Tg. The Carbon Sequestration Potential (CSP) of agroforestry systems would be about 158.55 Tg C for a simulated period of 30 years or CSP would be 5.28 Tg C yr^{-1} at country level. On the other hand, equivalent CO_2 absorption was 586.50 Tg for a period of 30 years or would be 19.55 Tg C yr^{-1} at country level.

Solanki and Sen (2019) described that as the tree provides multiple products and services, proportion of photosynthesis removed from the agroforestry system is minimum thereby facilitating more carbon in the agroforestry system compared to mono cropping system. They also concluded that agroforestry systems are better sequester of carbon in soil and biomass.

Tanwar *et al.* (2019) studied on carbon sequestration potential of eight suggested land-use systems of arid western Rajasthan and concluded that biomass carbon stock was maximum in farm forestry of *Acacia tortilis* (31.4 Mg C ha^{-1}) followed by *Prosopis cineraria* and *Hardwickia binata* based silvi-arable systems (8.8 and 10.6 Mg C ha^{-1} respectively). They also reported that soil C stock was maximum in farm forestry (47.6 Mg C ha^{-1}) followed by *Ziziphus* based systems (32.5–33.9 Mg C ha^{-1}).

Dhyani *et al*. (2020) reported that potential of agroforestry systems to accumulate C was 0.29–15.21 Mg ha^{-1} y^{-1} and effectiveness of agroforestry systems to sequestrate carbon depends on structure and functions of different component, environmental and socio-economic factors.

Uthappa and Devakumar. (2021) conducted a study in different land use systems viz., tree plantations (*Tectona grandis, Terminalia bellirica, Swietenia macrophylla, Artocarpus hirsutus),* natural forest, horticulture (*Mangifera indica*) and agroforestry (*Melia dubia*) at University of Agricultural Sciences, GKVK, Bengaluru, Karnataka. The CO_2 sequestered in tree biomass was recorded highest under *A. hirsutus* (3182.03 Mg/ha) followed by *T. bellirica*

(1519.66 Mg/ha), whereas the lowest CO_2 was sequestered under horticulture system (127.65 Mg /ha) followed by agroforestry (196.47 Mg/ha). Highest SOC (Mg/ha) was recorded under natural forest (25.59 Mg/ha) followed by S. macrophylla (17.44 Mg/ha) and it is lowest under horticulture (10.59 Mg/ha). The litter carbon was highest under A. hirsutus (3.87 Mg/ha/year) and lowest under T. grandis (1.16 Mg/ha/year). The highest CO_2 was sequestered under *A. hirsutus* (3321.44 Mg ha^{-1}) followed by *T. bellirica* (160.80 Mg ha^{-1}) and least under horticulture system (469.36 Mg ha^{-1}).

2.3 Assessment of the tree diversity

Huang *et al*. (2002) quantified the effects of agroforestry in concern with biodiversity conservation, which included identifying functional groups of agroforestry components. The study also analysed using the distinctness index of functional groups, demonstrated the impacts of various land-use systems on biodiversity conservation carried through Analytic Hierarchy process (AHP) provided ranking the priorities of various agroforestry and plantations on the protection of natural forests, aiming at the long-term solution for the resource support. The present study suggested that agroforestry systems for biodiversity conservation should take into account the impacts of functional groups in strategic planning.

Ouinsavi and Sokpon (2008) assessed the tree diversity in traditional agroforestry systems in Benin region and observed 45 species belonging to 24 plant families. The major families were Fabaceae (with 5 species), Bombacaceae, Moraceae, Anacardiaceae (with 4 species), Meliaceae, Sterculiaceae and Rubiaceae (with 3 species). Average tree density of systems varied from 1 to 7 stems ha^{-1} with diversity index ranging from 2.6 to 2.9. *Milicia excelsa* occurred sparsely in agroforestry systems in all regions, with density ranging from 1 to 4 stems ha^{-1}.

A study was conducted to quantify the density and diversity of both cultivated and non-crop trees in 25 coffee-based homegardens of Kerala, India and observed 101 fruit species belonging to 30 families. Among, 46 species belonging to 17 plant families were cultivated while the remaining 55 species, distributed among 23 plant families, were non- crop fruit tree species. Rutaceae, Moraceae and Rosaceae were the dominant families among cultivated trees represented by 8, 6 and 5 species, respectively. On the other hand, Myrtaceae with 9 species, Euphorbiaceae and Sapotaceae each with 5 species, were the dominant families in the non-crop fruit trees. Tree density, Shannon index of diversity and evenness index in Homegarden Type1 were significantly higher ($P<0.05$) than in Homegarden Types 2 and 3 (Chandrashekara, 2009).

Henry *et al*. (2009) examined the tree diversity in smallholder farming system of western Kenya and found higher Shannon diversity index ($1.3^{-1}.6$) in the home garden followed by scattered planting (0.74-0.86), windrow (0.4-0.6) and least was recorded with the wood lot (0.01). *Eucalyptus saligana* is the most frequently occurred and dominant species in the farming system.

Fifanou *et al*. (2011) studied on the floristic diversity within traditional agroforestry parkland systems around the Pendjari Biosphere Reserve in Benin and showed the diversityof tree species in the area as well as socio-economic factors which affect the practice of this farming system. Twenty-one tree species belonging to 14 botanical families were recorded during the surveys and the average stand density of the woody component of farmlands was 7.97 ± 5.43 stems/ha. Many of both native and exotic tree species occurred in the parkland agroforestry systems with dominance of indigenous tree species. Species richness varied with the size of household where households with small land holding conserve more tree species in their field than households with large land holdings. 64 percent of households surveyed were making deliberate efforts to plant tree species on theirfarmlands. The most important reasons which determined household ambitions to conservewoody species on farmland were tree products contribution to food and medicine.

Nandy and Das (2013) studied on population structure, diversity, and composition in a traditional Indian agroforestry system, called paan jhum, in comparison to natural forests of the Barak valley, Assam, northeast India. The results showed that species richness and diversity were higher in paan jhum than in natural forests, in all three study sites. A total of 47, 37 and 48 tree species were recorded in paan jhum, compared with 35, 32 and 42 species in natural forests of the three study sites, respectively. Paan jhum had higher stand density (790, 934 and 763) and basal area (74.05, 41.60 and 55.88 $m^2\ ha^{-1}$), whereas natural forests had lower stand density (775, 865 and 522) and basal area (68.75, 40.50 and 48.04 $m^2\ ha^{-1}$) in all the study sites, respectively.

Anandan *et al.* (2014) the studied on the diversity of tree species in four campuses of Roever Educational Institutions, found tree species richness, tree species dominance in each campus and also tree diversity Index using Simpson's Diversity Index. They found that Thanthai Hans Roever College has the highest tree species diversity indicating the D value of 0.057809222. Coconut was dominant among all species in richness followed by Drumstick trees.

Molla and Kewessa (2015) studied diversity of woody species in traditional agroforestry systems of Dellomenna district, Southeastern Ethiopia and observed total of 55 woody species belonging to 31 families, out of 55, forty-seven (85%) species were indigenous while the remaining 8 species (15%) were exotic. Anacardiaceae, Bignoniaceae, and Myrtaceae family had the highest number of woody species (7 each), while Apocynaceae, Cupressaceae, Flacourtiaceae, Meliaceae, Papilionoideae, Proteaceae, Rhamnaceae, Santalaceae, and Sapotaceae families had the lowest number of woodyspecies (2 each). Further, observed most dominantly occurred woody species were *Croton macrostachyus* (68.75%) followed by *Mangifera indica* (60.42%), *Persea americana* (35.42%) while 20 species had the lowest frequency (2.08%).

Sharma and Vetaasthe's (2015) study aimed at assessing the role of agroforestry in contribution in conserving tree species diversity by comparing the farmland with forest in the mid-hills of central Nepal. They found that farmlands are consistently richer in tree species than forest. Further investigation revealed that in spite of many shared species between forest and farmland, they are different in composition, due to differences in the relative abundance of shared species and the presence of unique species in each land use type. They highlighted that an agricultural landscape has a role in complementing, but not necessarily in substituting the tree species diversity.

Mengistu and Asfaw (2016) carried out identification of woody species diversity in home garden agroforestry practices, shade grown coffee agroforestry practices and adjacent natural forest, and to show how land use and management practice determine the plant species diversity. Based on this inventory a total of 39 woody plant species which areabout 23, 10, 15 woody plant species were recorded from natural forest, shade grown coffeeagroforestry and home garden agroforestry practices respectively. These species were classified as belonging to 24 families. The Shannon Wiener diversity index was used to estimate species diversity which ranged from 0.14 to 2.54 with a mean of 1.47. Also, 21% of woody species similarities were observed between those three land uses. The result shows that both agroforestry practices (shade grown coffee and home garden agroforestry practices) and adjacent natural forests are conserving several woody species diversity in itssystem.

Naidu and Kumar (2016) assessed species diversity and density of trees in the Eastern

Ghats of the Andhra Pradesh region at elevation 457 - 925 m and mostly comprisesof tropical deciduous forests. They compared tree community characteristics like stem density, basal area, diversity, and species composition of four plots in the study area. A total of 2,227 individuals of 44 families, 98 genera, and 129 species were recorded. Combretaceae, Euphorbiaceae, and Anacardiaceae, showed the greatest importance value index. It was noticed that the most species were contributed by Euphorbiaceae and the tree density varied from 435 ha^{-1} to 767 ha^{-1} with an average basal area of 25.82 m2 /ha. Shannon-Weiner index (H') ranged from 3.76 to 3.96, the Simpson index ranged from 0.96to 0.97, evenness index ranged from 0.60 to 0.78, and species richness index ranged from 10.04 to 11.24.

Doddabasawa *et al*. (2017) studied tree diversity in agroforestry systems under irrigated ecosystem in north-eastern part of Karnataka, India and observed 52 tree species with a mean species density of 9.04ha^{-1} and mean number of trees 104.24 ha^{-1}. Among different land holding sizes, higher number of trees occurred with large farmers (122.48 ha^{-1}) followed by medium farmer (100.45 ha^{-1}) and small farmer (91.82 ha^{-1}). Among the districts, significantly higher mean number of species was observed in Kalaburagi district (11.25 ha^{-1}) followed by Bidar (9.08 ha^{-1}) and lower mean number of species was recorded in Koppal (7.75 ha^{-1}) followed by Ballari (8.58 ha^{-1}). Further, observed most predominatelyoccurred tree species were *Tectona grandis*, *Azadirachta indica*, and *Cocos nucifera.*

Tarakeswara *et al*. (2018) conducted a rapid inventory study which provides information on the tree species diversity and stand structure in tropical deciduous forests of Northcentral Eastern Ghats, India. Tree diversity and its relation to habitat was explored using tree data-set of 12 belt transects (5 × 1000 m) totaling 6 ha in the study area. A total of 135 plant taxa (≥15 cm gbh) belonging to 105 genera of 45 families with 2959 individuals were recorded. *Anogeissus latifolia*, *Xylia xylocarpa*, *Cleistanthus collinus* and *Lannea coromandelica* were the predominant plant taxa where the members of Euphorbiaceae, Rubiaceae, Anacardiaceae and Mimosaceae contributed maximum stand density and species richness. The stand density ranged from 395 to 573 individuals ha^{-1} while basal area varied from 13.05 to 28.42 m^2 ha^{-1}. Shannon-Weiner index (H′) ranged from 3.59 to 4.05 while Simpson index from 0.97 to 0.98, evenness index from 0.66 to 0.78.

