PERFORMANCE OF SELECTED MEDICINAL HERBS UNDER TYPICAL HOMEGARDEN AND PURE COCONUT PLANTATION

By
NIYAS P
(2013-17-106)

THESIS

Submitted in partial fulfillment of the requirement for the degree of

Master of Science in Forestry

Faculty of Forestry
Kerala Agricultural University

Department of Silviculture and Agroforestry
COLLEGE OF FORESTRY
VELLANIKKARA, THRISSUR-680656
KERALA, INDIA
2015

DECLARATION

I hereby declare that this dissertation entitled **"Performance of selected medicinal herbs under typical homegarden and pure coconut plantation"** is a bonafide record of research done by me during the research and that the thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar title, of any University or Society to me.

Vellanikkara

19-09-2015

Niyas P

(2013-17-106)

Dr. T. K. Kunhamu
Associate Professor and Head
Dept. of Silviculture and Agroforestry
College of Forestry, Vellanikkara
Thrissur-680656

CERTIFICATE

Certified that this dissertation entitled "**Performance of selected medicinal herbs under typical homegarden and pure coconut plantation**" is a record of research work done independently by Mr.Niyas,P (2013-17-106) under my guidance and supervision and it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

Vellanikkara
19-09-2015

Dr. T. K. Kunhamu
Chairman
Advisory Committee

CERTIFICATE

We, the undersigned members of advisory Committee of **Mr. Niyas, P. (2013-17-106)** a candidate for the degree of **Master of Science in Forestry** agree that this thesis entitled **"Performance of selected medicinal herbs under typical homegarden and pure coconut plantation"**. may be submitted by **Mr. Niyas, P (2013-17-106)**, in partial fulfilment of the requirement for the degree.

Dr. T. K. Kunhamu
Associate Professor & Head
Dept. of Silviculture and Agroforestry
College of Forestry,
Kerala Agricultural University
Vellanikkara, Thrissur, Kerala-680656.
(Chairman)

Dr. V. Jamaludheen
Assistant Professor,
Dept. of Silviculture and Agroforestry
College of Forestry, Vellanikkara, Thrissur,
Kerala-680656.
(Member)

Dr. M.T. Kanakamany
Professor and Principal investigator,
AICRP on Medicinal, Aromatic Plants and Betel vines,
College of Horticulture
Vellanikkara, Thrissur, Kerala-680656.
(Member)

19/9/15
Dr. Asha, K. Raj
Assistant Professor,
Department of Silviculture& Agroforestry,
College of Forestry,
Vellanikkara, Thrissur, Kerala-680656.
(Member)

19/9/15
EXTERNAL EXAMINER
Dr R. C. Pandalai

ACKNOWLEDGEMENT

With deep admiration I evince my heartfelt gratitude and unforgettable owe to my major advisor Dr. T. K. Kunhamu, Associate Professor and Head ,Department of Silviculture and Agroforestry, College of Forestry for his valuable guidance, support, inspiration, critical advise, encouragement and friendly cooperation throughout the course of my research work. Words are not enough to express my gratitude and respect for him. I consider myself lucky to have him as my advisor.

I extend my wholehearted thanks to Dr. K. Vidyasagaran, Dean, Associate Professor and Head, Department of Forest Management and Utilization, College of Forestry for his keen interest and valuable suggestions he has provided throughout the course of my study. I take this opportunity to recognise Dr. K. Sudhakara, Former Dean, College of Forestry for his support during the study.

I owe my sincere thanks to my advisory committee member Dr. V. Jamaludheen, Associate Professor, Department of Silviculture and Agroforestry, College of Forestry for his cooperation and intellectual advice extended to me during the course of my study.

My earnest thanks are due to Dr. M.T. Kanakamany, Professor and Principal investigator, AICRP on Medicinal, Aromatic Plants and Betel vines, College of Horticulture, Assistant Professor, for her whole hearted cooperation and intellectual advice to me during the course of study.

My earnest thanks to Dr. Asha, K. Raj, Assistant Professor, Department of Silviculture and Agroforestry, College of Forestry and advisory committee member for the whole hearted cooperation and valuable advice to me during the study.

My deep sense of gratitude goes to Dr. S. Gopakumar, Associate Professor, Department of Forest Management and Utilization, College of Forestry and Dr. A. V. Santhosh Kumar, Associate Professor and Head, Department of Plant Physiology and Tree Breeding, College of Forestry for kindly providing me valuable advice and various facilities for the conduct of the study. My sincere thanks to Dr. C. Sunanda, Mr. Srinivassan K and Mrs. Jayasree for their valuable guidance.

I gratefully acknowledge the Kerala State Council for Science, Technology and Environment, All India Co-ordinated Research Project on Agroforestry and Kerala Agricultural University for providing me with the material and technical support for the conduct of this investigation.

I am grateful to all members of silviculture and agroforestry department for their ever willing help, great support, field practical's and kind co-operation rendered through all my works. My special thanks to Mrs. Ahalya, Mrs. Anu, Mrs, Sindhu, Mrs. Divya, Mrs. Saali, Mrs, Kiroshima, Mrs, Jayasree, Mrs. Sindhu, Mr. Sajith, Mr. Madhu, Mrs. Lathika, Mr. Raveendran and Mr. Sajeev for their patience in helping me during field and lab work.

I express my heartfelt thanks to Mr. Mir Faizan Anwar, Mr. Ajeesh, Mr. Adarsh, Mr. Harikrishnan, Mr. Nidhin, Mr. Sameer, Mr. Binu, Mr. Sachin, Mr. Anoop, Mr. Ashish, Mr. Rajkumar, Mr. Jithesh lal, Mr. Ranish, Mrs. Anu Sagaran, Mrs. Jyothi, Mr. Vikas, Mr. Rajan, Mr. Thangappan, Mrs. Salomi, Mr. Anoop, Mr. Nijin, Mr. Sooraj and Mr. Abu for the back-up which gave me enough mental strength to get through all mind-numbing circumstances.

At this juncture, I express my deep love to my father Mr. Musthafa, mother Mrs. Rasia, brother Mr. Nihal, sisters Mrs. Shifana and Mrs. Roomi, and other family members for their splendid moral and financial support and blessings. Finally I would like to convey my special thanks to Mrs. Ayisha, who always inspired me to complete this research work.

Above all I bow my head to THE ALMIGHTY whose blessings enabled me to undertake this venture successfully.

Niyas, P.

TABLE OF CONTENTS

Chapter No	Title	Page No.
1.	INTRODUCTION	1-3
2.	REVIEW OF LITERATURE	4-22
3.	MATERIALS AND METHODS	23-32
4.	RESULTS	33-91
5.	DISCUSSION	92-107
6.	SUMMARY	108-111
7	REFERENCES	112-131
	ABSTRACT	132-133
	APPENDICES	i

LIST OF TABLES (CONTD.)

Table No.	Title	Page No.
14	Total chlorophyll content of various intercrops as influenced by different landuse systems at Vellanikkara, Kerala.	58
15	Aboveground plant nutrient concentration in ginger under various landuse systems at Vellanikkara, Kerala	61
16	Aboveground plant nutrient concentration in turmeric under various landuse systems at Vellanikkara, Kerala	61
17	Aboveground plant nutrient concentration in galangal under various landuse systems at Vellanikkara, Kerala	62
18	Belowground plant nutrient concentration in ginger under various landuse systems at Vellanikkara, Kerala	65
19	Belowground plant nutrient concentration in turmeric under various landuse systems at Vellanikkara, Kerala	66
20	Belowground plant nutrient concentration in galangal under various landuse systems at Vellanikkara, Kerala	67
21	Aboveground plant nutrient accumulation in ginger under various landuse systems at Vellanikkara, Kerala	68
22	Aboveground plant nutrient accumulation in turmeric under various landuse systems at Vellanikkara, Kerala	69
23	Aboveground plant nutrient accumulation in galangal under various landuse systems at Vellanikkara, Kerala	70
24	Belowground plant nutrient accumulation in ginger under various landuse systems at Vellanikkara, Kerala	74
25	Belowground plant nutrient accumulation in turmeric under various landuse systems at Vellanikkara, Kerala	75
26	Belowground plant nutrient accumulation in galangal under various landuse systems at Vellanikkara, Kerala	76

LIST OF TABLES

Table No.	Title	Page No.
1	Plant height of ginger and turmeric in various landuse systems at Vellanikkara, Kerala	34
2	Pseudostem length of ginger and turmeric when intercropped under various landuse systems at Vellanikkara, Kerala	36
3	Leaf spread of galangal at various landuse systems at Vellanikkara, Kerala	36
4	Root length of various medicinal herbs grown under different landuse systems at Vellanikkara, Kerala	39
5	Number of tillers of various medicinal herbs grown under different landuse systems at Vellanikkara, Kerala	42
6	Number of leaves per tiller per plant of various medicinal herbs under different landuse systems at Vellanikkara, Kerala	43
7	Fresh aboveground biomass per plant of various medicinal herbs under different landuse systems at Vellanikkara, Kerala	45
8	Aboveground dry biomass per plant of various medicinal herbs under different landuse systems at Vellanikkara, Kerala	47
9	Fresh belowground biomass per plant of various medicinal herbs under different landuse systems at Vellanikkara, Kerala	52
10	Belowground dry biomass per plant of various medicinal herbs under different landuse systems at Vellanikkara, Kerala	52
11	Belowground dry weight of intercrops as influenced by various landuse systems at Vellanikkara, Kerala	53
12	Changes in net productivity among the of intercrops as influenced by various landuse systems at Vellanikkara, Kerala	56
13	Oleoresin content of various intercrops as influenced by different landuse systems at Vellanikkara, Kerala	57

LIST OF TABLES (CONTD.)

Table No.	Title	Page No.
14	Total chlorophyll content of various intercrops as influenced by different landuse systems at Vellanikkara, Kerala.	58
15	Aboveground plant nutrient concentration in ginger under various landuse systems at Vellanikkara, Kerala	61
16	Aboveground plant nutrient concentration in turmeric under various landuse systems at Vellanikkara, Kerala	61
17	Aboveground plant nutrient concentration in galangal under various landuse systems at Vellanikkara, Kerala	62
18	Belowground plant nutrient concentration in ginger under various landuse systems at Vellanikkara, Kerala	65
19	Belowground plant nutrient concentration in turmeric under various landuse systems at Vellanikkara, Kerala	66
20	Belowground plant nutrient concentration in galangal under various landuse systems at Vellanikkara, Kerala	67
21	Aboveground plant nutrient accumulation in ginger under various landuse systems at Vellanikkara, Kerala	68
22	Aboveground plant nutrient accumulation in turmeric under various landuse systems at Vellanikkara, Kerala	69
23	Aboveground plant nutrient accumulation in galangal under various landuse systems at Vellanikkara, Kerala	70
24	Belowground plant nutrient accumulation in ginger under various landuse systems at Vellanikkara, Kerala	74
25	Belowground plant nutrient accumulation in turmeric under various landuse systems at Vellanikkara, Kerala	75
26	Belowground plant nutrient accumulation in galangal under various landuse systems at Vellanikkara, Kerala	76

LIST OF TABLES (CONTD.)