MATERIAL AND METHODS

III MATERIAL AND METHODS

The study was conducted on 'Design and Diagnosis Survey of Trees in different Agroforestry Systems of Ramanagara District' of the southern Karnataka during 2022. This chapter gives a brief description of the study area, sampling procedure and methods used for the selection of samples, nature, and sources of data. The statistical tools and techniques were used in analyzing the data.

3.1 General description of the study area

The study was carried out in taluks that come under the Ramanagara district of Karnataka state which is situated in the South-eastern part of the geographical region of the southern part of Karnataka. It spreads between 12º 39' and 12º 57' Northern Latitude and 77º 12' and 77º 25' Eastern longitude. The Ramanagara district comprises four taluks; Ramangara, Channapatana, Kanakapura and Magadi.

3.1.1 Physiography and Climate

Ramanagara has significantly beneficial in agricultural, horticultural, animal husbandry, sericulture, and industrial potential. Here is a diverse investment portfolio in urban infrastructure, textiles and apparel, food processing, media, tourism development, and export promotion. The district is located between latitudes 12º 39' and 12º 57' N and 77º 12' and 77º 25' E. The district is bounded on the north by Bangalore Rural district, on the south by Chamarajanagar district, on the east by Bangalore Urban district and Dharmapuri district of Tamil Nadu, and on the west by Mandya district. The Ramanagara, Channapatna, Kanakapura, and Magadi taluks are the four that make up the district. The Ramanagara district is located in Zone-5 of the Eastern Dry Zone. The district's maximum and minimum temperatures, respectively, range from 29°C to 37°C and 16°C to 20°C respectively. The district experiences dry weather with humidity levels between 63 and 77%.

3.2 Collection of background information

The background information about the weather data such as rainfall, temperature, soil types, and altitude were collected from AICRP on agro-meteorology department from UAS, Bengaluru, GKVK. Further information collected by visiting Karnataka Forest Department and Department of Agriculture, Ramanagara. The coordinates of the study area were recorded through GPS (Global Positioning System).

3.2.1 Sampling procedure

Villages were identified and in each village farmers were randomly selected among the agroforestry practising farmers based on their land holding such as small (< 2 ha), medium (2 – 4 ha) and large farmer (> 4 ha).

3.2.2 Sample size

The total sample size was 112 farmers.

3.3 Method used for data collection

The information was obtained from the respondents through a personnel interview method adopting structured questionnaires prepared for the study purpose as detailed in (Appendix-I) and by visiting physically to their fields and recording observations.

3.3.1 Identification of different agroforestry systems

The information on the existing agroforestry systems practiced by the farmers in the study area was identified by visiting the field and classifying the system based on the nature of the component, pattern, and structure of the tree planting on the farmland (Nair, 1985). The number of farmers practicing specific agroforestry systems was recorded and expressed in percent out of the total farmers surveyed.

3.3.2 Utilization pattern of the tree species, perception and constraints on the adoption of agroforestry systems and tree preference

The information on utilization pattern, perception on the adoption of agroforestry systems and the interest of the farmer's preference of the tree species for further integrationof tree species on the farmland was obtained through a structured questionnaire (Appendix-I).

3.4 Assessment of agroforestry systems for productivity and carbon sequestration potential

Assessment of productivity and carbon sequestration potential of agroforestry system was done based on the preliminary information on the kind of agroforestry systems followed by the majority of the farmers in the region and the prominent species found in the systems.

The following prominent Agroforestry systems were selected to assess the productivity and carbon sequestration potentials.

Bund, boundary, scattered planting, and horti-silviculture systems were the major agroforestry systems that were practiced by the farmers in the selected study region. Neem and teak were the dominant tree species.

3.5 Assessment of the productivity of agroforestry systems

The productivity of the prominent agroforestry system was assessed in terms of yield and biomass of field crop and the perennial component of the agroforestry systems and carbon sequestration potential of the system. All these parameters were calculated on per hectare basis.

3.5.1 Biomass and grain yield of field crop

The biomass and grain yield of finger millet were recorded by four farmers in each agroforestry system and control area through interaction with the farmers. Later the obtained average biomass and yield per hectare is expressed in the form of total above ground carbon per hectare.

Biomass in terms of carbon (C kg ha^{-1}) = Yield or biomass X 0.45 (default value)

3.5.2 Tree productivity

The tree productivity refers to an increase in tree biomass per unit area. The productivity of tree biomass was calculated by the non-destructive method by taking the measurements of girth and height of the standing trees and then the volume was calculated.Twenty trees were randomly selected in each agroforestry system and girth, height and volume of the tree were recorded and extrapolated by multiplying with mean numberof trees in each agroforestry system on per hectare basis. The methods used to measure the height, girth and volume are detailed here under.

3.5.2.1 Tree height (m)

The total tree height was measured with help of Ravi altimeter (Chaturvedi and Khanna, 1981) from the ground level to the tip of the tree and expressed in a meter.

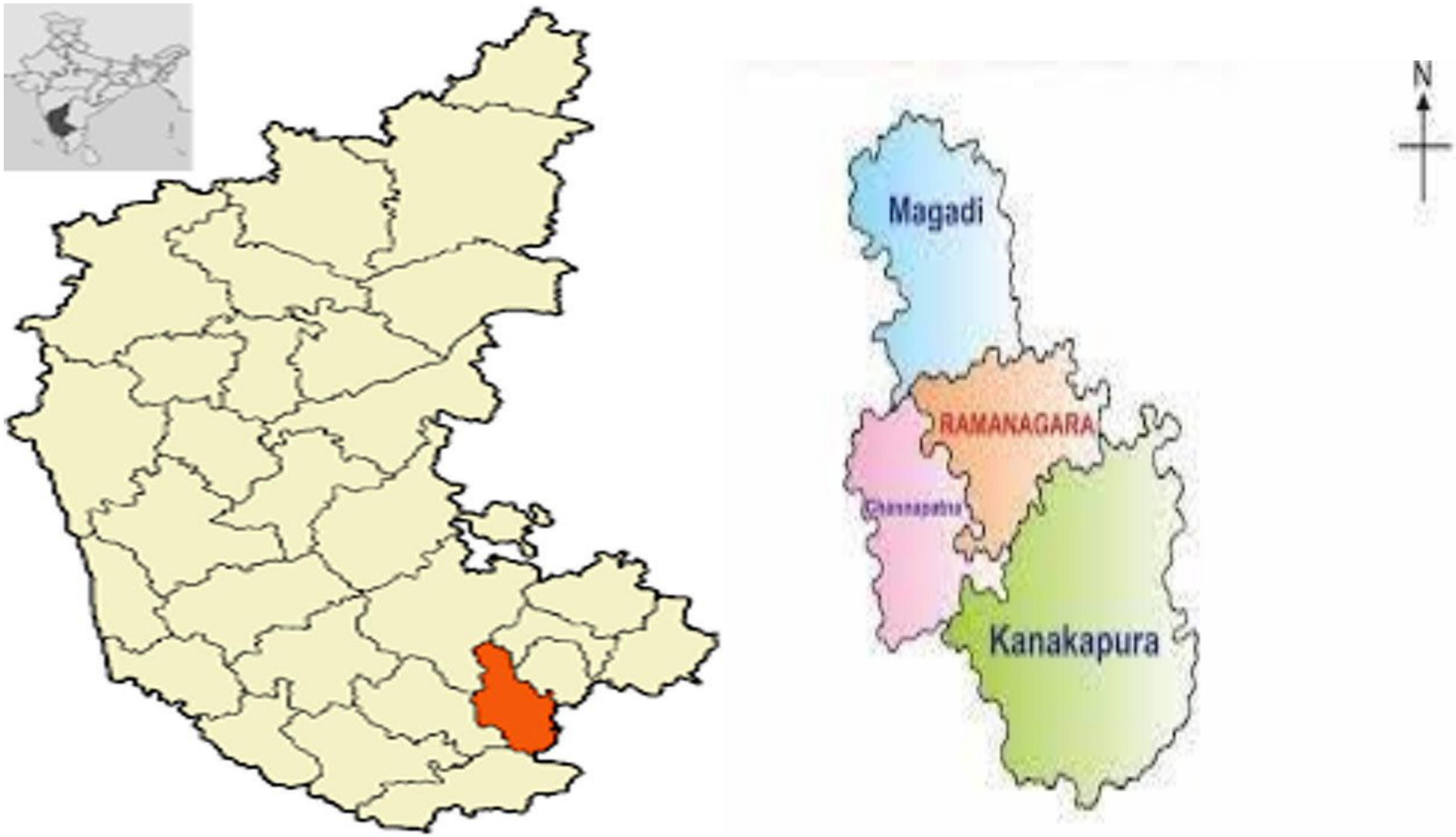

Fig. 1: Map indicating the study area of Ramanagara District and Taluk

3.5.2.2 Tree girth (cm)

The girth of the tree at breast height (1.37 m) from the ground level was measured by using the measuring tape and expressed in cm.

3.5.2.3 Volume (m3)

The tree volume was calculated with the following formula

$$V = \frac{g^2}{4\pi} X h$$

Where ‘g’ is girth at breast height (m), ‘h’ is height in (m), is 3.4125 (Chaturvedi andKhanna, 1981).

3.5.2.4 Computation of above ground biomass of tree

The tree biomass was estimated by multiplying mean volume with specific wood density and extrapolated by multiplying biomass with an average number of trees in each agroforestry systems on hectare basis and expressed in kg ha^{-1}. (Brown and Lugo, 1982)

Above ground biomass (dry biomass) = Volume X Specific wood density

The specific wood density used in the study was obtained from the (FAO, 1998). The specific wood density of teak is 675 kg m^{-3} and neem wood is 740 kg cm^{-3}.

3.5.2.5 Above ground biomass of tree of carbon equivalent (C kg ha^{-1})

The above ground dry biomass of trees in terms of carbon equivalent was computedby multiplying the total dry biomass with default value *i.e.*, 0.50 as it is assumed that the carbon content of the biomass varies between 0.45 - 0.50 and expressed in terms C kg $tree^{-1}$or ha^{-1} out of the total dry biomass.

3.5.2.6 Carbon estimation

Generally, for any plant species, 50% of its biomass is considered as carbon (Pearson *et al.* 2005).

i.e., Carbon Storage = Biomass x 0.45 (default value)

Table 3.1: The details of the prominent neem tree based agroforestry systems selected for assessment

Sl. No	Agroforestry systems	Tree species	Average age of trees (Years)	No. of farmers	Area of sample plot	Crop
1	Bund planting	Neem	25	4	1ha farmer^{-1}	Finger millet
2	Boundary planting	Neem	25	4	1ha farmer^{-1}	Finger millet
3	Scattered planting	Neem	25	4	1ha farmer^{-1}	Finger millet
4	Control (without trees)	-	-	4	1ha farmer^{-1}	Finger millet

Table 3.2: The details of the prominent teak tree based agroforestry systems selected for assessment

Sl. No	Agroforestry systems	Tree species	Average ageof trees (Year)	Orchard	Average ageof orchard (Year)	No. of farmers	Area of sample plot	Crop
1	Bund planting	Teak	15	-	-	4	1ha farmer^{-1}	Finger millet
2	Boundary planting	Teak	15	-	-	4	1ha farmer^{-1}	Finger millet
4	Horti-silviculture system	Teak	15	Mango	15	4	1ha farmer^{-1}	-
4	Control (without trees)	-	-	-	-	4	1ha farmer^{-1}	Finger millet

3.5.2.7 Annual increment of tree

The tree components in the agroforestry systems are of perennial in nature and rotation period is long. In order to assess the quality and quantity of timber in terms of biomass and value, the annual increment of the tree species in the agroforestry system was used. The average annual increment of the tree was computed for individual tree and extrapolated to per hectare and expressed as $m^3\ ha^{-1}$ or Rs. Ha^{-1}. The annual increment was calculated by the following manner.

$$\text{Annual increment } m^3\ ha^{-1} = \frac{\text{Average volume of a tree}}{\text{Average age of a tree}}$$

3.5.3 Fruit yield

Mango fruit yield information was obtained from the 4 farmers. It was recorded in the form of fruit yield per tree and expressed as mean kg $tree^{-1}$ and extrapolated to kg per hectare.