Table No.	Title	Page No.
27	Specific leaf area of ginger, turmeric and galangal in various landuse regimes at Vellanikkara, Kerala	77
28	Diurnal variation in understorey PAR transmission for homegarden and coconut at Vellanikkara, Kerala	79
29	Nutrient status and pH in the soils prior to the field trial at Vellanikkara, Kerala	81
30	Soil nutrient status of the landuse regime in ginger beds at Vellanikkara, Kerala	82
31	Soil nutrient status of the landuse regime in turmeric beds at Vellanikkara, Kerala	83
32	Soil nutrient status of the landuse regime in galangal beds at Vellanikkara, Kerala	84
33	Soil nutrient status of the landuse regime area devoid of medicinal plants at Vellanikkara, Kerala	85
34	Variation in bulk density as a function of soil depth for selected landuse regimes at Vellanikkara, Kerala	86
35	Variation in organic carbon as a function of soil depth for selected landuse regimes at Vellanikkara, Kerala	87
36	Variation in organic matter as a function of soil depth for selected landuse regimes at Vellanikkara, Kerala	88
37	Variation in mean soil organic carbon content as a function of soil depth for selected landuse regimes at Vellanikkara, Kerala	89
38	Allometric models for rhizome yield and understorey PAR transmittance for various herbaceous crops at Vellanikkara, Kerala	91

LIST OF FIGURES

Figure No.	Title	Page No.
1	Plant height of ginger and turmeric in various land use systems at Vellanikkara, Kerala	37
2	Pseudostem length of ginger and turmeric in various land use systems at Vellanikkara, Kerala	37
3	Leaf spread of galangal at various landuse systems at Vellanikkara, Kerala	38
4	Root length of various medicinal herbs grown under different landuse systems at Vellanikkara, Kerala	40
5	Number of tillers of various medicinal herbs grown under different landuse systems at Vellanikkara, Kerala	42
6	Number of leaves per tiller of various medicinal herbs grown under different landuse systems at Vellanikkara, Kerala	44
7	Fresh belowground biomass per plant of various medicinal herbs under different landuse systems at Vellanikkara, Kerala	49
8	Belowground dry biomass per plant of various medicinal herbs under different landuse systems at Vellanikkara, Kerala	51
9	Belowground dry rhizome yield of various medicinal herbs under different landuse systems at Vellanikkara, Kerala	55
10	Oleoresin content of various intercrops as influenced by different landuse systems at Vellanikkara, Kerala	57
11	Total chlorophyll content of various intercrops as influenced by different landuse systems at Vellanikkara, Kerala	59
12	Stand leaf area index under coconut and homegarden at Vellanikkara, Thrissur	77
13	Diurnal variation in understorey PAR transmission for Coconut garden and homegarden at Vellanikkara, Kerala	80
14	Variation in organic carbon as a function of soil depth for selected landuse regimes at Vellanikkara, Kerala	87
15	Variation in mean soil organic carbon content as a function of soil depth for selected landuse regimes at Vellanikkara, Kerala	89

LIST OF FIGURES (CONTD.)

Figure No.	Title	Page No.
16	Understorey PAR and rhizome yield under various land management systems	90

LIST OF PLATES

Plate No	Title	Between pages
1	Experimental layout of various land use systems located at Vellanikkara, Thrissur	24-25
2	Locations of the various landuse systems selected for the experiment	24-25
3	Medicinal plants selected for the experiment	27-28
4	Line quantum sensor established in the homegarden	31-32
5	Soxhlet apparatus for oleoresin estimation	31-32
6	Ginger grown in coconut garden	31-32
7	Turmeric grown in homegarden	31-32
8	Mature medicinal plants grown in open (control)	31-32
9	Medicinal plants arranged in the lab for taking biometric observations	31-32
10	Bulk density estimation using steel cylinder	31-32
11	Rhizome yield of various medicinal plants grown at different locations of Vellanikkara, Thrissur	57-58

LIST OF APPENDICES

Appendix No	Title	Page No
1	Weather parameters during the experimental period (Jan 2014-Dec 2014)	i

Dedicated to my father

Introduction

INTRODUCTION

The unique tropical location with bountiful climatic advantages makes Kerala one of the green states in the country with rich biodiversity. Ample rainfall and conducive edaphic attributes provide excellent agroclimate for the cultivation of array of agricultural and perennial crops. Prominent among them include coconut and rice in the lowlands; rice, tapioca, banana, arecanut, coconut, pepper, cashew and rubber in hot humid midlands and tea, coffee and cardamom in the cool subtropical highlands. Agriculture is practiced in over 55 % of the geographical area.

Kerala has a diverse land use and cropping patterns. Among these homegardens and coconut gardens are two prominent traditional landuse practices in Kerala. The multitier homegardens are internationally recognised as unique land management system primarily on account of their multi functionality, low input, self-reliance, socio-economic feasibility and market resilience. Round-the-year availability of diverse agricultural products ensure the dietary and nutritional security of the household in addition to assisting in economic stability of the family. However, the recent undesirable land use trends in the socio-economic milieu of Kerala mooted by intense population pressure has brought paradigm shift in the land use practise that has seriously influenced the stability of this unique agro-ecosystem both in quantitative and qualitative terms. Hence, consistent efforts are required to improve the productivity of homegardens. One of the strategies to revive the traditional homegarden is to promote the understorey productivity through judicious intercropping of compatible shade tolerant crops of commercial value. Such efforts can help to earn substantial returns to the farmer at a lower cost of cultivation.

Coconut (*Cocos nucifera* L.) forms yet another prominent agricultural land use activity extensively practiced in Kerala. The coconut palm is known as Kalpavriksha or tree of heaven for its multifarious uses. More than 90 % of the five million coconut holdings in the country are less than one ha in size. In the recent times, coconut cultivation has become unattractive owing factors such as productivity decline due to diseases and high maintenance cost resulting in lower income. This is particularly important in the light of declining soil health consequent to undesirable land use practices. In many coconut growing countries with less pressure on land resources, coconut is cultivated as pure crop. However, the wide spacing in coconut plantation offers good opportunity for the integration of suitable agricultural crops. This is particularly suitable for Kerala where the demographic pressure on the land is intense and generation of alternative revenue from coconut gardens form a viable land use strategy. Furthermore, adoption of agroforestry systems in coconut plantations could be helpful in improving the current poor performance. Prospects of coconut farming can be improved through the integration of compatible intercrops which help to provide higher farm income. Traditional wisdom suggest that many annual, biennial and perennial crops can be effectively grown in coconut garden giving complementary boost up in coconut yield. However, successful intercropping depends on the type of the intercrop, coconut growth phase, understorey light availability and related biophysical elements. Selection of the suitable intercrop and their planting pattern can assure successful intercropping.

The agroclimatic condition of Kerala provides an ideal habitat for cultivation of medicinal plants. The ever increasing demand for these medicinal plants necessitates the large scale cultivation in available spaces. However, limited land resources are a potential impediment in the large scale cultivation of medicinal plants in Kerala. Many workers have stressed the importance of intercropping medicinal plants in the different cropping systems. Therefore medicinal plants will be the ideal choice for both homegarden and coconut plantation, because majority of them are shade tolerant, resistance to pests and diseases and cultivation is less labour intensive compared to other cash crops. Medicinal plants are looked upon not only as a source of affordable health care products but also as a source of income. There is a growing demand for plant based medicines, health products, essential oils, fragrances, cosmetics and natural aroma chemicals in the National and International markets. Among the array of medicinal plants available, probably shade tolerant herbaceous medicinal crop of zingiberaceae family *viz.* ginger (*Zingiber officinale*), turmeric (*Curcuma longa*) and galangal (*Kaempferia galanga*) may be better candidates for intercropping under the low understorey light regimes and resource competitive conditions existing in homegardens and coconut gardens. Furthermore, these are crops with high demand in view of their medicinal and culinary values.

Hence, the present study focuses on evaluating the compatibility of selected shade tolerant intercrops *viz.* ginger (*Zingiber officinale*), turmeric (*Curcuma longa*) and galangal (*Kaempferia galanga)* when grown under the two major land management systems of Kerala *viz.* traditional homegarden and coconut garden. The understorey productivity in tree based systems is often a function of biophysical factors such as light availability, soil factors and below ground competitive interactions. Hence the comparative advantage of biophysical factors contributed by the perennial components in the system will be evaluated as part of the study. The specific objectives of the study are as shown below:

a. To study relative performance of selected herbaceous medicinal crops *viz.* ginger (*Zingiber officinale*), turmeric (*Curcuma longa*) and galangal (*Kaempferia galanga*) when grown under two major tree based cropping systems in Kerala *viz.* homegarden and pure coconut garden.
b. To analyze the biochemical changes affecting product quality of the medicinal crops from two tree based land use systems.
c. To examine the biophysical interactions between the medicinal crops and the soil variables.
d. To study and compare soil carbon sequestration in two land use systems

Review Of Literature

REVIEW OF LITERATURE

Agroforestry is a relatively new name for a set of old practices. Growing arable crops in association with tree species forms a dominant landuse system in many parts of the tropics. The term agroforestry describes such integrated landuse practices in which perennials are integral part. The concept of agroforestry is internationally accepted as a collective name for landuse systems in which woody perennials are grown in association with herbaceous plants and/or livestock in a spatial arrangement, a rotation or both and in which there are both ecological and economical interactions between the tree and non-tree components (Young, 1987). Basic attributes of all agroforestry system are productivity, sustainability and adaptability (Nair and Dagar, 1991).

2.1 AGRISILVICULTURE

Agrisilviculture is a branch of agroforestry which incorporates fast growing multipurpose tree species in the crop fields. Alley cropping, improved fallow, homegardens, taungya, multi-tiered tree gardens, plantation crop combinations, shelter belts and wind breaks are examples of Agrisilviculture. Smallholder farmers are inclined to intercrop young trees with intensively managed arable crops to confer nutrient and weeding benefits while gaining short-term returns. Charging the cost of timber establishment to the intercrop as well as reducing fire perhaps, provides small holders with comparative advantages not enjoyed by industrial plantations (Garrity and Mercado, 1994). The presence of woody perennials in such integrated landuse systems has both advantages (soil conservation and fertility improvement) as well as disadvantages (decreased productivity by competitive interactions). Tree-crop compatibility trials in pursuit of identifying ideal combinations for understorey productivity improvements were conducted at several locations in India. Some of the reported combinations include rubber-banana (Rodrigo *et al.*, 2001), *Hardwickia binata*-based agrisilvicultural system involving sorgum-pearl millet, pigeon pea, soybean and cotton (Khadse and Bharad, 1996), coconut-based crop combinations for humid tropics such as coffee-banana, banana with ginger turmeric pineapple, papaya-pineapple, coffee-MPT-pepper (Nair, 1983; Lyiange, *et al.*, 1985).

2.2 EFFECT OF TREE CHARACTERISTICS ON PRODUCTIVITY OF AGRISILVICULTURE SYSTEMS

The understorey productivity in polyculture system are influenced by an array of factors. Among them understorey PAR (Photosynthetically Active Radiation) and belowground competition for water and mineral nutrient are of paramount importance. Tree components exert a marked influence on system productivity. There are several reports relating the influence of root and canopy architecture, crown characteristics and other tree attributes on the productive efficiency of agroforestry systems (Mathew *et al.* 1992; George, 1993; Jamaludeheen, 1994). This includes the role of trees in bringing about 'microsite enrichment' through processes such as efficient cycling of plant nutrients, nutrient pumping (Huxley, 1985) and biological nitrogen fixation (Nair, 1989). Canopy architecture and structure play an important role in interception of the incoming solar radiation. Terjeing and Louise (1972) reported that conical trees intercepted a higher amount of radiation, especially at higher altitudes. Norman and Jarvis (1974) also evaluated the influence of canopy structure on interception of radiation. They concluded that the path length of light through crown silhouette area and canopy volume did not significantly affect shading capacities in five stands of tree species studied. According to Mathew *et al.* (1992), the cladophyllous canopy of *Casuarina equiestifolia* facilitated increased infiltration and thereby increased the herbage yield of understorey fodder crops.

2.3 BELOW GROUND INTERACTIONS

Competition for native and applied resources among component crops is an important factor that limits the productivity of agroforestry systems (George *et al.*, 1996). In Haryana *Acacia nilotica* based agroforestry systems reduced the yield of wheat (Puri *et al.*, 1995). Reduction of crop yield in agroforestry system may be observed due to several reasons, but it may also be compensated in the long term by microclimate modification (Kohli and Saini, 2003) and residual nitrogen after removal of old trees as a result of enhanced N fixation under Acacia. Root competition for nutrients is a complex combination of soil supply and plant uptake mechanism. Vandenbeldt *et al.* (1990) reported that soil nutrition and competition for soil water is dependent on root distribution pattern. Plants with deep root system generally decrease competition whereas shorter thick roots quickly deplete adjacent nutrient pools, promoting steep and extensive nutrient gradients (Gillespie, 1989). Ong *et al.* (1991) found that tree roots can exploit water and nutrients from the sub soil whereas field crops having shallow roots are actively involved in surface soil. Lott *et al.* (2009) examined the intercepted radiation, spatial distribution of shade in *Zea mays* grown in intercropping system and sole cropping in semi arid Kenya. Their study revealed that tree decreased photosynthetic photon flux density incident on understorey maize by 30 per cent. The yield reduction was much greater than in the 25 per cent shade. *Zea mays* shade was unaffected by 50 per cent shade but decrease with increase in shade. Gao *et al.* (2013) studied photosynthesis, growth and yield of *Glycine max* and *Arachis hypogaea* by measuring photosynthetically active radiation, net photosynthetic rate, soil moisture and soil nutrients in a plantation of apple (*Malus pumila*) at a spacing of 4 m x 4 m in China. The result showed that soil moisture was the primary factor affecting the crop yield following the light. They concluded that apple-soybean and apple-peanut intercropping systems can be practical and beneficial. However distance between crops and tree rows should be adjusted to minimize interspecies competition. Agronomic measures such as regular canopy pruning, root barriers, additional irrigation and fertilization also should be applied in the intercropping systems.