3.6 Economic analysis of agroforestry systems

Economics of the systems were analyzed by calculating the cost of cultivation, gross returns and net returns per hectare on an annual basis. The cost and return were worked out with an average of four farmers for each agroforestry system and control without any trees on the farmland. The initial investment cost, land rent, and machinery depreciation value were not considered and economics was analyzed for the study year with the existing market price. The data was collected by visiting the farmer field as per the schedule and by interacting with farmers. The details are given in **(**Appendix- I & II).

3.6.1 Cost of cultivation

The cost of cultivation of field crops and tree maintenance was worked out on per hectare per year basis. The requirements of biological and mechanical power for different operations such as ploughing, harrowing, weeding and harvesting were calculated as perthe prevailing market prices and the cost of inputs such as fertilizers, seeds, insecticides, and fungicides were calculated based on the quantity applied to the system of one-hectare scale with existing market price (Appendix-II).

3.6.2 Gross return

The economic yield of the systems was quantified per hectare per year basis and converted into rupees per hectare based on the prevailing market prices. The detailed market price that prevailed during the study period is given in (Appendix-III).

3.6.3 Net return

The net return for each agroforestry system was calculated by deducting the total cost from the gross return and expressed (Rs. Ha^{-1}).

Net return = Gross return – Total cost

3.7 Species richness, tree density and diversity

Species richness, species density and tree density in the existing agroforestry systems were recorded with a plot size of the one-hectare scale representing the total farmland of each farmer (Thaman, 1975).

The presence of various species is the most basic and measurable variable in the agroforestry system. The data on species richness was worked out by aggregating the number of tree species present in one-hectare plot and expressed as mean total number of species present in each category of the farmer, agroforestry systems and taluks.

Tree density was calculated by counting the total number of individuals of all the tree species divided by the number of sample plots and expressed as the mean number of trees per hectare with respect to the farmers, agroforestry systems and taluks.

Species dominance on the farmland was calculated with relative density and relative frequency as follows.

$$\text{Relative density} = \frac{\text{Total number of individuals of a species}}{\text{Total number individual of all the species}} \times 100$$

$$\text{Relative frequency} = \frac{\text{No.of sample plots in which a species occurs}}{\text{Total number of sample plots}} \times 100$$

3.7.1 Diversity Indices

The aggregate total number of tree species, mean species and tree density on farmland do not provide the real difference. Hence, the following diversity indices were used which are popularly used to take into account both the richness and evenness or abundance of the species.

3.7.1.1 Shannon diversity index (H')

The Shannon diversity index (Shannon and Wiener, 1949), is a measure of heterogeneity which takes into account the evenness of abundance of species, was calculated for each farm and averaged over categories of the farmer, agroforestry systems and districts. The Shannon index was calculated by using the formula.

$$H = \sum_{i=0}^{n} Pi(lnPi)$$

Where 'Pi' is the proportion of individuals of i^{th} species relative to the total number ofspecies on the farm and 'n' is the total number of species at a site, ln is the natural logarithm.

3.7.1.2 The Simpson index

This Simpson index (Simpson, 1949) is popularly used to know the evenness in distribution or degree of concentration and calculated by using the formula

$$Simpson\ index = \sum_{i=0}^{n} Pi^2$$

Where 'Pi' is the proportion of individuals of i^{th} species relative to the total number of species on the farm, 'n' is the total number of species at a site.

3.8 Statistical analysis

The data were analysed with descriptive statistics and one-way ANOVA at a significance level of 0.05 using MS- Excel and SPSS (Statistical Package for Social Science).

RESULTS AND DISCUSSION

IV RESULTS AND DISCUSSION

In an agroforestry system, agricultural and forestry resources are purposefully managed together on the same piece of land. For sustainable forestry and agriculture, it's crucial to have this intermediary land use system. These land use systems offer economic benefits besides ecological services commonly associated with agroforestrysystems such as high productivity, soil fertility, water quality, biodiversity and better carbon sequestration (Nair, 2011). However, in recent days human population growth associated with agricultural intensification and expansion reduced forest area and traditional agroforestry land use systems in the farms and adversely affected biodiversity. The adoption and implementation of agroforestry practices are lacking due to the non- availability of information about its importance of economic and sustainability efficiency to the farmers. In the area of agroforestry, there is a great need for research and extension activities. However, in recent years the national agroforestry policy, agroforestry mission, and agroforestry plan is implemented by the government. They may boost up the action of Agroforestry in India (Kumar *et al*, 2017). The research approach concerned about the performance and adaptability of agroforestry practices by the farmers further, the importance of agroforestry systems in socio-economic and ecological aspects in maintaining the sustainability of the system is studied. However, the study on characteristics of existing agroforestry systems and their performance in Ramanagara is district lacking. Based on this background the study was undertaken during 2022.

The first component of the study was to evaluate the farmers' use of agroforestry systems. For the study survey, a multistage purposive randomized sampling procedure was used. Villages were selected with the representation of the farmers fromsmall (< 2 ha) medium and (2-4 ha) larger farmers (> 4 ha) in each village. The total sample was 112. Data was collected by visiting farmsphysically and interacting with farmers using a structured questionnaire.

The dominant agroforestry systems used by farmers and the dominant species composition of the system were taken into consideration when selecting the agroforestry systems to assess the economic analysis, productivity, and carbon sequestration potential as the second component of the study. This was done based on the preliminary data from the first phase study. Further, the information collected through the structured questionnaire such as the species richness, density and diversity of the agroforestry systems which were followed by the farmers also assessed as the third component.

4.1 Agroforestry Systems in Ramanagara District

4.1.1 Agroforestry systems followed by different categories of farmer

The different types of agroforestry systems practiced by the different categories of farmers are presented in (Table 4.1) and expressed in the percentage of respondents following the agroforestry system. Majorly five prominent agroforestry systems are mainly observed in Ramanagara Taluk. In addition to this it was also noticed that based on the structure and component tree species grown in the field, some of the farmers following different combinations of agroforestry systems, these systems are expressed in respective combinations. Among different agroforestry systems, it was recorded that a large number of farmers practicing bund planting (25.33 %) followed by bund + boundary planting (22.35 %) and boundary planting (22.00 %). Considering the different categories of the major small farmers following bund planting (46%) and scattered planting (12.11 %). Boundary planting (16 %) and bund + boundary planting (20.5 %) is found to be followed by medium farmers in the majority. Further, it was revealed that Horti-silviculture system (23 %) is majorly followed by the large farmers.

4.1.2 Agroforestry systems followed in different taluks

The bund planting and boundary planting were the main agroforestry systems set up in all the taluks which come under Ramanagara district (Table 4.2), Ramanagara (38.34 %) and Kanakapura (36.24 %) were found to be major taluks in following bund planting and Magadi (32.31 %) found to be major taluk following boundary planting system. Further, it was noticed that bund + boundary planting (58.44%) was followed in Channapatna and Kanakapura accounted for practicing Horti-silviculture system (10.10 %) as major agroforestry system among the Ramanagara District.

The study's findings on the various agroforestry practises used in Ramanagara Taluk showed that bund plating and boundary planting are the two main agroforestry practises used by farmers in their farms, as opposed to including tree species in scattered planting, practising block planting, and engaging in horti-silviculture. These findings demonstrated that farmers are more interested in retaining the tree species on their farm's bund and boundary because they are more concerned with growing agricultural crops there than with including tree

Table 4.1: Agroforestry systems followed by different categories of farmers in Ramanagara District.

Sl. No.	Agroforestry systems	Farmers following the agroforestry systems (%)			Average (N=112)
		Categories of Farmers			
		Large farmer (n=30)	Medium farmer (n=40)	Small farmer (n=42)	
1	Bund planting	15.00	15.00	46.00	25.33
2	Boundary planting	15.00	35.00	16.00	22.00
3	Scattered planting	0.00	3.00	12.11	5.04
4	Block planting	3.00	5.00	0.00	2.67
5	Horti-silviculture system	23.00	2.00	0.00	8.33
6	Bund + Boundary planting	18.00	29.00	20.05	22.35
7	Bund + Scattered planting	0.00	0.00	1.10	0.37
8	Bund + Horti- silviculture	0.00	6.00	2.44	2.81
9	Boundary + Block planting	3.00	1.00	0.00	1.33
10	Block+ Horti-silviculture	9.00	0.00	0.00	3.00
11	Block+ Scattered planting	0.00	2.00	0.00	0.67
12	Scattered + Horti-silviculture	13.00	0.00	1.32	4.77

Table 4.2: Agroforestry systems followed by different taluks come under Ramanagara District.

Sl. No.	Agroforestry systems	The agroforestry systems (%)				Average (%) (N=112)
		Channapatna (n= 28)	Magadi (n=28)	Ramanagara (n=28)	Kanakapura (n=28)	
1	Bund planting	19.35	26.74	38.34	36.24	30.17
2	Boundary planting	10.10	32.31	24.73	15.61	20.69
3	Scattered planting	7.80	2.80	2.50	8.54	5.41
4	Block planting	0.00	2.68	0.00	0.00	0.67
5	Horti-silviculture system	2.68	2.88	0.00	10.10	3.92
6	Bund + Boundary planting	58.44	10.10	24.77	13.67	26.75
7	Bund + Scattered planting	0.00	0.00	0.00	0.00	0.00
8	Bund + Horti- silviculture	0.00	15.55	2.47	0.00	4.51
9	Boundary+ Block planting	0.00	0.00	0.00	0.00	0.00
10	Block + Horti-silviculture	0.00	0.00	0.00	6.33	1.58
11	Block + Scattered planting	0.00	0.00	0.00	0.00	0.00
12	Scattered + Horti-silviculture	0.00	2.55	4.90	6.89	3.59

species. Farmers are interested in having tree species on the bund of the farm as trees on bund which acts as a protection of bund between different farmers' fields and also involved in minimizing the soil erosion. As well as this also provides an additional source of income to the farmers. In supplementary to the bund planting, boundary planting also has many advantages such as it acts as a barrier against stray cattle menace, wind, and soil erosion, increase the water holding capacity of the farm and increase the farm soil fertility with litter deposition and decomposition in the field. Finally turns as an additional source of income in the form of valuable timber wood. The results are consistent with a study by Doddabasawa *et al*. (2017) that found six prominent agroforestry practises were used by the farmers, with bund and boundary planting being the most important ones. According to Varadaranganath and Madiwalar (2010), the two main agroforestry systems used in all agro-ecological conditions were bund planting and scattered planting.