2.4 PRODUCTIVITY UNDER PLANTATION CROP COMBINATION

Variation in understorey productivity has been observed for many plantation crops such as coconut and arecanut. A well designed high density multi-storeyed crop model suited to a given agroclimatic situation generates greater biomass output, yields more economic produce, generates steady and higher total income, additional employment opportunities for family labours and meets diversified needs of the farmers, such as food, fruit, vegetables, fuel, etc (Ghosh and Hore, 2007). Shade loving species, requiring low light intensities are likely to perform better under high-density multi-storeyed cropping system. Reduction in yield of seasonal crops under reduced light conditions (as intercrop) is reported by Oswald *et al.* (1995) in sweet potato. In any intercropping system, light appears to be one of the most important limiting factors deciding the productivity of crops.

2.5 COCONUT BASED INTERCROPPING SYSTEMS

Multispecies and multi-storeyed cropping system ensures maximum resource capture and use, leading to higher yield per unit area of soil, water and light. Improvement in the soil properties and biological activities in the root region of coconut due to intercropping, results in the modification of soil environment for the benefit of the plant growth (Maheswarappa *et al.*, 1998). Kasturibai *et al.* (1991) reported that, lower light intensity reaching canopy of intercrops due to interception by coconut canopy appears to be the limiting factor for their growth and productivity. Studies revealed that natural resources i.e., soil, water, air space and solar radiation are not fully utilized under the spacing schedule 7.5 m x 7.5 m. Ghosh and bandopadhyay (2011) observed that multiple cropping in coconut plantation under recommended package of practice of both main crop and intercrop, had no adverse effect on production of coconut. Fruit based cropping system with coconut, comprising of black pepper, pineapple was found best under West Bengal condition. Manjunath *et al.* (2002) reported that mean transmission of PAR in 12 year old coconut plantation varied from 23.1 to 36.6 % of the open light depending on the period of year (season). Menon *et al* (2013) observed leafy plants like *Boerhaavia diffusa*, *Cassia tora* and *Alternanthera sessilis* performed better in treeless open than coconut garden. *Boerhaavia diffusa, Cassia tora* and *Alternanthera sessilis* yielded 44, 94 and 57 % more in open than in shaded conditions respectively. Kumar *et al.* (2005) revealed that galangal yield was not affected by light interception levels by the upperstorey canopy up to 82 % of the open. Shade-tolerant and rhizomatic MAPs can be grown on a longer-term basis in widely spaced plantations. Intercropping of medicinal plants in coconut (*Cocos nucifera*) stands is an age-old practice in India and other parts of south- and south-east Asia. These palms allow 30 % to 50 % of incident light to the underneath, which is ideal for some MAPs, including cardamom (*Elettaria cardamomum*). Galangal (*Kaempferia galanga*) is traditionally intercropped in mature coconut gardens in Kerala, India. Twelve year old coconut trees did not adversely affect the growth and yields of a number of medicinal species grown as intercrops compared to the yields in the open (Nair *et al.,* 1989).

2.6 HOMEGARDEN BASED INTERCROPPING SYSTEMS

The scope of definition of a homestead was widened by Nair and Sreedharan (1986), who define it as an operational farm unit in which a number of crops (including tree crops) are grown with livestock, poultry and/or fish production mainly for the purpose of satisfying the farmer's basic needs. Nair (1993) observed that all homegardens consist of a herbaceous layer near the ground, a tree in the upper layer, and intermediate layers with different crops. The lower layer may be partitioned into two, with the bottom layer (of a height less than 1 m) dominated by different vegetable and medicinal plants, and the layer above it (1–3 m in height) composed of food plants such as cassava, banana, yam, and so on. The upper layer of the home garden, again divided into two, may comprise fully grown timber and fruit trees of 25 m height or more, and medium-sized trees ranging from 10–20 m in height. The intermediate layer may hold fruit trees of a height of 3–10 m but which could potentially increase in height. This layered structure also includes tuber crops such as taro, cassava, yam and/or sweet potato, since these crops require less care and provide reasonable yields.

2.7 MEDICINAL PLANTS AS INTERCROPS

Many tropical medicinal and aromatic plants are well adapted to partial shading, moist soil, high relative humidity and mild temperatures (Vyas and Nein 1999), allowing them to be intercropped with timber and fuel wood plantations, fruit trees and plantation crops. Some well-known medicinal plants that have been successfully intercropped with fuel wood trees (*e.g.*, *Acacia auriculiformis*, *Albizia lebbeck*, *Eucalyptus tereticornis*, *Gmelina arborea*, and *Leucaeana leucocephala*) in India, include safed musli (*Chlorophytum borivilianum*), rauvolfia (*Rauvolfia serpentina*), turmeric (*Curcuma longa*), wild turmeric (*C. aromatica*), *Curculigo orchioides*, and ginger (*Zingiber officinale*) (Mishra and Pandey 1998; Prajapati *et al.*, 2003). Only 10 out of 64 herbaceous medicinal plants tried in intercropping with two-year old poplar (*Populus deltoides*) spaced 5 m apart gave poor performance (Kumar and Gupta 1991), indicating that many medicinal plants can be grown in agroforestry systems. The trees may benefit from the inputs and management given to the intercrops. Short stature and short cycle MAPs and culinary herbs are particularly suited for short-term intercropping during the juvenile phase of trees. Wherever markets are established, MAPs are remunerative alternative intercrops to the traditionally grown annual crops (Maheswari *et al.*, 1985; Zou and Sanford 1990). The number of years MAPs can be intercropped with a given tree species depends on the size and intensity of its canopy shade, tree spacing and management, especially pruning of branches and nature of the MAPs.

In Karnataka and Kerala states, India, arecanut palm is commonly intercropped with ginger, turmeric, black pepper (*Piper nigrum*) and cardamom (Korikanthimath and Hegde, 1994). Some of these intercrops may cause small reduction in arecanut yields but the combined returns from both the components are greater than from arecanut alone. Another plantation crop intercropped with MAPs is rubber (*Hevea brasiliensis*), for example with *Dioscorea floribunda* in the state of Assam in India (Singh *et al.*, 1998) and with *Amomum villosum* in Yunnan province of China (Zhou, 1993). In Sikkim, India, large cardamom (*Amomum subulatum*) is grown under 30 different shade tree species (Patiram *et al.*, 1996). In Fujian Province, China, *Cunninghamia lanceolata* -an important timber tree - is intercropped with a variety of cereals, cash and medicinal and oil-producing crops (Chandler, 1994). Many of the medicinal herbs commonly grown in thinned forests can also be grown intercropped with trees (Zhou, 1993).

In the Caribbean islands, there has been increased interest on alternative crops that have better economic potential than traditional crops. For example, in the U.S. Virgin Islands, a number of farmers are now opting for specialty crops such as the West Indian hot peppers (*Capsicum chinense*), thyme (*Thymus vulgaris*) and chives (*Allium schoenosprasum*) instead of vegetables (Crossman *et al.*, 1999). The prospects of growing indigenous MAPs such as 'japana' (*Eupatorium triplinerve*), worrywine (*Stachytarpheta jamaicensis*), inflammation bush (*Verbersina alata*) and lemongrass (*Cymbopogon citratus*) in association with the medicinal trees noni (*Morinda citrifolia*) and moringa have been explored at the University of the Virgin Islands, St. Croix, (Palada and Williams, 2000). These local herbs are commonly used as bush teas and very popular in the Caribbean. Medicinal plants and herbs in intercropping produced similar yields to those in sole cropping at the first harvest, but they tended to be lower than in sole cropping at subsequent harvests.

2.8 GROWTH ATTRIBUTES OF RHIZOMATOUS SPICE CROPS AS INTERCROP

Rhizomatous spice crops are known for their compatibility for intercropping under various cropping system. This is primarily attributed to the shade tolerance. Bavappa (1990), based on the trials conducted in India, Philippines, Sri Lanka, Malaysia and West Samoa reported that, tuber crops, rhizomatous spice and chilli are found to be more profitable crops under different agroclimatic conditions in coconut plantation. Sujatha *et al.* (1994) recorded the maximum number of leaves (27.75) in ginger cv. PGS-10 when grown as intercrop with coconut. Also, Jayachandran *et al.* (1992) observed significant differences in the performance of turmeric grown under different shaded (25, 50 and 75 %) conditions. The turmeric grown under 50 per cent shade recorded maximum plant height (44.30 cm) followed by 25 per cent (43.30 cm) and 75 per cent shade (42.08 cm) whereas crop grown under open condition (full light) recorded the lowest plant height (32.5 cm).

Performance of rhizomatous spice crops, *viz.*, ginger and turmeric was investigated under rain fed condition as pure stands and as intercrop with five years old poplars (*Populus deltoids* L.) under Solan (Himachal Pradesh) conditions by Jaswal *et al.* (1993). Significantly higher plant height, tiller per plant, leaves per plant in ginger and leaf length and leaf breadth besides plant height in turmeric when intercropped with poplar (*Populus deltoids* L.) indicating the suitability of ginger and turmeric as intercrop in poplars based intercropping systems. Both turmeric and ginger performed better as intercrop than as pure stands.

2.8.1 Intercrop varietal difference

Varietal difference in intercrop performance has been reported from many studies. Hegde (1998) recorded maximum number of leaves per clump (13.75) in ginger variety Suprabha under arecanut based intercropping system when compared to sole crop in open area (44.30). Latha *et al.* (1995) reported that, plant height, number of leaves, leaf area index and fresh weight was higher in turmeric cultivar under Leucaena. Further, they indicated the need for standardising optimum light requirement for each cultivar for higher yield. Hegde (1998) recorded the maximum plant height in ginger variety Suprabha (40.70 cm) grown as intercrop with arecanut when compared to crop grown in open (25.70 cm). Bandyopadhyay *et al.* (2003) recorded maximum plant height (157.3 cm), leaf production (11.4), leaf length (75.3 cm) and leaf breadth (19.1 cm) in turmeric cv. Sugandhum when intercropped with young arecanut plantation followed by ACC-360 and Roma. There was no adverse effect of turmeric on growth of arecanut plant. Kumar (2005) reported higher plant height and number of tillers was produced by turmeric (69.33 cm and 6.69 cm, respectively) under intercropping compared to sole cropping (49.66 cm and 5.29, respectively). Similarly, in ginger higher plant height and number of tillers (11.33) in tamarind plantation compared to open area (26.50 cm height and 7.06 tillers). Significantly higher plant height (43.66 cm) and number of tillers per clump (6.06) were recorded by turmeric under intercropping compared to sole cropping (34.46 cm and 5.13 respectively) and in ginger higher plant height (47.10 cm) and number of tillers per clump (9.06) under tamarind based intercropping situation compared to open area (32.26 cm height and 7.46 tillers) as reported by Kumar (2005).

2.9 UNDERSTOREY LIGHT AND PLANT HEIGHT GROWTH

Solar radiation is the primary source of energy for plant growth and development. The efficiency of crop growth depends on the ability to absorb and utilize the PAR for various metabolic activities and its efficiency in portioning of assimilates into the sink effectively. The above condition is influenced by the surroundings in which the plant grows, besides the genetic makeup. The growth, yield and quality of many crops are influenced by shade at various stages of growth and development. Differential response of crops to varying light intensities has been studied for various crops including rhizomatous and tuberous crops. Plant height has been reported as a character responsive to shading. Many workers have noticed a decidedly positive influence of shade on plant height. Increase in height of shade grown plants was reported by Moss and Stinson (1961) in corn. Under low light condition the height of the rice plants was increased by 15 % (Venkateshwarlu *et al.*, 1977). Ramanujam *et al.* (1984) reported that plant height continued to increase in all the cultivars of cassava grown under shade. Similar results were reported by Maheshwarappa *et al.* (2000) in arrow root. Minami *et al.* (1981) found that shaded tomato plants were taller than control. However, an inverse trend in intercrop height with an inverse shade level also has been reported by many. For instance, Palis and Bustrillos (1976) in Sorghum observed reduction in plant height with shade similar observation was made by Tarila *et al.* (1977) in cowpea and George (1982) in red gram and grain cowpea. Cooper (1966) noticed in tomato that the effect of shade on plant height was positive, negative or neutral depending on the time of the year and age of the plant. Shade had significant influence on the height of groundnut as reported by George (1982); in vegetable cowpea by Krishnankutty (1983) and capsicum by Yinghua and Jianzhen (1988) and Sreelathakumary (2000). The general effect of shading on plants was studied by Ross (1976) and reported that plants under shaded conditions exhibited increased growth of main axis. Allen (1975) observed that soybean grown under 70 per cent shade grew much taller than those in light. Crockston *et al.* (1975) reported an increase in plant height in beans with increase in shade intensities. Aclan and Quisumbing (1976) reported that ginger plants grown under full sunlight were found to be shorter compared to shaded plants. According to Kulasgaram and Kathirvetpillai (1980), height of tea plant was greater under 60 per cent sunlight and was least under 10 per cent as compared to 30 and 100 per cent. In *Mentha piperita*, plant height under 44 per cent day light was significantly greater than under 100 or 14 per cent day light (Virzo and Alfani, 1980). Bai and Nair (1982) observed positive influence of shading on plant height in ginger, coleus and sweet potato. According to Mullakoya (1982) maximum height was recorded under 50 per cent shade and the minimum under full sunlight in guinea grass var. Mackuenii. Jung *et al.* (1994) observed that main stem length of pepper increased significantly under shaded conditions.

Effect of shading on black pepper yields has been observed in general. In a study it was observed that the length of primary and secondary branches increased with decrease in light intensity from 100 to 50 per cent (Devdas, 1997). Senanayake and Kirthisinghe (1983) observed longer shoot length in black pepper under 50 per cent light compared to 75 and 25 per cent light. Verghese (1989) reported that in ginger plant height increased with increase in shade intensity from zero to 75 per cent at 60 DAP only, after which plants grown at 25 per cent shade had the highest plant height, whereas in turmeric, with increase in shade, plant height increased up to medium shade of 50 per cent and then decreased. Increase in plant height with increasing shade intensities in ginger were also reported by Jayachandran *et al.* (1991), Ancy (1992), and Sreekala (1999). Pushpa Kumari and Sasidharan (1992) noticed increased vine length with increase in shade intensity in *Dioscorea alata* and *Disocorea esculenta*. Though no significant difference was observed between shade levels with respect to plant height in turmeric, taller plants were observed at 75 per cent shade in the initial stages and 50 per cent shade in the later stages (Sheela, 1992). Ginger plants grown as intercrop in arecanut plantation were significantly taller than those under open conditions when measured 200 days after planting and had significantly lower number of functional leaves and tillers per clump (Hedge *et al.*, 2000). Greater shoot height was noticed in seven soybean cultivars sown under shade in a coconut plantation (Babu and Nagarajan, 1993). In a field experiment to study response of blackgram to shade by Lakshmamma and Rao (1996) using 0, 33 and 66 per cent shade, it was revealed that shading increased plant height.

2.10 EFFECT OF SHADE ON NUMBER OF LEAVES

Seedlings of *Quercus floribunda* at sunny microsites were superior in terms of number of leaves (Negi *et al.*, 1996). The plants of *Centella asiatica* produced a greater number of leaves under high light than under low light (Wankher and Tripathi, 1990). Leaf production in plants has been found to correspond to the light levels. Many reports suggest an increase in leaf production corresponding to reduction in light level. According to Nair (1964), the production as well as the retention of leaves will be more under the shade than in the open, in peppermint. In ginger, Aclan and Quisumbing (1976) reported reduced number of leaves per plant when grown under full sunlight. According to Senanayake and Kirthisunghe (1983) maximum number of leaves in black pepper under 50 per cent light compared to 75 and 25 per cent shade. Clove, seedlings kept under shade produced more number of leaves than those exposed to the sun according to Venkatakkraman and Govindappa (1987). Use of plastic tunnels (protected cultivation) to protect tomato plants from cool weather and frost damage increased transpiration rate, plant height, leaf area and number of leaves (Abou-Hadid *et al.*, 1988). In *Enicistemma littorale,* Sharma and Peshin (1994) reported that vegetative growth was enhanced in the shade compared with plants grown in full sun. In arrowroot, number of leaves was higher under intercrop compared to open crop (Maheshwarappa *et al.* 2000). Contrary to these reports, a reduction of leaf production has also been noticed with provision of shade. In ginger, Babu (1993) observed maximum leaf production under 25 per cent shade and found it significantly superior to other shade levels at 120 and 180 DAP.

However, better leaf production has been observed for ginger at full sunlight. For example, leaf production in ginger under open conditions was found to be significantly superior compared to other shade levels (Laura *et al.,* 1986).

2.11 EFFECT OF SHADE ON DRY MATTER PRODUCTION

Blackman and Wilson (1951) reported that the ability of plants to tolerate shade depends on the efficiency of total DMP. Montith (1969) noticed that the maximum amount of DMP by a crop was strongly correlated with the amount of light intercepted by the foliage. In a study on the effect of shading on Cassava, Okoli and Wilson (1986) observed that stem and leaf dry weight increased with decrease in degree of shade. Maheshwarappa *et al.* (2000) reported a higher dry matter in arrowroot grown under partial shade in coconut gardens compared to open conditions. Bai (1981) reported that in ginger and turmeric maximum dry weight were obtained from 25 and 50 % shade respectively. Similar results were reported by Babu (1993) in ginger. Decline in DMP with increase in shade intensities was also reported by Bai (1981) in sweet potato, Coleus and colocasia; Verghese (1989) in turmeric and Patterson (1982) in showy crotalaria.

2.12 EFFECT OF SHADE ON YIELD AND YIELD ATTRIBUTES

Prameela (1990) noticed that colocasia gave maximum tuber yield under 25 per cent shade followed by a reduction in yield with further increase in shade intensity. According to Nayar and Sadanandan (1991) the cassava var. Shri visakham was found to be best under shaded conditions recording superior yield attributes. In ginger Aclan and Queisumbing (1976) found that yield under full sunlight was just as high as those obtained under 25 and 50 per cent light attenuation. Bai (1981) observed that in ginger and turmeric maximum yield were obtained under 25 per cent and 50 per cent shade levels respectively. Ravisankar and Muthuswami (1988) observed that fresh ginger rhizome yield increased when ginger was grown as an intercrop in arecanut plantations. The screening of ginger cultivars for shade tolerance at Vellanikkara revealed that most of the ginger cultivars were shade loving and gave more yield and dry matter production under 25 per cent shade (Verghese 1989). Suma *et al.* (1989) assessed the performance of 16 cultivars of banana as intercrops with coconut in non irrigated, partially shaded conditions in which Booditha Bontha Batheesa and Kachikela gave the highest yields (8925 and 8890 kg ha^{-1} respectively). Contrary to these reports, negative trends in yields were reported by many results. Reduction in grain yield due to increasing shade was curvelinearly related to radiation such that smaller reduction had little effect on yield at any developmental stage in wheat (Fisher, 1975). Increase in shade intensity decreased the number of tillers and spikes, dry weight, fruiting efficiency, grain weight per plant and yield of grain and straw in wheat (Moursi *et al.*, 1976).

Togari (1950) reported that cambial activity and tuberisation were suppressed in sweet potato tubers under shade. A considerable delay in tuber initiation due to shade was reported in tapioca (Ramanujam *et al.*, 1984). A decreasing trend in yield with decreasing light was noticed in colocasia. The effects of shading and mulching on the yield of potato was studied by Asandhi and Suryadi (1982) and reported that shading has no beneficial effect on potato growth and reduced dry matter production and tuber yield. Mathai and Sasthry (1988) reported that pruning the support trees of pepper produced more number of laterals and spikes consequent to increasing light. Samad (1953) reported no significant response to fertilizer application in ginger grown in Malabar region though there was no increase in yield with 60 kg N ha^{-1}.

2.13 EFFECT OF SHADE ON PRODUCT QUALITY

Light regimes received by plant determine the productivity and quality of its produce. Positive effects of shading on oil content in plants have been reported. Shade has been reported to influence oil content in crop plants. Ohasi (1962) noticed changes in the content of essential oils with differences in temperature at different stages of development in Japanese mint. Plants synthesize organic compounds during their metabolic processes when they grow. The nature and amount of these chemical substances vary according to the agroclimatic conditions and growth stage of the plant (Chopra *et al.*, 1958). Gupta (1964) carried out studies in this respect and reported that the shade dry herb contains 4 per cent (w/w) of oil against 3 per cent in the sun dry hay in Japanese mint. Ginger cultivar, Rio de Janerio grown as an intercrop in a six year old arecanut plantation recorded highest volatile oil and non-volatile ether extract (NVEE) contents followed by those grown in two year old plantations compared to those grown in the open as a pure crop (Ravisankar and Muthuswamy, 1988). Joseph and Jayachandran (1993) recorded the highest rhizome volatile oil content (2.19 % on dry weight basis) in ginger under 25 per cent shade and higher non-volatile ether extract (NVEE) content under 25 or 50 per cent shade than under open. Babu (1993) found that in ginger, volatile oil content showed an increasing trend with increasing levels of shade. Lowest contents of volatile oil were in 25 per cent shade, which was on par with open. Shading has also been reported to have an adverse effect with respect to oil contents in plants. Graded shade levels of 20, 47, 63, 80 and 93 per cent were found to have little effect on quality parameters of soybean *viz.* oil and protein content of seeds except at 93 per cent shade where the protein content was the highest and oil content was the lowest (Wahua and Miller, 1978). Ginger showed a steady decrease in the oleoresin content up to 50 per cent level of shade (Verghese, 1989). Ancy Joseph (1992) recorded the highest volatile oil content under 25 per cent shade followed by that under 50 shade.

2.14 EFFECT OF SHADE ON CHLOROPHYLL CONTENT

Geetha (2004) reported that chlorophyll a, b and total contents decreased with increase in shade levels. Chlorophyll content has been found to either increase or decrease in response to shading in most plants. Most scientists have quoted positive effect of shading on chlorophyll content in plants. Gardener *et al.* (1952) and Bjorkman and Holmgren (1963) observed that the concentration of chlorophyll per unit area weight of leaf increased with decreasing light intensities until the intensity was so low that it hazarded the survival of plants. An increase in chlorophyll content with increase in shade levels was reported by Okali and Owasu (1975) in cocoa. Shade plants usually have higher chlorophyll content than the sun plants (Copper and Qualls, 1967; Bjorkman, 1968). An increase in chlorophyll content with increase in shade levels were reported by Frydrych (1970) in bean. Similar trend was noticed in crops like black gram, groundnut, red gram (George, 1982) and groundnut (Singh, 1994). Misra *et al.* (1968) reported increased chlorophyll content in leaves of shaded bougainvillaea plants. Increase in chlorophyll content with increasing shade levels was reported in cotton (Bhatt and Ramanujan, 1975), pepper (Vijayakumar *et al.*, 1985). In the case of fruit crops also studies revealed that there was an increase in chlorophyll content with increase in shade intensities as reported by Radha (1979) in pineapple. Ravisankar and Muthuswamy (1988) observed higher content of total chlorophyll and its components in ginger in two-year and six-year old arecanut plantations compared to those grown in pure stand in the open. Sreekala (1999) reported that in ginger there is a general increasing trend in chlorophyll content with increasing shade levels. Summary report of ICAR Ad-hoc scheme on shade studies of coconut based intercropping situation conducted from 1988 to 1991 at Vellanikkara indicated an increase in chlorophyll of turmeric due to shading (KAU, 1992). Total chlorophyll and its components increased steadily with increased levels of shade in turmeric at 135 DAP (Sheela, 1992). Contrary to these reports, some scientists have noticed a negative effect of shading on chlorophyll content in some crops.