4.2 Design and diagnosis survey of trees in different agroforestry system of ramanagara district

4.2.1 Biomass estimation of trees under different agroforestry systems

4.2.1.1 Growth and tree biomass of neem in different agroforestry systems

The neem tree growth performance in various agroforestry systems is presentedin Table 4.3. Significant difference was recorded in girth and height of trees among different agroforestry systems. Highest girth of tree was recorded in bund planting (73.22 cm) followed by scattered planting (72.22 cm) and boundary planting (66.15 cm). Further, the significantly highest height of trees was reported in boundary planting (6.16 m) followed by bund (6.08 m) and scattered planting (6.00 m). However, volume and biomass of neem tree shows no significant differences grown in different agroforestry systems.

The tree height was recorded highest in boundary planting followed by bund planting. This mention that the trees grown on the boundary and bund of the farms are well managed to avoid shading effect on field crops by pruning the trees to make trees to grow straight and to have low crown spread.

Table 4.3: Growth performance of neem trees in different agroforestry systems

Sl. No.	Agroforestry systems	Girth (cm)	Height (m)	Volume (m^3)	Biomass (kg/tree)
1	Bund planting	73.22^{a} (±4.11)	6.08^{a} (±0.20)	0.257 (±0.04)	200.17 (±45.71)
2	Boundary planting	66.15^{c} (±6.11)	6.16^{b} (±0.27)	0.198 (±0.05)	179.94 (±54.88)
3	Scattered planting	72.22^{b} (±6.06)	6.00^{c} (±0.45)	0.295 (±0.05)	199.59(±53.87)
	P- value	**<0.05**	**<0.05**	**0.330^{NS}**	**0.330^{NS}**

Note: Values in the parentheses indicate the standard deviation
At the 5% level of significance, the values in the column with the same letter are not statistically different.

Table 4.4: Growth performance of teak trees in different agroforestry systems

Sl. No.	**Agroforestry systems**	**Girth (cm)**	**Height (m)**	**Volume (m^3)**	**Biomass (kg / tree)**
1	Bund planting	69.50^{a} (±13.61)	7.55 (±0.78)	0.21 (±0.15)	190.65 (±103.33)
2	Boundary planting	62.45^{b} (±9.91)	7.88(±0.79)	0.15 (±0.12)	155.73 (±77.6)
3	Horti-silviculture system	59.90^{c} (±9.11)	7.47 (±1.00)	0.21 (±0.10)	159.67 (±69.99)
	P – Value	**<0.05**	**0.105^{NS}**	**0.332^{NS}**	**0.330^{NS}**

Note: Values in the parentheses indicate the standard deviation

The values within the column with same letter are not significantly different at 5% level of significance

4.2.1.2 Growth and tree biomass of teak in different agroforestry systems

The data presented in Table 4.4 represents growth performance of teak trees in different agroforestry systems. Among different agroforestry systems, the girth of trees differed significantly.Whereas the height, volume and biomass did not differ significantly. However, significantly highest girth was observed in bund planting (69.50 cm), boundaryplanting (62.45 cm) and Horti-silviculture system (59.90 cm). The height of trees was recorded higher in the Horti-silviculture system (7.55 m) followed by boundary (7.88 m) and bund planting (7.47 m). Moreover the tree volume and biomass were recorded higher in bund planting (0.21 m^3, 190.65 kg respectively) followed by Horti-silviculture (0.21 m^3, 159.67 kg respectively) and boundary planting (0.15 m^3, 155.73 kg respectively). The results obtained reveals that tree height was recorded higher in the Horti-silviculture systemthis may be due to management practices such as pruning and concern about the horticulture crops to avoid competition. Further, the girth and volume of trees recorded higher in bund planting followed by boundary planting attributed to the availability of space and well growth performance in bund and boundary area of the farms. The results are in line with the Singh and Oraon (2017) reported that tree growth (height and collar diameter) was better in agroforestry than in sole tree plantings.

4.2.2 Productivity of crop under different agroforestry systems

4.2.2.1 Grain and straw yield of finger millet in neem based agroforestry systems

The productivity of finger millet crops in Neem based different agroforestry systems in comparison with control is presented in Table 4.5 & Fig 4.1. It was found that the grain yield and straw yield of finger millet significantly different. Higher grain yield (2015 kg ha-1) and straw yield (4200 kg ha-1) was observed in control condition without trees compared to other agroforestry systems. Whereas the lower grain yield (1787.43 kg ha-1) and straw yield (3559.18 kg ha-1) was recorded in boundary planting. In general, it was recorded higher yield and biomass in the control condition where the agriculture field was devoid of trees.

The lower crop yield and biomass was found in different agroforestry systems comparing with control condition due to the reduction in growth performance of field crops under the line of trees in the farm through shading effect, moisture condition, competition for nutrients and root extension in the crop field. This could be avoided by taking appropriate pruning management and other practices. The results obtained are on for with Khan and

Plate 1: Picture showing Bund planting in Ramanagara

Ehrenreich, (1994) who reported that wheat crops which are close proximity to trees, adversely affected tillers and grain yield of wheat planted up to a distance of 7.5 m from the trees.

Table 4.5: Productivity of finger millet in neem based different agroforestry systems

Sl. No.	Agroforestry systems	Crop (Finger millet)	
		Grain yield ($Kg\ ha^{-1}$)	**Straw yield ($Kg\ ha^{-1}$)**
1	Bund planting	1975.75^{b} (±80.11)	3781.53^{b} (±160.12)
2	Boundary planting	1787.43^{cb} (±119.75)	3559.18^{c} (±183.51)
3	Scattered planting	2021.49^{abc} (±90.11)	4000.30^{ab} (±164.45)
4	Control	2015.87^{a} (±75.29)	4200.00^{a} (±300.75)
	P – Value	**<0.05**	**<0.05**

Note: Values in the parentheses indicate the standard deviation

The values within the column with same letter are not significantly different at 5% level of significance.

4.2.2 Grain and straw yield of finger millet in teak based agroforestry systems

The productivity of finger millet and in different teak based agroforestry systems in comparison with control is presented in Table 4.6 & Fig 4.2. Different agroforestry systems with control land devoid of trees were found to have significantly different finger millet grain and straw yields. Higher grain yield (2015 kg ha^{-1}) and straw yield (4200 kg ha^{-1}) was observed in control condition without trees comparedto other agroforestry systems. While the lower grain yield (1976.85 kg ha^{-1}) and straw yield (3405 kg ha^{-1}) was recorded in bund and boundary planting respectively. Overall, the higher yield and biomass was recorded in the control condition where the agriculture land devoid of trees.

The lower crop yield and biomass recorded in different agroforestry systems compared to control condition could be due to the competition of trees with crop for light,nutrients and moisture. Yield reduction in crops occurs below the line of high shading trees in the farm and root extension in the crop field. The effect of trees on crops can be reduced through proper management of trees by practicing pruning of tree branches to avoid shade and growing crops maintain distance from trees can implement the crop yield. The results obtained are in concurrence with Kaushal and Verma, (2003) who reported that the growth and yield of the wheat crop were influenced negatively below the tree crown, while it increased with an increase in distance from the tree trunk. Khan and Ehrenreich, (1994) who reported that wheat crops which are close proximity to trees adversely affected tillers and grain yield of wheat planted up to a distance of 7.5 m from the trees.

Table 4.6: Productivity of finger millet in teak based different agroforestry systems

Sl. No	Agroforestry systems	Crop (Finger millet)	
		Grain yield (kg ha^{-1})	**Straw yield (kg ha^{-1})**
1	Bund planting	1976.85^{cb} (±68.26)	3987.50^{b} (±90.65)
2	Boundary planting	1999.63^{b} (±67.28)	3405.00^{c} (±200.13)
3	Horti-silviculture	-	-
4	Control	2008.07^{a} (±76.21)	4200.00^{a} (±299.23)
	P – Value	**<0.05**	**<0.05**

Note: Values in the parentheses indicate the standard deviation

The values within the column with same letter are not significantly different at 5% level of significance

4.3 Carbon Sequestration Potential of different agroforestry systems

4.3.1 Neem based agroforestry systems

The above ground biomass and carbon stock in neem based agroforestry systems are depicted in Table 4.7. Significantly higher above-ground carbon stock was recorded in boundary planting (4.00 t ha^{-1}) followed by bund planting (3.12 t ha^{-1}) and scattered planting (3.05 t ha^{-1}), whereas lower above carbon stock was recorded with control without perennial tree component (2.02 t ha^{-1}).

The results obtained specifies that the aboveground biomass and carbon stock was higher in agroforestry systems compared to a control condition where crop land was devoidof trees. Boundary planting recorded the higher carbon stock which could be considered due to higher tree density in boundary planting compared to other agroforestry systems. These findings suggest that the trees play a major role in the sequestration of carbon and stores carbon in the form of wood in an agroforestry system. These results are in line with Dhyani *et al*. (2016) who reported that agroforestry systems have more potential in carbon sequestration compare to crop lands.

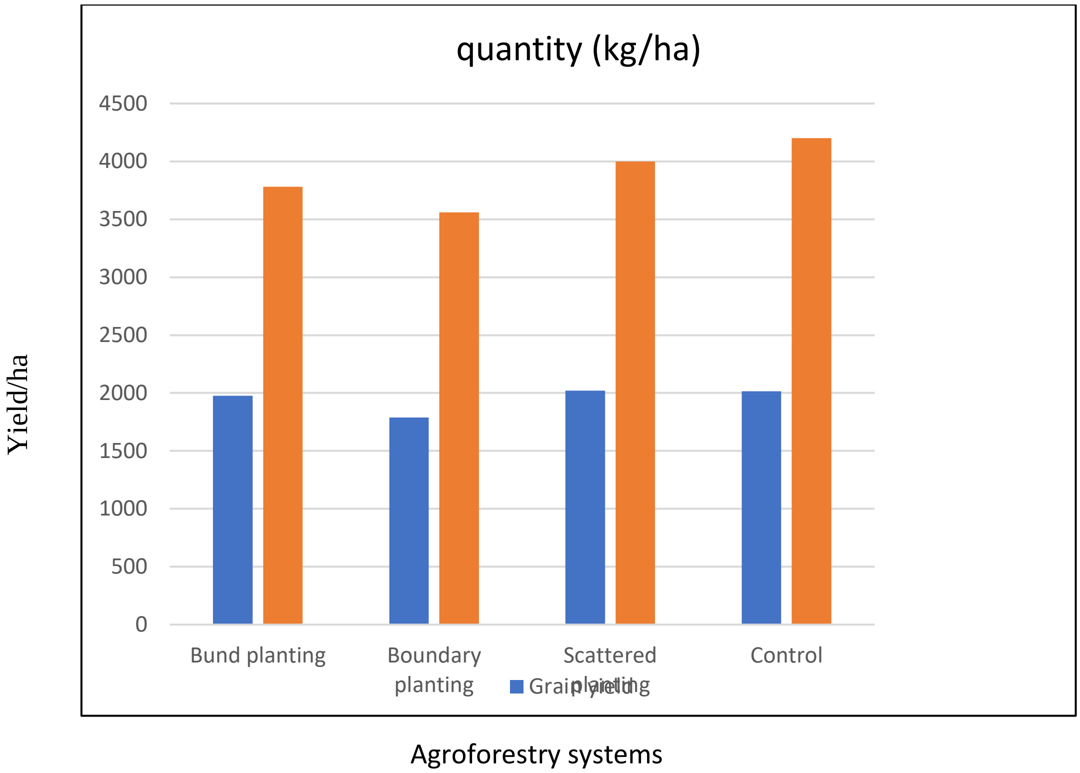

Fig. 4.1: Productivity of finger millet under different neem based agroforestry systems

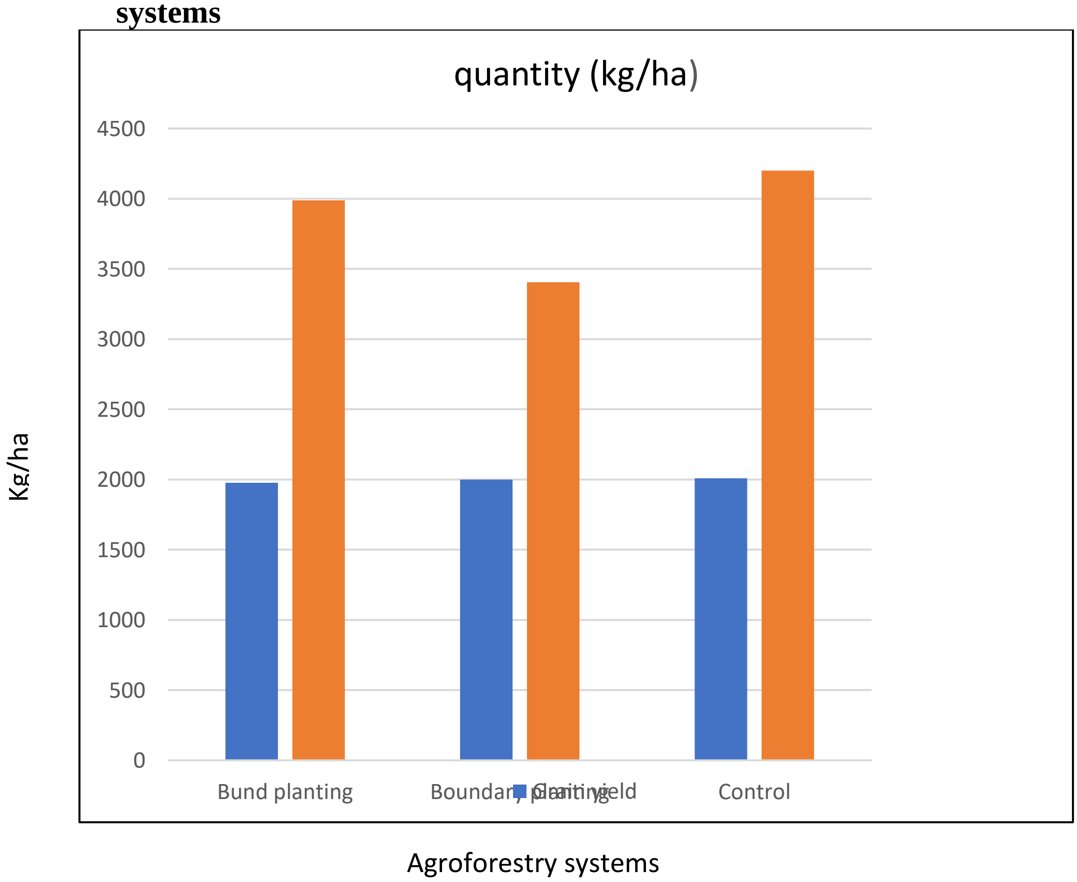

Fig. 4.2: Productivity of finger millet under different teak based agroforestry systems

Table 4.7: Above ground biomass and carbon stock in neem based agroforestry systems under Ramanagara.

Sl. No.	Agroforestry systems	Mean biomass (kg tree-1)	Mean no. of trees ha-1	Total above ground biomass (t ha-1)			Total carbon stock (t ha-1)
				Tree	Crop	Total	
1	Bund planting	190.21	18.70	3.11	5.17	9.00	3.12
2	Boundary planting	179.91	27.69	4.22	4.11	10.10	4.00
3	Scattered planting	195.94	10.21	1.50	5.50	06.99	3.05
4	Control	-	-	-	5.99	05.01	2.02

Note: Average age of neem trees is 25 year

Plate 2: Picture showing Boundary planting in Ramanagara

4.3.2 Teak based agroforestry systems

Above ground biomass and carbon stock of teak based on different agroforestry systems is presented in Table 4.8. The Horti-silviculture system recorded the higher carbon stock (7.00 t ha^{-1}) which was followed by boundary planting (5.33 t ha^{-1}) and bundplanting (4.17 t ha^{-1}) where lower carbon stock was recorded in control land with field crop(2.44t ha^{-1}).

This proposes that the carbon sequestration potential is much higher in agroforestry systems compared to agriculture crops alone. The higher carbon stock was recorded in horti-silviculture system due to the presence of more density of fruit and forest tree speciesand proper management of trees in the system. The results are in concurrence with Henry*et al*. (2009) who observed that in any systems involving perennial component trees are themost important part of the systems with a higher carbon pool in above ground biomass.

4.4 Economic analysis of Agroforestry Systems

4.4.1 Cost-benefit analysis of neem based agroforestry systems

The cost-benefit analysis of Neem based on different agroforestry systems is presented in Table 4.9. Pure crop stand recorded the higher cost-benefit ratio of 2.00 with a net return of Rs. 30,970.25 ha^{-1} yr^{-1} followed by scattered planting (1.68, Rs. 26,680.25 ha^{-1} yr^{-1}), bund planting (1.66, Rs. 25,641.10 ha^{-1} yr^{-1} respectively) and boundary planting (1.60, Rs. 23,278.65 ha^{-1} yr^{-1}). The results were not having much difference among control and agroforestry systems.

Table 4.8: Above ground biomass and carbon stock in teak based agroforestry systems under Ramanagara Taluk.

Sl. No.	Agroforestry systems	Mean biomass (Kg tree^{-1})		Mean no. of trees ha^{-1}		Total above ground biomass (t ha^{-1})				Total carbon stock (t ha^{-1})
		Teak	Mango	Teak	Mango	Teak	Crop	Mango	Total	
1	Bund planting	190.38	-	30.13	-	5.16	5.33	-	10.55	4.17
2	Boundary planting	155.06	-	56.22	-	7.69	4.81	-	13.11	5.33
3	Horti-silviculture	154.30	99.45	65.32	72	10.44	-	5.25	16.63	7.00
4	Control	-	-	-	-	-	5.37	-	05.92	2.44

Note: Average age of teak trees is 15 year

Table 4.9: Cost benefit analysis of neem based agroforestry systems under Ramanagara Taluk.

Sl. No.	Cost/Benefits	Rs. Ha^{-1} yr^{-1}			
		Bund planting	**Boundary planting**	**Scattered planting**	**Control (without trees)**
	Cost				
1	Land preparation	2500	2500	2400	2500
2	Seeds and sowing	6000	6000	6000	6000
3	Intercultivation	1000	1000	1000	1000
	Fertilizers				
4	FYM	3900	3900	3900	3900
5	Chemical fertilizers	2009.10	2200	2070	2300
6	Agrochemicals	1600	1330.10	1600	1330.10
7	Human labor	7950	7950	7950	7600
8	Harvesting and threshing	4400	4400	4400	4400
	Total cost	**29,359.10**	**29280.10**	**29420**	**29,030.10**
9	**Returns**				
a	Crop output	53500	50500.75	55100.5	60000
b	Tree biomass	1500	2050	1000	-
	Gross return	**55000**	**52558.85**	**56100.50**	**60000**
	Net return	**25641.10**	**23,278.65**	**26,680.25**	**30,970.75**
	B:C ratio	**1.66**	**1.60**	**1.68**	**2.00**

The findings indicate that lower net returns and returns per rupee of expenditure in agroforestry systems than in control crop land may be attributable to those systems' lower grain yields. Additionally, scattered and bund planting systems among the various agroforestry systems recorded higher net income. These systems' higher returns may be the result of the availability of sources of income from both agricultural production and tree products like timber and fuel wood, which have a higher systemwide tree density.

4.4.2 Cost-benefit analysis of teak based agroforestry systems

The cost-benefit analysis of different teak based agroforestry systems is presented in Table 4.10. Amongst different agroforestry systems higher returns per rupee expenditure and net returns were recorded in horti-silviculture system (3.66, Rs. 1,45,920 ha^{-1} yr^{-1} respectively) followed by boundary planting (3.00, 60,033.50 Rs. ha^{-1} yr^{-1} respectively), bund planting (2.51, Rs. 50,724.50 ha^{-1} yr^{-1}) and control (2.00, Rs. 22,830.25ha-1 yr-1).

The results obtained indicated that the net returns and B:C ratio were higher in horti-silviculture system since the integration of trees with horticultural crops or fruit trees provide higher economic value for products and act as the major source of income. The other agroforestry systems also recorded higher income compare to control land because in addition to crop yield, the teak trees products have high economic value providing additional source of income to the farmers. The results are on for with the Rani *et al.* (2016)reported teak tree-based land use system with agriculture crops is economically viable.

4.5 Species richness, tree density and diversity

Under agroforestry system assessed, it was recorded 18 tree species belonging to 11 botanical families. Among these families, Fabaceae family contributed seven species followed by two species by Meliaceae and rest of the families’ one species each. Further, the study indicated that out of the total species 66.12% were of indigenous ones. The study also recorded one threatened species namely *Santalum album* which is listed in IUCN red data book.

Table 4.10: Cost benefit analysis of teak based agroforestry systems under Ramanagara Taluk.

Sl. No.	Cost/Benefits	Rs. ha^{-1} yr^{-1}			
		Bund planting	**Boundary planting**	**Horti-silviculture**	**Control (without trees)**
	Cost				
1	Land preparation	2500	2500	4000	2600
2	Seeds and sowing	6000	6000	-	6000
3	Inter cultivation	1000	1000	2200	1000
	Fertilizers				
4	FYM	3800	3800	5800	3800
5	Chemical fertilizers	2119.25	2300	7250	2200
6	Agrochemicals	1600	1330.25	2080	1130.25
7	Human labour	8200	8200	17250	7500
8	Harvesting and threshing	4450	4450	12800	4500
	Total cost	**29669.25**	**29580.25**	**51380**	**28830.25**
9	**Returns**				
a	Crop output	55293.75	52113.75	152000	60000
b	Tree biomass	25100	37500	45300	-
	Gross return	**80393.75**	**89613.75**	**197300**	**60000**
	Net return	**50724.50**	**60033.50**	**145920**	**22830.25**
	B:C ratio	**2.51**	**3.00**	**3.66**	**2.00**

The detailed botanical description, status and uses of the species are given in (Appendix-IV). These findings indicated that the majority of the tree species retained on the farm are local, multipurpose tree species that are useful to the farming community and which grow naturally on the farmland. The results are in line with Vodouhe *et al*. (2011) who reported 21 species of 14 plant families in traditional agroforestry systems in Benin (West Africa). Further, they reported that 85 per cent of the total 21 tree species were indigenous to the area.

4.5.1 Different categories of farmers

In the Ramanagara Taluk, there were 45.04 ha of trees on average, representing an average of 14 different tree species (Table 4.11, Fig 4.3 & 4.4). However, there were noticeable differences in the tree density between the various farmer categories, with large farmers having the most trees per hectare (86.60), followed by medium farmers (47.04), and small farmers (27.04). (26.03).