2.15 AVAILABILITY OF PHOTOSYNTHETICALLY ACTIVE RADIATION

Understorey productivity is generally a function of the photosynthetically active radiation (PAR) which varies considerably among the tree species (Hazra and Tripathy, 1986; Yirdaw and Luukkanen, 2004). The amount of solar radiation received in the sub-canopy is however, variable and mostly dependent on stand density, canopy structure, row orientation, leaf area index, site, latitude, season, spectral quality of incoming light (Jackson *et al.*, 1989; Baldochhi and Collineau, 1994). In addition to the reduction in the quantity of PAR beneath a forest canopy, changes in spectral quality, with a shift of red to far-red wavelength (Whitmore, 1998) is frequent, presumably because the canopy absorbs wavelengths more in the 400-700 nm band width than in the near infra-red (700-

1000 nm) range (Pons, 1992). Compact, candle-flame shaped tree crowns and sparse crowns with low leaf area facilitate light infiltration and hence favour understorey production (Mathew *et al.*, 1992). However, inter specific variation in canopy structure and consequent changes in PAR have been observed. For instance, Kumar *et al.*,(2001) in a silvopastoral experiment involving four MPTs and grass species, observed strong inter specific differences in understorey photosynthetic photon flux density (PPFD) with *Acacia auriculiforrmis* intercepting much of the incoming solar radiation while *Ailanthus triphysa* intercepted the least. The characteristic crown architecture and tree foliage attributes explained the differences in PPFD levels. Kumar (2004) recorded higher PAR interception by turmeric (25225 Lux and 38787 Lux) under intercropping and sole cropping situations, respectively. Interception of PAR by crop canopy was lower in intercropping situation in all seasonal crops throughout the period of observation compared to open situation.

Performance of ginger under agroforestry systems was studied in Bangladesh by Amin *et al.*(2010). The ginger was grown under three agroforestry systems *viz.* under *Psidium guava* trees with 70 % shade, below *Albizia odoratissima* trees providing 60 % shade and underneath Mango trees having 50 % shade and open field. They reported that ginger-mango intercropping having 50 % shade recorded maximum rhizome yield of ginger (12.42 ton ha^{-1}) compared to ginger-guava system (5.07 ton ha^{-1}). The effect of canopy management on the intercrop production was monitored by Thakur and Singh (2002) in *Morus alba* based agrisilvicultural system at Solan, India. The growth performance of the crops *Phaseolus mugo* and *Pisum sativum*) invariably were highest in the treeless control followed by plants under least shade (75 % crown removal). However, the positive crop response to reduced light availability has also been reported earlier which include higher cocoa yield (415 g wet beans $tree^{-1}$) in combination with papaya (Tan *et al.*, 1991), increase banana from intercropped immature rubber plantations from Srilanka (Rodrigo *et al.*, 2001). Also, Sankar and Mathuswamy (1986) reported higher ginger yield when intercropped in a 6-year-old areca nut plantation at light intensity of 15.3 kilo lux. In brief, understorey productivity is dependent on the shade tolerance of the crop species and shade intensity (Rao *et al.*, 1998). Jackson *et al.*, (1989) studied the light requirements of trees and crops in agroforestry and identifies four main crop-tree light responses which include, type A: yields as a linear function of light intensity, type B: yield increases linearly with light intensity up to a certain level and then decreases, type C: economic yield is only produced at high levels of irradiance and the crop or tree cannot effectively use low intensity light and in type D: exposure to high light levels is harmful and some degree of shade is needed. They further stressed the need for devising management strategies like shading pattern for crop-tree productivity optimization under these categories.

2.15.1 Physiology of PAR

The growth and development of plants are influenced by solar radiation as light energy is the main input of the photosynthetic process in green plants (Noggle and Fritz, 1979). In comparison with un shaded grape vines at flowering and venation, the leaves of shade grown vines (6 % and 30 % sunlight) showed significantly lower values of saturated rate of net photosynthesis (Pn_{sat}) and dark respiration (Rd), and lower light compensation (PAR_c) and light saturation points (PAR_{sat}) whereas the apparent quantum yield of CO_2 assimilation was significantly higher. The growth habit of shade grown vines also changed to a more open canopy, which increased the PAR trapping efficiency (Cartechini and Palliotti, 1995). In Norway Spruce (*Picea abies*), at the saturating photosynthetically active flux density (PPFD), the maximum rate of CO uptake of exposed shoots (E-shoots) was 1.7 times that of the shaded shoots (S-shoots). The apparent quantum yields of E-shoots was 0.9 times that of the S-shoots. A lower ability to use excess energy at high PPFD in photosynthesis was observed in the S-layer. The CO_2 and PPFD saturated rate of CO_2 uptake of the E-shoots was 112 times and carboxylation efficiency (t) 1.6 times that of the S-shoot. In addition to the irradiation conditions in shade needles was due to carboxylation. This limitation of photosynthesis in shade needles was due to carboxylation. This limitation of pohotosynthesis was accompanied by lower stomatal conductance

(Sprtova and Marek, 1999). An experiment conducted in Pune, Maharashtra, India to study the reflected photosynthetically active radiation (RPAR) under sorghum-based intercropping system revealed that generally, RPARs values were the highest during the initial stages of crop growth due to less leaf area index (LAI). Generally, RPAR increased with the increase in crop age up to 42 days after sowing (DAS) due to the increase in leaf area and LAI. RPAR values increased significantly in sole sorghum and pigeon pea than in groundnut 112 DAS. This was due to the dense canopy and small size of groundnut leaves (Singh *et al.* 2002).

2.16 UPTAKE OF NUTRIENTS

Kraybill (1922) recorded higher content of moisture and nitrogen in shade leaves of Apple. In cocoa leaf nitrogen and phosphorus contents were found to be influenced by shading. Shading increased leaf N whereas it decrease leaf P (Maliphant, 1959). The K content of some grass species when grown under 85 to 90 per cent shade was nearly double than those in full day light (Myhr and Saebo, 1969). Gopinathan (1981) observed higher percentage of N, P and K in cocoa seedling grown under direct seedlings than under shaded conditions. However between the plants exposed to different shade intensities, the nutrient content showed no significant differences. According to Bai (1981) contents of N, P and K in all plant components of coleus, ginger and turmeric increased with increasing shade intensities. In turmeric uptake of all the nutrients were found to decrease with shade except potassium, where uptake was maximum at 50 % shade. In ginger uptake of N and K increased from 0 to 20 per cent shade and then showed a progressive decrease. However the uptake of P decreased with increase in shade intensities. In galangal the yield, yield attributes and uptake of N, P and K showed a significant increase with increasing shade intensities (Geetha, 2004).

2.17 SOIL CARBON SEQUESTRATION

The term "soil C sequestration" implies net removal of atmospheric CO_2 by plants and its storage as soil organic matter. Processes of Soil organic carbon sequestration include humification, aggregation, deep incorporation of C in the subsoil, and calcification. Soil plays a major role in global C sequestration (Lal, 2002) and has a higher capacity to store C compared to vegetation and atmosphere (Bellamy *et al.*, 2005). The soil C pool is 2300 Pg, which is 3 times the size of the atmospheric (770 Pg) and 3.8 times the size of biotic pool (610 Pg; Lal, 2004). The soil carbon sequestration in an agro ecosystem depends on large number of location and system-specific factors such as climate, soil type, vegetation, and management practices (Saha *et al.*, 2010).

Depth wise distribution of soil carbon varies in different land use system. Recent research has reported higher soil C stock under deeper soil profiles in tree based agroforestry systems compared to treeless agricultural or pasture systems under similar ecological settings (Haile *et al.*, 2008; Nair *et al.*, 2009). Roots are the sources of soil organic carbon in deeper soil depth, where they are better protected. The deeper root development accumulates C at lower depths and the soil at lower depths is better protected from the disturbances leading to longer residence time.

Tree management practices like thinning, pruning and litter fall removal also influence the extent of soil carbon storage in an agroforestry system. Study conducted in 6.5 year old *Acacia mangium* with four planting density with or without 50 % pruning level shows significant difference in soil organic carbon production. The soil carbon stocks range from 24 to 35 Mg $ha^{-1}$and soil carbon stock under denser stand is higher (2500 trees ha^{-1}) than the stand with wider spacing. The importance of organic matter input from tree prunings and litterfall, to help maintain or increase the soil organic carbon pool, has been demonstrated by several studies in tropical and temperate agroforestry systems. Soil organic carbon study conducted in a 21-year-old *Grevillea robusta* plantation found to be 77.45 Mg C ha^{-1} within 1 m depth (Samritika, 2013). Similar study conducted in a pepper based production system involving six MPTs revealed that soil organic carbon content decreases with depth and the highest value recorded for *Acacia auriculiformis* 71.39 Mg ha^{-1}, *Ailanthus triphysa* recorded a value of 65.56 Mg ha^{-1} and lowest recorded for *Grevillea robusta* 61.26 Mg ha^{-1} (Aneesh, 2014).

Materials And Methods

MATERIALS AND METHODS

3.1 CLIMATE AND SOIL

The experimental site is located at Vellanikkara, Thrissur, Kerala. Vellanikkara experiences a tropical warm humid climate with a mean annual rainfall of 3062 mm, most of which is received during the South-West monsoon, June to September. The mean maximum temperature ranged from 29.10° to 35.40° C in July - March. The mean minimum temperature varied from 22.19° to 24.83° C in December - May. The soil of the experimental site was a Typic Plinthustult-Vellanikkara series midland laterite (Thomas *et al.*, 1998). The weather parameters of the study area during 2014 were collected from Agrometeorological Observatory in the Kerala Agricultural University (KAU) campus and is given in Appendix I.

3.2 LOCATION

The study sites included two land management systems at Vellanikkara, Thrissur *viz.* coconut plantation and homegarden. All the study sites were identified at similar agroclimatic and edaphic locations. The mature coconut plantation and control plot were located in the Kerala Agricultural University (KAU) main campus, Vellanikkara, Thrissur and the homegarden selected was located at Pandiparambu, Thrissur adjoining the KAU. The 20-year-old coconut (var.Lakshaganga) was planted at standard spacing of 7.5 m x 7.5 m. The plantation has been managed under recommend practices (KAU, 2011). The average coconut yield is 62 nuts/year. Soil is predominantly lateritic with moderate fertility. The selected homegarden was a typical multi-tier system owned by a progressive farmer Mr. K.A. Kuttan at Pandiparambu, Thrissur, which is close by the KAU main campus. This constitutes a typical medium sized traditional homegarden with multi-storied structural characteristics and extends over an area of 2.5 ha. The dominant arboreal components in the homegarden include coconut, arecanut, nutmeg, gliricidia, cinnamon, clove, citrus, sapota, guava along with perennial climbers such as black pepper, betel *etc.* The understorey is less intensive and by and large underutilized.

3.3 INTERCROPPING OF HERBACEOUS PLANTS

The understorey crops selected for the study include ginger (*Zingiber officinale* R. var. Aswathi), turmeric (*Curcuma longa* var. Sona) and galangal (*Kaempferia galanga* var. Thodupuzha local). Randomized Block Design with three replications was followed for the intercropping experiment. The intercrops were grown in beds of size 5 m × 1 m × 0.3 m in the selected land management systems based on the available planting spacing under land use systems. The beds will be established in the coconut garden in such a way that two parallel rows beds of size 5 m^2 will be occupying in between the planted rows of coconut palms taking care to maintain a crop free zone at 2 m radius from the coconut palms. Staggered beds were taken in homegarden because of lack of continuous space. In addition an absolute treeless control was established where the crops were raised in open contiguous plots. The intercrops were planted at 25 cm × 25 cm spacing following recommended package of practices (KAU, 2011).

3.3.1 Lay out and preparation of land

The experimental plots were cleared during April-May and the weeds, stubbles and roots etc. were burnt *in situ.* Land was prepared by ploughing with a tractor thoroughly to bring the soil to fine tilt. Beds of size 5 m × 1 m × 0.3 m were prepared with an inter-space of 50 cm in between beds. The beds were established in such a way that two parallel row beds, each of size 5m × 1m were established in between the planted rows of coconut taking care to maintain a convenient crop free zone of 2 m^2.

3.3.2 Planting material and Pre-treatment

Rhizomes were used for planting. Seed rhizomes were carefully handled to avoid damage to buds. The selected rhizomes were soaked for 30 minutes in a solution of mancozeb to give terminal concentration of 0.3 per cent. The treated rhizomes were dried in shade by spreading on the floor.