The findings revealed that the mean number of trees per hectare in the large farmer category was significantly higher, demonstrating that the size of the landholding affects the farm's tree density. Most likely because a farmer with a larger land holding has the chance to integrate more trees than a farmer with a smaller holding, where field crops are more crucial to their economic survival and landholding becomes a limiting factor. The findings are consistent with those of Endale *et al*. (2016), who found a significant positive relationship between the size of the landholding and the number of trees on the farm. This relationship indicates that small farms have fewer trees than large farms, which is likely due to land constraints. According to Bucagu *et al*. (2013)'s study on the assessment of farmers' interest in agroforestry in two distinct agro-ecological zones of Rwanda, wealthier farmers had a higher tree density than poorer farmers. According to Baul *et al*. (2015), who conducted research on the conservation of agro-biodiversity, marginal farms have the lowest diversity of tree species and larger farms have the highest. A positive correlation between actual farm size and species diversity was discovered. This implies that one of the controlling factors for species richness and diversity on farms was found to be the variation in farmland size.

Table 4.11: Species richness, tree density and diversity in different categories of farmer land holding under Ramanagara Taluk

Particulars	Species richness (Total number)	Tree density (ha^{-1})	Simpson index	Shannon index
Categories of farmer				
Large farmer (n=30)	14	86.60^{a}	0.27	0.56
Medium farmer (n=40)	12	47.04^{b}	0.21	0.51
Small farmer (n=42)	16	26.03^{c}	0.29	0.51
P – Value		**<0.05**	**0.166^{NS}**	**0.200^{NS}**
Average (n=112)	**14**	**45.04 (±34.37)**	**0.36 (±0.03)**	**0.60 (±0.39)**

Note: Values in the parentheses indicate the standard deviation

The values within the column with same letter are not significantly different at 5% level of significance

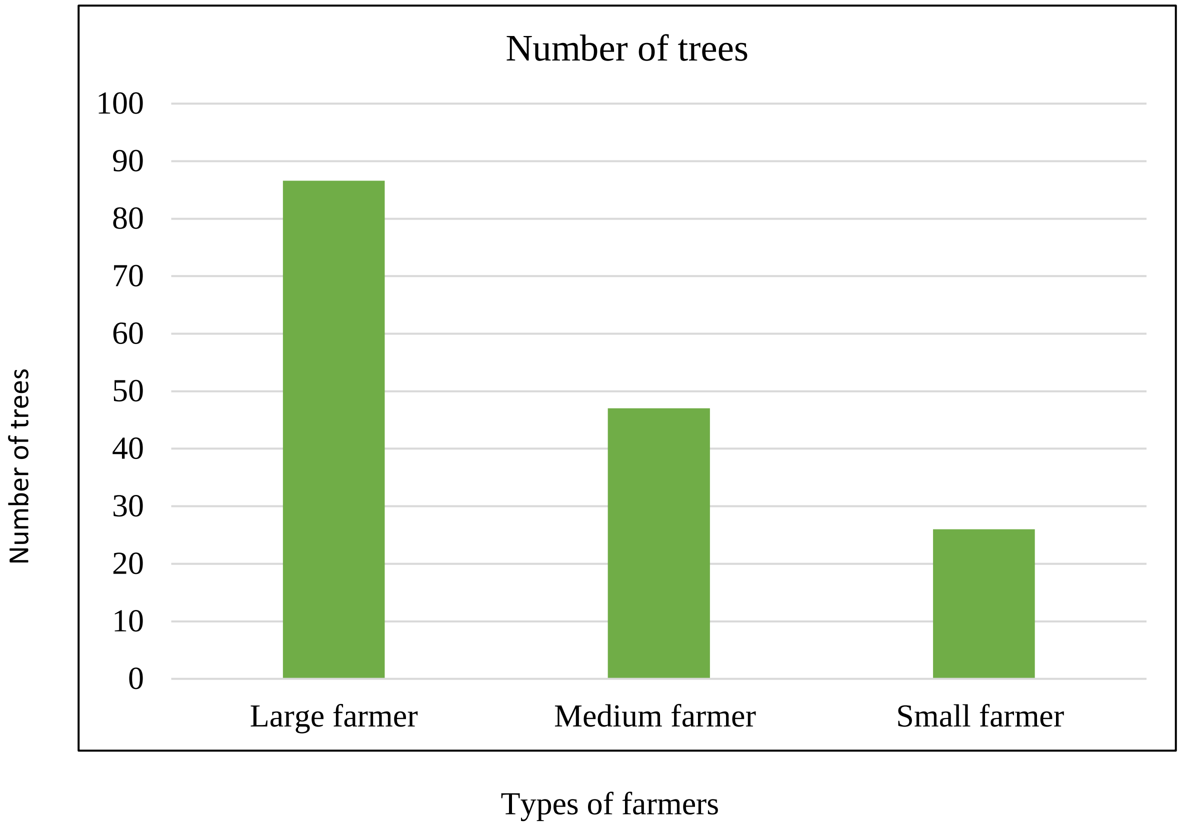

Fig 4.3: Number of trees with farm holding size in Ramanagara

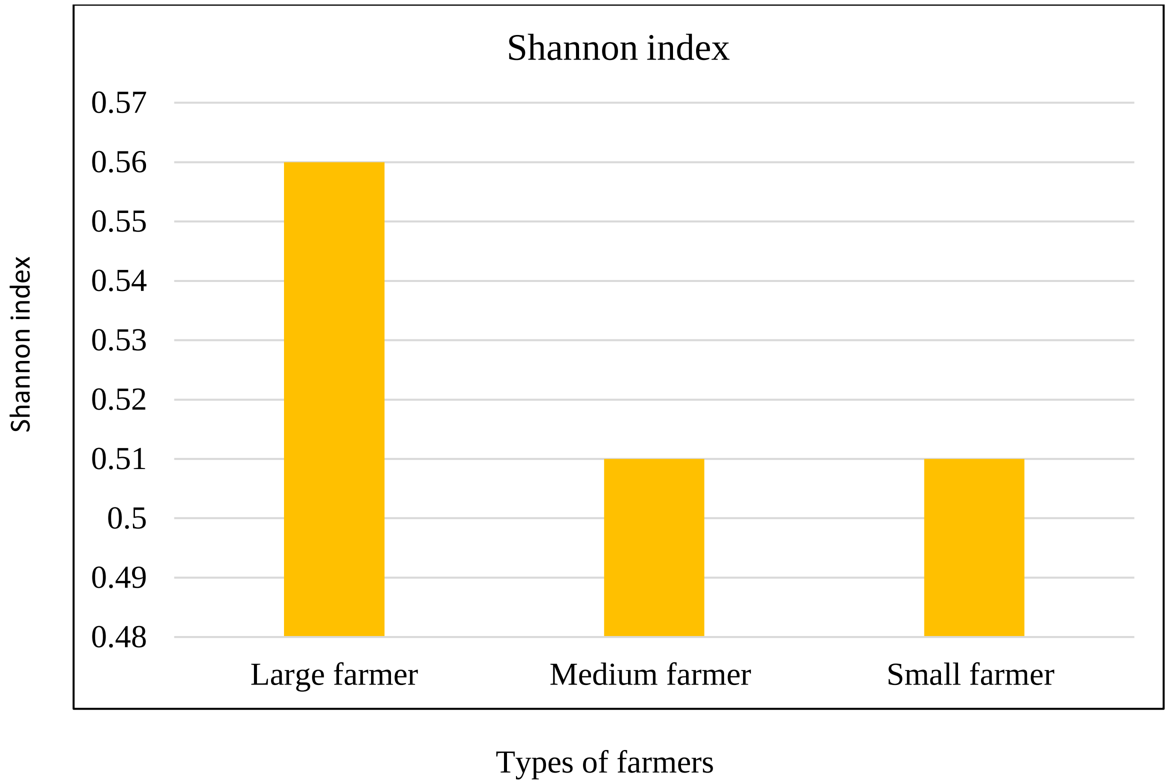

Fig 4.4: Shannon's index for no. of trees with farm holding size in Cauvery waterbasin

4.5.2 Agroforestry systems

Among the major different agroforestry systems, it was revealed that the mean number of tree species per hectare and biodiversity indices were significantly different (Table 4.12). Where, between major agroforestry systems it was revealed significantly higher number of trees per hectare was found in the Horti-silviculture system (93.51) followed by block planting (78.10) and boundary planting (38.43) whereas least number of trees per hectare was recorded in scattered planting (9.42). However remarkably, a significantly higher Shannon diversity index was observed in Horti-silviculture (0.78) followed by boundary planting (0.48), whereas lower value recorded in block planting (0.39).

Moreover, agroforestry systems and combinations thereof for each hectare of land. It was discovered that there were significant variations in the average number of species per hectare among the various agroforestry systems. However, boundary + block planting (164) had the highest number of trees per hectare, followed by block Horti-silviculture (152) and scattered planting + Horti-silviculture (100), while scattered planting (9.42) and bund+ scattered planting had the lowest number of trees per hectare (15). Further, it was observed that the boundary + block planting system had a significantly higher Shannon diversity index (1.03) than did the scattered planting + horticulture system (1.07), whereas block planting had a lower value (0.39).

The higher density of trees and species diversity was recorded in the Horti- silviculture system, block planting, boundary + block planting, block + Horti-silviculture and scattered + Horti-silviculture as it is dependent on the farmers land holding size and thesystem they are practicing in their farm. The results are in togetherness with Baul *et al*. (2015) who studied on conservation of agro-biodiversity concluded that the larger farms have the highest tree species diversity and marginal farms have the lowest. Actual farmsize and the species diversity were found positively correlated. Abebe, *et al.* (2013) reported an increase in species richness and density with an increase in the farm size.

Table 4.12: Species richness, tree density and diversity in different agroforestry system under Ramanagara.

Particulars	Species richness (Total number)	Tree density (ha^{-1})	Simpson index	Shannon index
Agroforestry systems				
Bund planting (n=30)	11	26.64[ifh]	0.25[efghi]	0.46[fh]
Boundary planting (n=26)	10	38.43[hf]	0.32[cgh]	0.56[dh]
Scattered planting (n=7)	02	9.42[khij]	0.26[fghij]	0.48[e]
Horti-silviculture(n=6)	05	93.51[cb]	0.49[a]	0.78[af]
Block planting(n=3)	02	78.10[eb]	0.22[ghij]	0.39[gh]
Bund + Boundary planting (n=25)	07	44.58[gf]	0.48[a]	0.76[a]
Bund + Scattered planting (n=1)	02	15.00[jhi]	0.52[ad]	0.90[ae]
Bund + Horti- silviculture (n=5)	07	52.63[fe]	0.40[af]	0.70[bc]
Boundary + Block planting (n=2)	07	164.00[a]	0.55[ac]	1.07[a]
Block + Horti-silviculture (n=2)	02	152.10[a]	0.36[bg]	0.80[ae]
Block + Scattered planting (n=2)	03	78.10[db]	0.33[dghi]	0.51[e]
Scattered + Horti-silviculture (n=3)	08	100 .00[b]	0.58[a]	1.04[a]
P - Value		**<0.05**	**<0.05**	**<0.05**
Average (n=112)	**7.00**	**71.01 (±30.11)**	**0.40 (±0.10)**	**0.70 (±0.22)**

Note: Values in the parentheses indicate the slandered deviation

The values within the column with same letter are not significantly different at 5% level of significance

The Shannon diversity index was observed significantly higher in horti-silviculture combination with boundary, block and scattered planting. This proposed that the tree species are more evenly distributed, the lower Shannon diversity index recorded in the block planting system due to uneven distribution and the higher concentration of individualspecies in the farm. The results are in congruence with the findings of Tadesse *et al.* (2019)who reported in his study that the home garden agroforestry system have higher diversity compared to park land agroforestry system, because of high intensity in management and cultivation.

4.5.3 Different taluks

In the study, it was revealed that there was no significant difference in tree density and diversity indices among the taluks (Table- 4.13). However, the higher mean numberof trees per hectare recorded in Kanakapua and lowest recorded in Ramanagara taluk and the Shannon diversity index was found higher in Kanakapura taluk followed by Ramanagara taluk.

The higher tree density in Kanakapura may be attributed to considerably higher rainfall in these taluks and another factor is that it was recorded that horti- silviculture and block planting agroforestry practices were followed in the majority. Further, the higher diversity recorded in eastern dry zone (Kanakapura and Ramanagara) because of more contribution from the horti-silviculture and bund + boundary planting agroforestry practices in that area. The findings are consistent with those of Nyaga *et al*. (2015), who also noted a preference for particular species in particular agroforestry systems. According to Singh *et al*. (2007), the density of trees and shrubs varied from one agroforestry system to another based on the resources that were available.

Table 4.13: Species richness, tree density and diversity in different taluks under Ramanagara

Particulars	Species richness (Total number)	Tree density (ha^{-1})	Simpson index	Shannon index
Taluks				
Channapatna (n=28)	07	39.17	0.31	0.47
Ramanagara (n=28)	09	37.19	0.40	0.65
Kanakapura (n=28)	11	57.34	0.44	0.72
Magadi (n=28)	09	42.11	0.32	0.54
P – Value		**0.671^{NS}**	**0.204^{NS}**	**0.119^{NS}**
Average (n=112)	**10.00**	**45.11 (±30.24)**	**0.36 (±0.11)**	**0.59 (±0.38)**

Note: Values in the parentheses indicate the standard deviation

4.6 Dominant tree species in agroforestry systems of Ramanagara

In the Ramanagara district a total of 6,101 individuals of 19 species were recorded. *Tectona gradis* (n = 2982) was the most predominant species found in the Ramanagara and in all the samples of the farms it was recorded highest relative frequency when compared to other tree species (RF = 65.07) followed by *Grevillea robusta*(n =953, RF = 30.00), *Azadirachta indica* (n = 427, RF = 28.36), *Cocos nucifera* (n = 389,RF =10.19), and five species recorded less than 31 individuals. (Table 4.14)

The dominant species among the various categories of farmers was found to be *Tectona gradis,* followed by *Grevillea robusta* and *Azadirachta indica* (Table 4.14). Alternatively, the species dominance was categorised in relation to the various agroforestry systems (Table-4.15). While *Azadirachta indica* was discovered to be the dominant species in the bund, boundary, and scattered planting, *Tectona gradis* and *Grevillea robusta* were found to be the dominant species in the bund and boundary planting. In block plantations, *Tectona gradis* and Eucalyptus globulus were particularly abundant. Horti-silviculture was predominately *cocos nucifera.* The most common tree species grown in the taluks were found to be *Tectona gradis Grevillea robusta*, *Azadirachta indica*, and *Cocos nucifera* (Table-4.16). However, there were notable differences in the dominance of the other species among the taluks. In Kanakapura taluk, *Tectona gradis* and *Grevillea robusta* were found to be predominant. Whereas in Magadi Taluk, the three dominant species were *Azadirachta indica*, Melia dubia, and *Cocos nucifera*. The predominant tree species in the Channapatna and Magadi taluks was *Pongamia pinnata.*

The results obtained revealed that Teak, Silver oak, Neem, Hebbevu and Coconut were the predominant species found in the agroforestry systems under different taluk of Ramanagara. This gives a comprehension that farmers grew these trees based on their preference and selectivity in the farm mainly for economic benefit, multipurpose utility of the trees and cultural preference of the locality. Farmers are more interested on growing teak and silver oak as preferred species because of economic value, availability of seedlings, availability of market, using trees as wind breaks and knowledge about growth habit of tree species. The Neem tree was one of the dominant species found as it is one of indigenous and multipurpose tree seen on bunds, boundary and scattered planting of the farms. Coconut was also a tree which found in majority as it is a horticulture crop providesregular income to the farmers. Further one more tree Hebbevu was also found to be dominant species

Table 4.14: Dominant tree species found in different categories of farmers land holdings of Ramanagara.

Sl. No.	Species name	Large farmer (n=30)			Medium farmer (n=40)			Small farmer (n=42)			Grand total (112)		
		Total No.	Rd	RF	Total No.	Rd	RF	Total No.	Rd	RF	Total No.	Rd	RF
1.	*Tectona grandis*	1015	45.55	75	1240	48.81	69	727	40.20	50.13	2982	44.19	65.07
2.	*Grevillea robusta*	242	10.31	31	360	13.27	34	351	19.19	23.07	953	13.07	30.00
3.	*Azadirachta indica*	109	04.33	23	128	04.99	17	190	10.18	40.03	427	06.03	28.36
4.	*Melia dubia*	100	04.00	10	190	07.00	20	102	05.67	14.57	392	05.13	14.29
5.	*Cocos nucifera*	180	08.18	20	149	05.00	08	60	03.00	01.00	389	05.15	10.19
6.	*Pongamia pinnata*	40	02.00	03	70	02.21	21	110	05.13	27.00	220	02.99	16.63
7.	*Mangifera indica*	60	02.19	14	30	01.00	03	15	01.00	04.00	105	01.00	7.11
8.	*Manilkara zapota*	40	02.00	10	30	01.00	02	02	00.11	00.33	72	01.11	3.17
9.	*Acacia auriculiformis*	2	00.11	03	2	00.11	03	04	00.19	02.33	8	00.10	2.00
10.	*Artocarpus heterophyllus*	15	00.80	03	20	00.88	03	14	00.79	02.33	49	00.86	2.99
11.	*Sesbaniagrandiflora*	15	00.80	03	17	00.67	03	05	00.31	02.33	37	00.62	2.99
12.	*Gliricidia sepium*	25	01.00	03	5	00.30	03	02	00.13	01.11	32	00.42	1.11
13.	*Eucalyptus grandis* Sm.	188	07.50	03	100	03.99	04	04	00.20	01.11	292	04.68	3.00
14.	*Dalbergia sissoo*	15	00.80	03	7	00.00	03	0	00.00	00.00	22	00.21	1.00
15.	*Santalum album*	13	00.58	03	6	00.00	03	04	00.19	01.19	23	00.21	1.01
16.	*Leucaena leucocephala*	0	00.00	00	25	01.00	05	12	00.78	02.33	37	00.60	2.02
17.	*Tamarindus indica*	10	00.50	03	2	00.41	01	40	02.00	04.00	52	00.62	1.99
18.	*Annona reticulata*	0	00.00	00	4	00.15	03	0	00.15	03.00	4	00.06	0.57
19.	*Jatropha curcas*	4	00.38	00	0	00.00	00	01	00.10	01.21	5	00.02	0.47
	Total number of trees	2073			2385			1643			6101		
	Mean number of tree ha^{-1}	69.1			59.62			39.11			54.47		

Note: Rd- Relative density, RF-Relative frequency

Table 4.15: Dominant tree species found in different agroforestry systems of Ramanagara Taluk

Sl. No.	Species name	BND (n=30)		BDR (n=26)		SP (n=7)		HS (n=6)		BP (n=3)	
		Total No.	**Rd**	**Total No.**	**Rd**	**Total No.**	**Rd**	**Total No.**	**Rd**	**Total No.**	**Rd**
1.	*Tectona grandis*	515	48.13	660	53.61	20	21.10	248	39.95	162	54.30
2.	*Grevillea robusta*	130	11.91	200	15.19	0	00.00	50	07.15	0	00.00
3.	*Azadirachta indica*	116	10.61	82	06.11	49	53.02	0	00.00	0	00.00
4.	*Melia dubia*	72	06.00	100	07.20	0	00.00	37	05.10	47	14.77
5.	*Cocos nucifera*	08	00.77	25	02.00	0	00.00	210	33.10	0	00.00
6.	*Pongamia pinnata*	42	04.00	9	00.62	10	10.20	0	00.00	0	00.00
7.	*Mangifera indica*	10	01.00	13	01.11	4	05.99	19	02.47	0	00.00
8.	*Manilkara zapota*	4	00.36	13	01.11	3	02.88	17	02.30	0	00.00
9.	*Acacia ferruginea*	5	00.46	4	00.42	3	02.88	0	00.00	0	00.00
10.	*Artocarpus heterophyllus*	10	01.00	15	01.33	0	00.00	0	00.00	0	00.00
11.	*Sesbania grandiflora*	19	01.99	5	00.42	0	00.00	0	00.00	0	00.00
12.	*Gliricidia sepium*	3	00.18	1	00.13	0	00.00	0	00.00	0	00.00
13.	*Eucalyptus globulus*	1	00.10	8	00.62	0	00.00	0	00.00	70	24.05
14.	*Dalbergia sissoo*	1	00.10	0	00.00	0	00.00	0	00.00	0	00.00
15.	*Santalum album*	0	00.00	4	00.31	0	00.00	0	00.00	0	00.00
16.	*Leucaena leucocephala*	13	01.11	3	00.13	0	00.00	0	00.00	0	00.00
17.	*Tamarindus indica*	18	01.24	9	00.62	0	00.00	0	00.00	0	00.00
18.	*Annona reticulata*	0	00.00	0	00.00	0	00.00	6	00.96	0	00.00
19.	*Jatropha curcas*	3	00.13	1	00.10	0	00.00	0	00.00	0	00.00
	Total number of trees	970		1152		89		587		279	
	Mean number of tree ha^{-1}	32.33		44.30		12.71		97.83		93.00	

Table 4.16: Dominant tree species found in different taluks of Ramanagara District.

Sl. No.	Species name	Channapatna (n=28)		Ramanagara (n=28)		Kanakapura (n=28)		Magadi (n=28)	
		Total No.	RD	Total No.	RD	Total No.	RD	Total No.	RD
1.	*Tectona grandis*	580	50.05	450	41.10	800	48.00	440	35.08
2.	*Grevillea robusta*	83	07.07	162	15.11	320	19.11	201	15.11
3.	*Azadirachta indica*	77	07.00	86	07.79	78	04.00	101	08.19
4.	*Melia dubia*	36	03.00	76	07.00	61	03.88	131	10.22
5.	*Cocos nucifera*	42	04.10	50	04.91	132	08.09	105	08.70
6.	*Pongamia pinnata*	65	06.17	29	03.00	26	01.12	58	05.00
7.	*Mangifera indica*	30	02.99	44	03.91	4	00.32	10	01.00
8.	*Manilkara zapota*	16	01.11	12	01.00	30	02.01	12	01.01
9.	*Acacia ferruginea*	2	00.18	5	00.52	0	00.00	0	00.00
10.	*Artocarpus heterophyllus*	17	01.51	30	03.00	5	00.36	8	00.81
11.	*Sesbania grandiflora*	4	00.32	6	00.39	6	00.40	3	00.18
12.	*Gliricidia sepium*	2	00.18	4	00.31	4	00.20	3	00.18
13.	*Eucalyptus globulus*	69	06.21	41	04.21	26	02.80	40	03.01
14.	*Dalbergia sissoo*	5	00.35	5	00.35	16	01.22	0	00.00
15.	*Santalum album*	4	00.32	5	00.35	12	00.81	4	00.40
16.	*Leucaena leucocephala*	20	02.	6	00.49	0	00.00	4	00.32
17.	*Tamarindus indica*	6	00.51	4	00.32	16	01.03	22	02.01
18.	*Annona reticulate*	0	00.00	0	00.00	0	00.00	0	00.00
19.	*Jatropha curcas*	2	00.12	0	00.00	3	00.13	0	00.00
	Total number of trees	1060		1015		1539		1142	
	Mean number of tree ha^{-1}	37.85		36.25		54.96		40.78	

This specifies that farmers are having knowledgeabout selection and integration of tree species in their farms. The results are on par with theViswanath *et al*. (2000) who reported in their study on *Acacia nilotica* trees in rice field that farmers are integrating *Acacia nilotica* trees in rice field as it accounts for nearly 10% of the annual farm income of smallholder farmers (<2 ha) on a short-term (10-year) harvest cycle of trees.