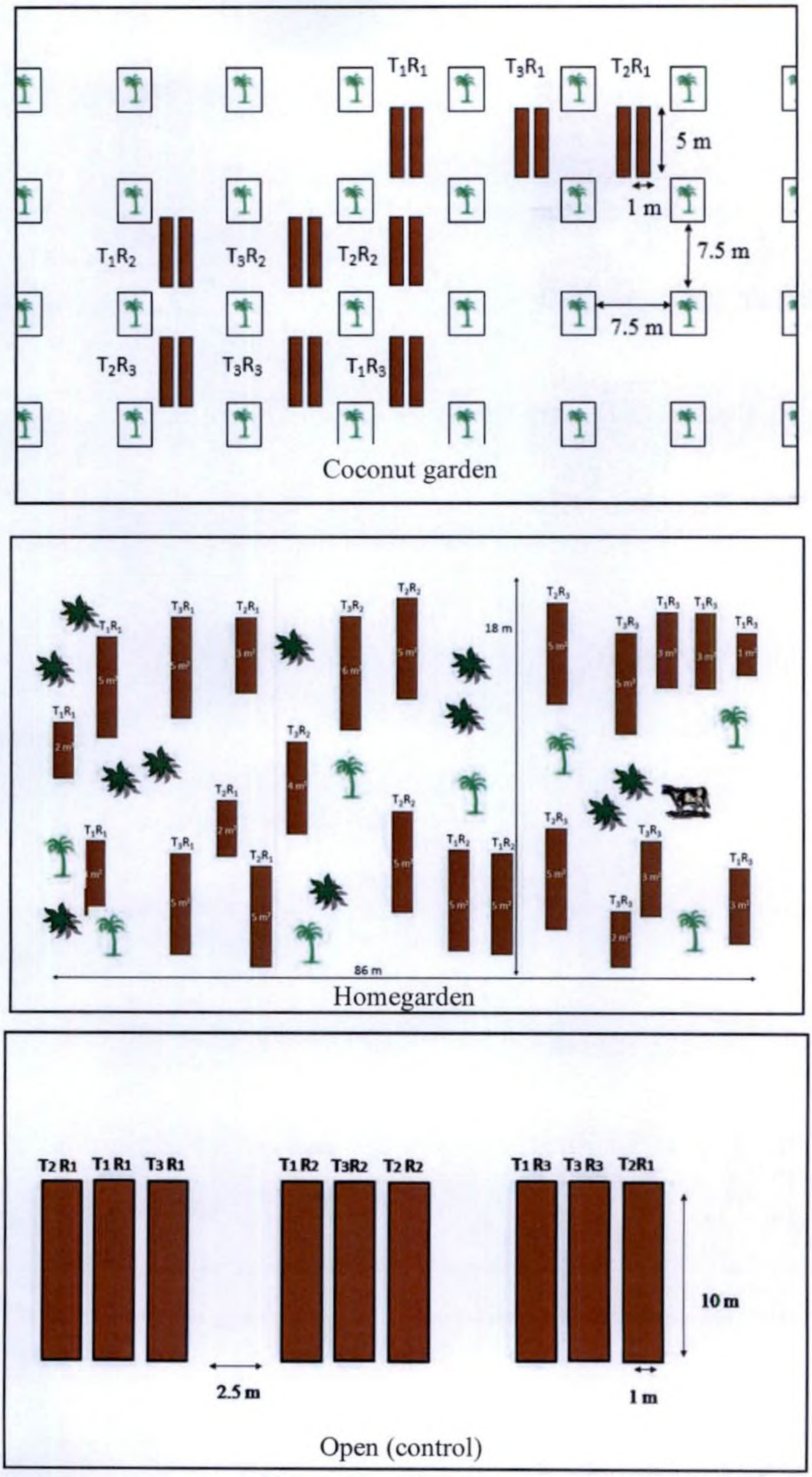


Plate 1. Experimental layout of various landuse systems located at Vellanikkara, Thrissur

Plate 2. Locations of the various landuse systems selected for the experiment

3.3.3 Season and method of planting

The intercrops were planted during the month of June. Rhizome bits of 15 g weight were planted in small pits at a spacing of 25 cm x 25 cm at a depth of 4-5 cm with at least one viable healthy bud facing upwards.

3.3.4 Manuring

Manures and fertilizers were applied at the following rates: FYM @ 30 t ha^{-1} and $N:P_2O_5:K_2O$ @ 75:50:50: kg/ha/year. Full dose of P_2O_5 and 50 per cent of K_2O was applied as basal dose. Half the quantity of N was applied 60 days after planting. The remaining quantity of N and K_2O was applied 120 days after planting.

3.3.5 Mulching and weeding

Immediately after planting, the beds were mulched thickly with green leaves preferably *Macaranga peltata* @ 15 t ha^{-1}. Mulching with green leaves was repeated twice first 44-60 days and second 90-120 days after planting. Weeds were removed by hand weeding before each mulching and repeated according to weed growth.

3.3.6 Plant Protection

The incidence of shoot borer and rhizome rot were observed in ginger in the early stages of growth. Shoot borer was controlled by spraying Quinalphos (Ekalux) 2 ml per liter and the rhizome rot was controlled by drenching the beds with Mancozeb (Indophil M- 45) @3 g per litre. To prevent the attack of Wild Boar and Porcupine, all the plots were tightly fenced.

3.4 BIOMETRIC OBSERVATIONS

The growth performance of the intercrops was monitored by taking biometric observations at regular intervals of 90 and 150 days after planting (DAP). Eight plants in randomly placed quadrats (50 cm × 50 cm) in each bed was sampled for growth observation. The ginger, turmeric and galangal grown in all the experimental sites were destructively sampled at 90, 150 and 230 days after planting (DAP). All plants in the quadrat were then uprooted carefully. After cleaning, the aboveground and belowground portions were separated and their fresh weight recorded. The samples were then oven dried at 70° C until constant weight was achieved. The dry matter production and final rhizome yield (230 DAP) for ginger, turmeric and galangal was determined.

3.4.1 Growth and yield attributes of intercrop

3.4.1.1 Plant height

The height of the plants (ginger and turmeric) was measured at 90, 150 and 230 days after planting from the base of the main pseudo stem to the tip of the top most leaf and was expressed in cm.

3.4.1.2 Pseudostem length

Pseudostem height (ginger and turmeric) was determined by measuring length from the base of the plant to the point where first leaves emerged.

3.4.1.3 Leaf spread

In case of galangal leaf spread was recorded by measuring the distance between the farthest leaves in opposite directions.

3.4.1.4 Number of tillers

Number of tillers was determined by counting the number of aerial shoots arising around a single plant.

3.4.1.5 Number of leaves per tiller

Number of leaves per tiller was determined by counting the number of leaves of all the tillers.

3.4.1.6 Root length

The plants were uprooted at 90^{th}, 150^{th} and 230^{th} days after planting and maximum length of roots was measured and expressed in cm.

3.4.1.7 Aboveground biomass

The shoot portions corresponding to each plant in the quadrat were separated and fresh weight recorded. The shoot samples were oven dried at 70^0 C for constant weights. The aboveground yield was recorded at 90, 150 and 230 DAP and expressed as g plant^{-1}.

3.4.1.8 Belowground yield

The belowground yield was assessed for the selected medicinal crops at 90th, 150th and 230th DAP. The fresh rhizomes were washed, all roots from the rhizome were removed and rhizome weight of observational plants from each treatment was determined. The weight was expressed in g plant^{-1}.

3.4.1.9 Final rhizome yield

The understorey ginger, turmeric and galangal (230 DAP) were harvested (left out crop after sampling) from each experimental plot. The rhizomes were separated from the plant portions and soil clods were detached from the rhizome. After cleaning, the rhizomes were weighed in kg per plot and converted to Mg ha^{-1} from each experimental site.

3.4.1.10 Dry matter production (DMP)

Leaves, petioles, pseudostem, rhizome and roots of the uprooted plants were separated and dried to a constant weight at 70°C in a hot air oven until constant weight and expressed in Mg ha^{-1}.

3.5 PHYTOCHEMICAL ANALYSES

In order to estimate the nutrient accumulation in the aboveground and belowground biomass, triplicate samples were analyzed for N, P and K. Three sub samples were drawn from the composite samples of aboveground and belowground components for phytochemical analysis. Nitrogen and phosphorus were analyzed using continuous flow analyzer (SKALAR) method and potassium by flame photometry (Jackson, 1958).

3.5.1 Estimation of nitrogen

Total nitrogen content in plant samples was determined by continuous flow analyzer (SKALAR) method. The automated procedure for the determination of ammonia / total nitrogen is based on the modified Berthelot

Ginger *(Zingiber officinale)*

Turmeric *(Curcuma longa)*

Galangal (*Kaempferia galanga)*

Plate 3. Medicinal plants selected for the intercropping trial at Vellanikkara, Thrissur

reaction: after dialysis against a buffer solution of pH 5.2, the ammonia in the sample is chlorinated to monochloramine which react with salicylate to 5 aminosalicylate. After oxidation and oxidative coupling a green coloured complex is formed. The absorption of the formed complex is measured at 660 nm. The various reagents used include potassium sodium tartrate solution, sodium salicylate solution, sodium nitroprusside solution, sodium dichloroisocyanurate solution, rinsing liquid sampler, distilled water + Brij 35.

3.5.1.2 Sulphuric acid and Se powder mixture

One litre of conc. H_2SO_4 was carefully and slowly poured into a two litre beaker. Se (3.5 g) powder was then dissolved into the H_2SO_4 by heating the beaker for 4 to 5 hours at 300^0C. The black colour of the solution slowly changed to deep blue colour and then light yellow. The solution was then cooled.

3.5.1.3 Digestion mixture

Salicylic acid (10.8 g) was weighed and added to 150 ml of H_2SO_4 and Se mixture already prepared.

Procedure

Plant sample of weight 0.2 g composed of leaves, stem wood, branches and twigs was weighed in the digestion tube. 2.5 ml of the digestion mixture was poured into the digestion tube. The tube was then swirled well and allowed to stand for 2 hours or overnight. It was then inserted into the digestion block and heated at 100^0C for 2 hours. After cooling the tubes were removed from the block and 1 ml of 30 % H_2O_2 was added. After the reaction ceased, they were again placed in the digestion block and heated at 330^0C for 2 hours. When the digest turned colourless, the digestion was completed. The digest was made up to 75 ml in a standard flask. The nitrogen content of the plant sample was then analyzed using SKALAR.

3.5.2 Estimation of Phosphorous

One gram of the plant sample was weighed and digested with diacid mixture (HNO_3 and $HClO_4$ in 9:4 ratio) in a digestion chamber until the solution became colorless. After that the digest was made up to 50 ml. About 5ml of the liquid was used to determine the phosphorous content using SKALAR method using reagents. The various reagents used include sulphuric acid solution, distilled water + FFD6, ammonium heptamolybdate solution, ascorbic acid solution, distilled water + FFD6 (required for predilution) and rinsing liquid solution.

The automated procedure for the determination of phosphate/total phosphate is based on the following reaction; after dialysis against distilled water, ammonium heptamolybdate and potassium antimony (III) oxide tartarate react in an acidic medium with diluted solutions of phosphate to form an antimony-phospho-molybdate complex. This complex is reduced to an intensely blue-colored complex by L (+) ascorbic acid. This complex is measured at 880 nm.

3.5.3 Estimation of potassium

The potassium content was estimated in a known liquid of diacid extract using a flame photometer (Jackson, 1958).

3.6 SOIL ANALYSIS

3.6.1 Physico-chemical properties of soil under various land use systems

The soil in the respective experimental site were sampled for physico-chemical properties prior to the experiment and at regular intervals (150 DAP and 230 DAP). The air dried soil samples were ground to pass through a 2 mm sieve. For pH estimation 1: 2.5 ratio of soil: water suspension was prepared. The pH was measured using pH meter (Jackson, 1958). The total nitrogen content of soil was determined by Kjeldahl digestion and distillation method (Jackson, 1973). The available phosphorus was extracted by Bray No. 1 and estimated by reduced molybdate blue color method (Watanabe and Olsen, 1965). The exchangeable potassium content of soil was determined by neutral normal ammonium acetate extract using flame photometer (Jackson, 1958).

3.6.2. Total nitrogen

Total nitrogen under each treatment at different soil depths was determined by Kjeldahl digestion and distillation method (Jackson, 1973).

3.6.3. Available phosphorus

Available phosphorus in the soil samples were extracted using Bray No.1 reagent and estimated colorimetrically by reduced molybdate Ascorbic acid blue color method (Watanabe and Olsen, 1965) using spectrophotometer.