4.7 Constraints in expansion of trees on farm land

Major constraints in expansion of trees on farm land are presented in the form of ranks (Table 4.17) based on the information obtained from the farmers through interaction and recording in semi-structured questionnaire. Foremost constraint expressed by the farmers is lack of irrigation facility. In addition, small land holding size, competition with field crops, non-availability of seedlings and long gestation period were also recorded as major constraints in expansion of cropland with more number of trees. Major constraint was lack of irrigation facility as the area is dependent mainly on rainfall.

4.8 Utilization pattern of the tree species

Farmers interacted with one another to gather data on how different tree species were used on their farm, which they then recorded in a semi-structured questionnaire. The majority of tree species cultivated in agroforestry systems are used for timber production, followed by fodder and fruit. The importance of medicinal, religious, and ornamental species is minimal. The findings are consistent with Bayala *et al*. (2011), who claimed that the utility of a tree species played a major role in its ability to survive on farmland.

4.9 Management of trees in agro forestry system

The management practices of trees in agroforestry systems followed by farmers presented (Fig 4.5). It was found that branch pruning (49%) is the major management practice of trees in the farm by the farmers because to avoid the tree canopy shade and reduce competition to the field crops. Soil working (23%), fertilization (12%) and weeding(13%) were recorded as minor management practices followed. Root pruning was the least management practice followed by the farmers. The results are in line with Devaranavadgi*et al.*, (2010) who also reported branch pruning (56%) and soil working (16%) were most important practices adopted by the farmers.

Table 4.17: Constraints in growing tree species on farm land

Sl. No.	Constraints	Mean Score (n = 112)	Rank
1	Competition with other crops	55.10	3
2	Fear of theft	40.11	6
3	Small Land holding	60.36	2
4	Long gestation period	50.19	5
5	Non availability of seedling	55.00	4
6	Lack of adequate irrigation	74.04	1
7	Stray cattle menace	35.28	8
8	Lack of marketing facility	40.39	7
9	Shortage of labour	21.29	9

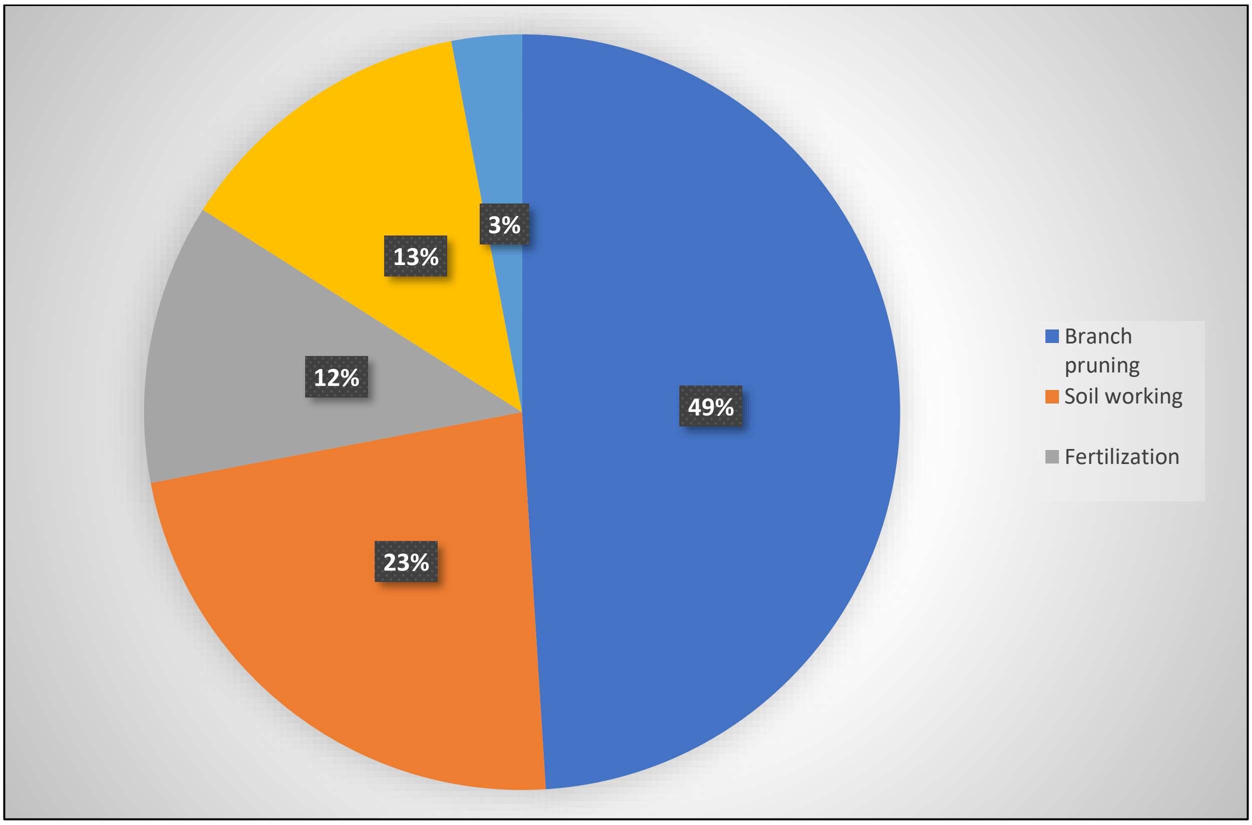

Fig. 4.5: Management of trees in agroforestry systems

SUMMARY

V SUMMARY

Along with enhancing soil fertility, securing livelihoods, and reducing the impact of climate change, agroforestry as an alternative land use system is essential for maintaining crop productivity. Due to their lack of understanding of ecological and economic sustainability, farmers are constrained in their ability to expand and adopt perennial tree components on farmland. Other socio-cultural factors, such as the labour shortage, the size of the average landholding, and farmer awareness or perception, are also significant in the country's restriction of agroforestry practices. So, it is necessary to investigate the ecological and economic viability of different agroforestry systems. However, India has a lot of potential for the growth of agroforestry. Because of their complexity, agroforestry land use systems need to be studied from a variety of angles, including socioeconomic and ecological ones. Based on this context, the current study was carried out to determine the current status of the agroforestry systems that are currently in place and their effectiveness in the Ramanagara Taluk.

- Among different agroforestry systems, the majority of the farmers practised bund planting (25.33 %) followed by bund + boundary planting (22.35 %) and boundary planting (22.00 %).

- Majority of large farmers followed the Horti-silviculture system (23 %).

- Significant differences in the girth and height of trees were seen in Neem-based agroforestry systems. Bund planting reported the trees with the largest girth (73.22 cm), and boundary planting reported the trees with the highest height (6.16 m). However, there were no appreciable variations in the volume and biomass of the trees.

- Tree girth varied significantly in agroforestry systems based on teak. Nevertheless, there were no appreciable differences in height, volume, or biomass. The height of trees was recorded higher in the horti-silviculture system, and the largest girth was recorded in bund planting (69.50 cm) (7.74 m).

- Finger millet produced significantly different grain and straw yields in Neem-based agroforestry systems. The control condition without trees produced the highest grain yield (2015.87 kg ha 1) and straw yield (4200 kg ha 1) when compared to other agroforestry systems.

- The grain yield and straw yield of finger millet varied significantly between different Teak-based agroforestry systems. In comparison to other agroforestry systems, the control condition without trees had the highest grain yield (2,008.07 kg ha^{-1}) and straw yield (4,200 kg ha^{-1}).

- Under neem-based agroforestry systems significantly higher above-ground carbon stock was recorded in boundary planting (4.00 t ha^{-1}).

- Horti-silviculture system was recorded the higher carbon stock (7.00 t ha^{-1}) in teak based agroforestry systems

- Higher cost benefit ratio of 2.00 with a net return of Rs.30,970.75 ha^{-1} yr^{-1} recorded in pure crop stand compared to other neem dominant agroforestry systems.

- Returns per rupee expenditure and net returns were recorded higher in Horti- silviculture system (3.66 t ha^{-1}, Rs.1,45,920 ha^{-1} yr^{-1} respectively) of teak based agroforestry systems.

- Eleven different botanical families represented by 18 different tree species were identified in agroforestry systems. The Fabaceae family produced the most species among these families with seven, followed by Meliaceae with two, and the remaining families with one each. The study also revealed that 66.12% of the total species were indigenous. One threatened species, the Santalum album, which is listed in the IUCN Red Data Book, was also noted in the study.

- The small farmer (16) recorded the most tree species, followed by the large farmer (14) and the medium farmer (12). The higher number of trees per hectare was recorded with the large farmer (86.60%), followed by a medium farmer (47.04%) and a small farmer (47.04%), but there were noticeable differences in the tree density among the various categories of farmers (26.03%).

- The Horti-silviculture system had the most trees per hectare (93.51%) among the agroforestry systems, followed by block planting (78.10%) and boundary planting (38.43%), while scattered planting had the fewest trees per hectare (9.42%).

- Significantly highest Shannon diversity index was witnessed in Boundary + Block planting (1.07) followed by Scattered planting + Horti-silviculture system (1.04), whereas a lower value was recorded in block planting (0.39).

- In the Ramanagara Taluk, 19 different species of trees have been identified. The most common species in the Ramanagara Taluk was *Tectona grandis* (n = 2982), which also had the highest relative frequency (RF = 65.07) among all the tree species in the farm samples.

- Lack of irrigation facilities, small land holding and competition with crops were regarded as major constraints in the expansion of trees in croplands.

- The majority of tree species were cultivated in agroforestry systems for timber followed by fodder and fruit.

- Branch pruning of trees was the major management practice followed by farmers to manage the light competition with the field crops.

Major Research Findings of Practical Significance

The present study titled "Design and Diagnosis Survey of Trees in different Agroforestry System of Ramanagara Taluk" came out with the following findings of practical significance.

- Bund planting and boundary planting were the major agroforestry systems practised by the farmers in the Ramanagara.

- The number of trees in the farm positively correlated with the land holding of the farmers and the agroforestry system practised by the farmers.

Future line of work

- Only the neem and teak agroforestry systems were assessed for economic advantages in this study. We must evaluate the financial advantages of other agroforestry systems with a commercial base.
- We also need to evaluate the ability of various tree species with varying tree densities and agricultural components to sequester carbon.
- In addition, research is required to evaluate the species diversity, species density, and documentation of various tree species in various other agroforestry systems.

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