3.6.4. Available potassium

Available potassium in the soil samples were extracted using neutral normal ammonium acetate and its content in the extract was estimated by flame photometry (Jackson, 1958).

3.6.5 Soil C- sequestration

Soil samples for bulk density measurement were done using specially designed steel cylinder (Jackson, 1958). Bulk density was estimated by taking out a core of undistributed soil by using steel cylinder. The core was taken out without pressing the cylinder too hard on soil so that the natural bulk density of soil is disturbed. The soil samples were oven dried and weight was determined. The volume of soil was calculated by measuring the volume of cylinder (πr^2h). The bulk density was calculated by dividing the oven dry weight of soil samples (g) by volume of soil. Soil samples collected at different soil depth were air dried and passed through 2 mm sieve and stored in polyethylene containers. For estimating the soil C stock under experimental sites, triplicate soil samples were collected from five soil depths. The soil were stored in plastic zip lock bags, sealed for transport and re-opened within Organic carbon of the soil was estimated by wet digestion method. Soil mass for each soil depth were computed from the corresponding bulk density and soil C-sequestration were calculated for each soil depth by multiplying soil mass with soil organic C-concentration (%). Also, representative triplicate soil samples were collected from contiguous treeless plots as control.

3.7 OLEORESIN CONTENT

The method adopted for oleoresin estimation was soxhlet extraction method (Meadows *et al.*, 2005). Five gram of finely powdered rhizome sample was covered in a filter paper and packed with Whatman No.1 filter paper. This was distilled in a soxhlet apparatus with 250 ml acetone as a solvent for six hours. The extract was then transferred to a 250 ml flask and acetone evaporated. The difference in weight of flask recorded for estimating oleoresin content.

$$\text{Percent of oleoresin} = \frac{W_2 - W_1 \times 100}{S}$$

Where,

W_1 = weight of empty flask (g)

W_2 = weight of flask with extractives (g)

S = weight of sample (g)

3.8 TOTAL CHLOROPHYLL CONTENT

The total chlorophyll content of the leaf samples was estimated using the method described by Arnon (1949). Leaf sample weighing 250 mg is macerated with 10 ml of 80 per cent acetone using a pestle and mortar and the extract is centrifuged at 3000 rpm for 10 minutes. The supernatant solution was transferred into a 25 ml volumetric flask and made up to 25 ml using acetone. Then the color intensity of the green pigment was read at 645 nm and 663 nm for chlorophyll a and chlorophyll b content respectively.

Calculations were made using the formula below:

Total Chlorophyll = [(8.022 x Absorbance at 663) + (20.2 x Absorbance at 645)] x V/1000W mg g^{-1}

Where,

V - Total volume of the chlorophyll solution (25 ml)

W - Weight of the tissue extracts (0.25 g)

The chlorophyll content of the leaf sample is expressed as mg g^{-1} of fresh leaf

Plate 4. Line quantum sensor established in the homegarden

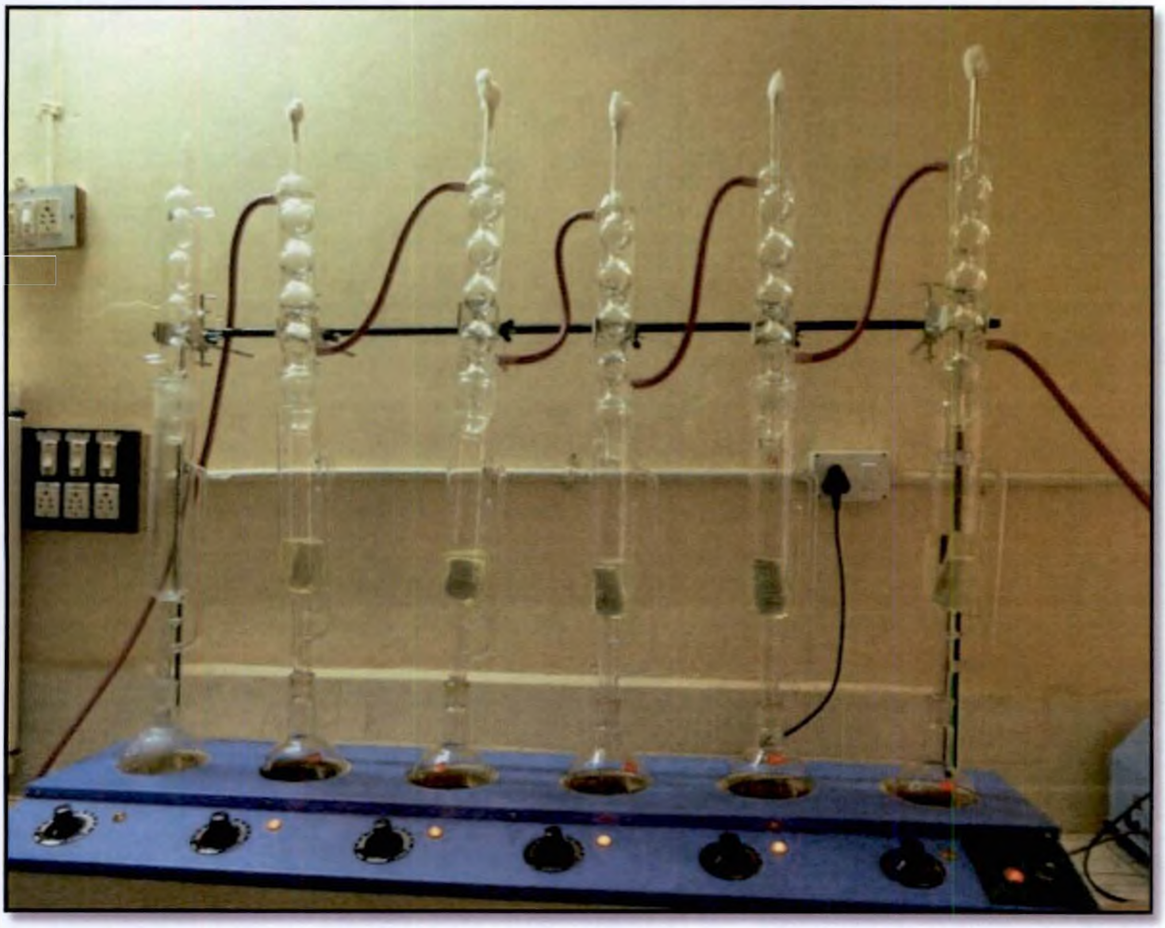


Plate 5. Soxhlet apparatus for oleoresin estimation

Plate 6. Ginger grown in coconut garden

Plate 7. Turmeric grown in homegarden

Plate 8. Mature medicinal plants grown in open (control)

Plate 9. Medicinal plants arranged in the lab for taking biometric observations

Plate 10. Bulk density estimation using steel cylinder

3.9 UNDERSTOREY PHOTOSYNTHETICALLY ACTIVE RADIATION (PAR)

Diurnal PAR measurement was carried out using Line Quantum Indicator (LQI 2404, K131). A battery powered data logger integrated the mean PAR at hourly intervals from 8 a.m. to 5 p.m. within each plot. PAR above the canopy of each plot was simultaneously recorded by the instrument from contiguous open area. PAR was then converted to canopy transmittance (in per cent) which is the ratio of light below the canopy to light incidence on the top of the canopy.

3.10 STAND LEAF AREA INDEX (LAI)

Leaf area index is the ratio of total upper leaf surface of vegetation divided by the surface area of the land on which the vegetation grows. This is used to predict understorey crop growth, photosynthetic primary production and evapo-transpiration. The LAI of each plot was estimated using Plant Canopy Analyzer (LAI 2000, LI-COR Inc., and Lincoln, Nebraska, USA). The instrument can measure the LAI of plant canopies indirectly from measurement of radiation above and below the canopy based on relationship between leaf area and canopy transmittance (Stenberg *et al.*, 1994). LAI was measured at periodic intervals for coconut and homegarden. Care was taken to ensure that the unit was facing the same direction both outside and inside the stand. A view restrictor of 90° prevented direct sunlight from reaching the sensor and occluded the measuring person from the view.

3.11 STATISTICAL ANALYSIS OF DATA

Biometric, biochemical, phyto-chemical and soil physico-chemical parameters were analysed following one-way ANOVA using SPSS version 20. Regression models were developed linking rhizome biomass and understorey PAR for all the three intercrops using various allometric models (SPSS version 20). Models were tested for ANOVA and those with higher r^2 values were selected for comparisons.

Results

RESULTS

The one year long field study involved the evaluation of the performance of selected medicinal herbs *viz.* ginger, turmeric and galangal under two dominant land management systems in Kerala *viz.* mature coconut palm and homegarden. Detailed investigations on the growth characteristics of the intercrop such as plant height, root length, tiller production, number of leaves, aboveground and belowground biomass production *etc.* were performed. Salient results of the investigation are presented hereunder.

4.1 PLANT HEIGHT

Variation in plant height of ginger and turmeric when intercropped under various selected cropping systems are presented in Table 1

4.1.1 Ginger

At 90 days after planting (DAP), ginger plant height was significantly higher in homegarden (69.04 cm) followed by coconut (50.63 cm) and treeless open (43.17 cm) which were on par. The increase in ginger plant height was 60 and 17 % respectively for homegarden and coconut compared to treeless open. However, at 150 days after planting (DAP) ginger plant height was on par for coconut (73.71 cm) and homegarden (71.54 cm). The ginger height growth was consistently lower in the treeless control during both sampling periods. Considerable variation has been observed in plant height for ginger during the two sampling periods among land use systems. For instance about 45.39 % increase in plant height was observed under coconut and in treeless open it was 37.43 % while the increase was notably marginal in the homegarden at 150 DAP compared with 90 DAP.

4.1.2 Turmeric

The plant growth trends were quite variable in the case of turmeric. Across the different land use systems highest plant height for turmeric during both the sampling periods was observed under coconut garden (98.13 cm at 90 DAP and 112.04 cm at 150 DAP). At 150 DAP the turmeric height under coconut was on par with treeless open. During both sampling periods homegarden recorded lowest height for turmeric (70 cm at 90 DAP and 75.38 cm at 150 DAP). In brief, the height increment for turmeric under coconut was about 29 % at 90 DAP while it reduced to 8.69 % at 150 DAP in comparison with tree less control plot. Across the sampling periods, control plot resulted in 35.4 % increase in turmeric plant height from 90 to 150 days whereas it was considerably lower for coconut (14.18 %) and homegarden (7.69 %).

Table 1. Plant height of ginger and turmeric in various land use systems at Vellanikkara, Kerala

Landuse type	Plant height (cm)			
	Ginger		Turmeric	
	90 DAP	150 DAP	90 DAP	150 DAP
Coconut	50.63^b (3.36)	73.71^a (1.62)	98.13^a (1.47)	112.04^a (10.99)
Homegarden	69.04^a (3.93)	71.54^a (0.99)	70^b (2.31)	75.38^b (5.11)
Treeless open	43.17^b (1.19)	59.33^b (1.58)	76.13^b (8.54)	103.08^a (6.43)
F	18.929	29.595	8.156	8.820
p	0.003	0.001	0.019	0.016

Values with same superscript do not differ significantly
Values in the parenthesis represent standard error of the mean
DAP – Days After Planting

4.2 PSEUDOSTEM LENGTH

Variation in pseudostem length of ginger and turmeric during the two sampling periods are presented in Table 2.

4.2.1 Ginger

Variable trends were observed in pseudostem length for ginger during both sampling periods across the landuse systems. For instance, at 90 DAP ginger pseudostem length was highest in homegarden (11.83 cm) and lowest in coconut (8.63 cm) while changes were marginal for treeless open. This amounts to 15.87 % increase in homegarden and 15.48 % decrease in coconut compared to control. Despite the weak statistical significance in ginger pseudostem length among the various woody systems at 150 DAP, the pseudostem length were better under tree crops as compared to treeless open. However, across the sampling periods, there was almost 100 % increase in ginger pseudostem length in coconut followed by tree less open (47.7 %) and the lowest by homegarden (27.9 %).

4.2.2 Turmeric

The trends in pseudostem height were variable for turmeric as compared to ginger. Turmeric showed distinctly higher pseudostem length in coconut (17.88 cm) as compared to homegarden (12.46 cm) during initial sampling period (90 DAP) while height in treeless open was 16.33 cm. This indicate that pseudostem growth was about 9.5 % higher in coconut and 23 % lower in homegarden as compared to the growth in treeless open. At final sampling, coconut recorded higher pseudostem length though this change was not statistically significant. In general over two periods of sampling (90 to 150 DAP) treeless open showed 60.26 % increment in pseudostem height whereas coconut and homegarden exhibited 51.73 and 35.79 % increase respectively.

4.3 LEAF SPREAD

4.3.1 Galangal

Owing to the variable growth habit for the galangal, leaf spread was measured for growth comparison among the landuse system. Leaf spread of galangal in various land uses is presented in Table 3. Appreciable change in leaf spread was not visible for galangal among different land management systems during the various sampling periods. Initially leaf spread was observed maximum in homegarden (28.51 cm) although during final sampling galangal under coconut showed a modest increase (30.15 cm). In essence from 90 to 150 DAP coconut grown galangal showed higher increment of leaf spread (28.19 %) followed by treeless open (5.32 %) and lowest by homegarden (2.67 %).

Table 2. Pseudostem length of ginger and turmeric when intercropped under various landuse systems at Vellanikkara, Kerala

Landuse type	Pseudostem length (cm)			
	Ginger		Turmeric	
	90 DAP	150 DAP	90 DAP	150 DAP
Coconut	8.63[b] (0.87)	17.33 (1.04)	17.88[a] (1.46)	27.13 (5.11)
Homegarden	11.83[a] (0.29)	15.13 (0.82)	12.46[b] (0.71)	16.92 (0.97)
Treeless open	10.21[ab] (0.15)	15.08 (0.40)	16.33[ab] (1.45)	26.17 (2.67)
F	9.002	2.610	5.932	2.792
p	0.016	0.153	0.044	0.139

Values with same superscript do not differ significantly
Values in the parenthesis represent standard error of the mean
DAP – Days After Planting

Table 3. Leaf spread of galangal under various landuse systems at Vellanikkara, Kerala

Landuse type	Galangal Leaf spread (cm)	
	90 DAP	150 DAP
Coconut	23.52 (2.09)	30.15 (1.40)
Homegarden	28.51 (0.55)	29.27 (0.65)
Treeless open	25.36 (0.26)	26.71 (4.14)
F	4.025	1.820
p	0.078	0.241

Values with same superscript do not differ significantly
Values in the parenthesis represent standard error of the mean
DAP – Days After Planting

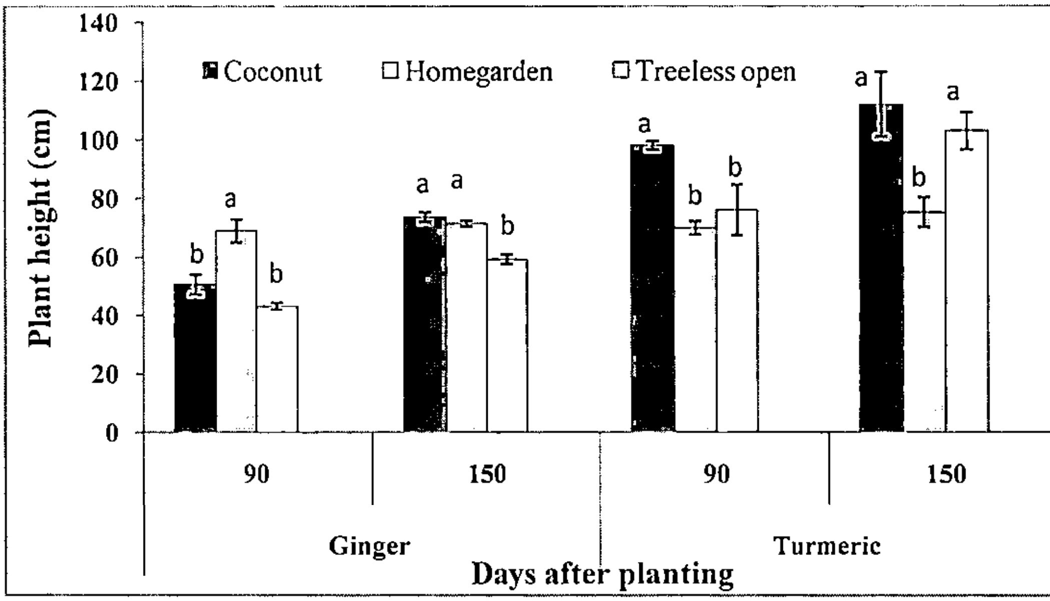


Figure 1. Plant height of ginger and turmeric in various land use systems at Vellanikkara, Kerala

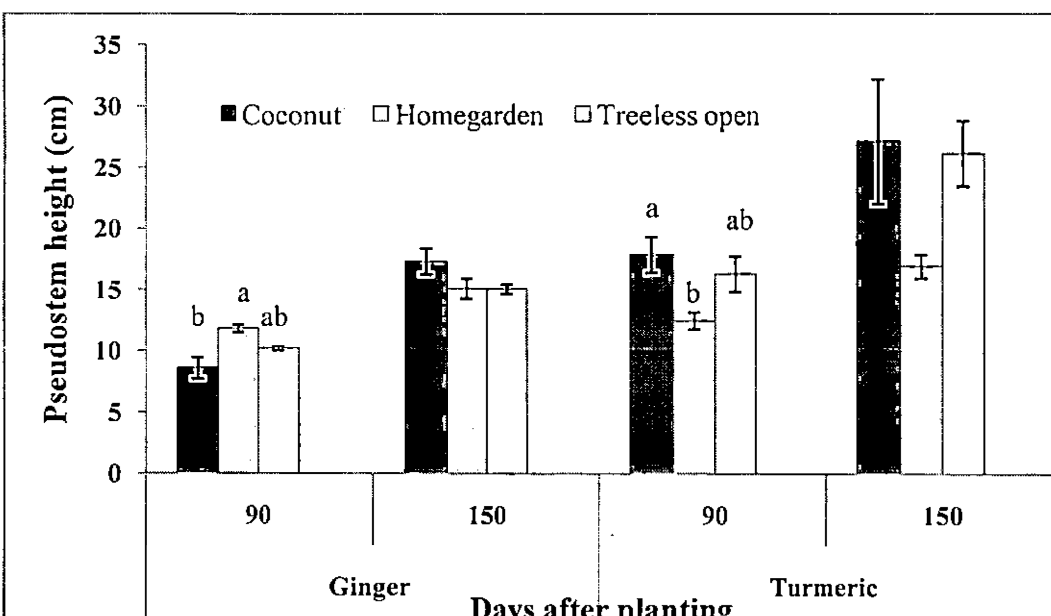


Figure 2. Pseudostem length of ginger and turmeric in various land use systems at Vellanikkara, Kerala

4.4 ROOT LENGTH

Biometric observations of the intercrops were taken after destructive sampling of plants. The data on root length of ginger, turmeric and galangal during different growth stages as influenced by different landuse systems are given in the Table 4.

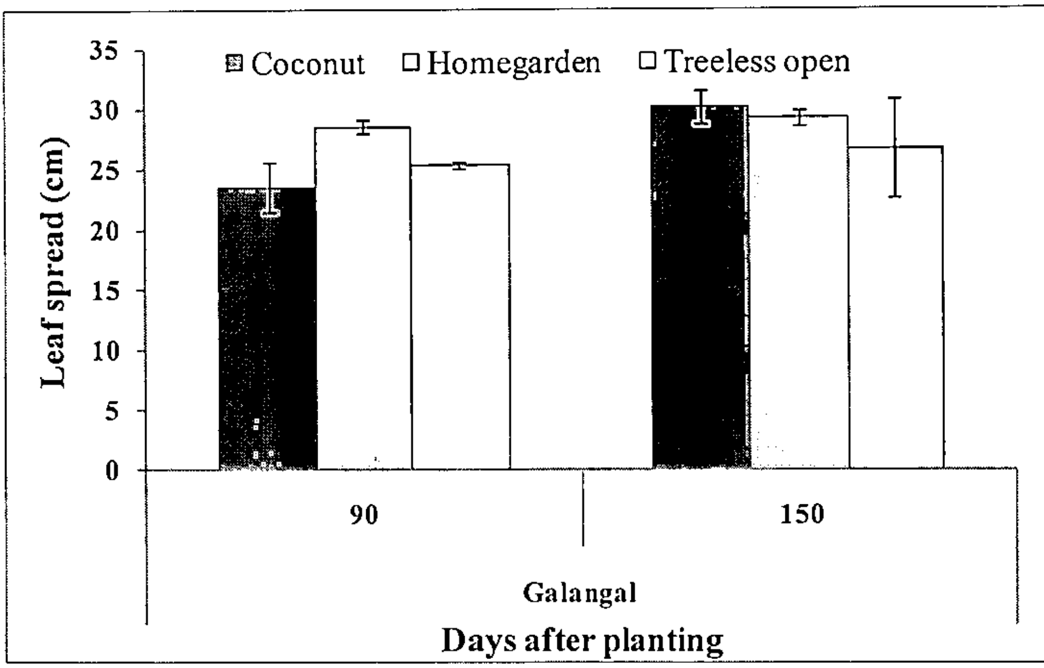


Figure 3. Leaf spread of galangal at various landuse systems at Vellanikkara, Kerala

4.4.1 Ginger

The belowground growth trends for ginger were quite variable as compared to the aboveground growth. Treeless open represented highest root length (21.33 cm at 90 DAP and 21.67 cm at 150 DAP) while homegarden showed lowest (14.29 cm at 90 DAP and 14.75 cm at 150 DAP) for ginger irrespective of time of observation. Ginger root length under coconut was higher compared to homegarden during both observational periods, though the differences were not significant. At 90 DAP, homegarden exhibited 33.01 % reduction in ginger root length while under coconut it registered 4.88 % reduction as compared to treeless open. Likewise at 150 DAP, ginger grown under coconut and homegarden displayed 4.8 and 31.93 per cent reduction in root length in contrast to control plot. Interestingly, the increment in ginger root growth across sampling periods was marginal.

4.4.2 Turmeric

Variation in root length was noticed for turmeric at 90 DAP with higher root growth associated with treeless open condition closely followed by coconut which were on par while lowest value was observed for homegarden grown turmeric (8.96 cm). The reduction in turmeric root length in homegarden was 8.05 % as compared to treeless open. At 150 DAP, turmeric root length showed marginal variation among cropping systems. It was better in control plot (18.33 cm) followed by coconut (18.29 cm) and homegarden (13.42 cm). Overall, homegarden showed root length increment nearly 50 % during two month sampling interval. Across growth period between 90 and 150 DAP an increase of 4.99 and 3.74 % was noticed in coconut and control plot respectively.

4.4.3 Galangal

Significant variation in root length has been observed for galangal during both the sampling periods among selected land systems. At 90 DAP, root length was higher in treeless open (18.75 cm) followed by coconut (14 cm) and least by homegarden (12.88 cm). In both homegarden and coconut root length for galangal was lower than treeless open by 31.31 and 25.33 % respectively. At 150 DAP galangal root (20.67 cm) growth under coconut improved considerably higher than homegarden (12.93 cm) which was on par with treeless open (19.38 cm). Galangal root growth during the two sampling periods suggest only marginal increase except for coconut which registered about 47 % increase during two month sampling interval (90 to 150 DAP).

Table 4. Root length of various medicinal herbs grown under different landuse systems at Vellanikkara, Kerala

Landuse type	Root length (cm)					
	Ginger		Turmeric		Galangal	
	90 DAP	150 DAP	90 DAP	150 DAP	90 DAP	150 DAP
Coconut	20.29^{ab} (2.30)	20.63^{ab} (1.31)	17.42^{a} (0.36)	18.29 (1.27)	14.00^{b} (2.01)	20.67^{a} (1.84)
Homegarden	14.29^{b} (1.96)	14.75^{b} (2.3)	8.96^{b} (1.01)	13.42 (0.40)	12.88^{b} (0.33)	12.93^{b} (1.63)
Treeless open	21.33^{a} (1.49)	21.67^{a} (1.34)	17.67^{a} (0.67)	18.33 (0.40)	18.75^{a} (0.95)	19.38^{ab} (2.95)
F	13.827	5.714	45.956	2.033	5.756	7.023
p	0.025	0.039	0.000	0.212	0.040	0.018

Values with same superscript do not differ significantly
Values in the parenthesis represent standard error of the mean
DAP – Days After Planting

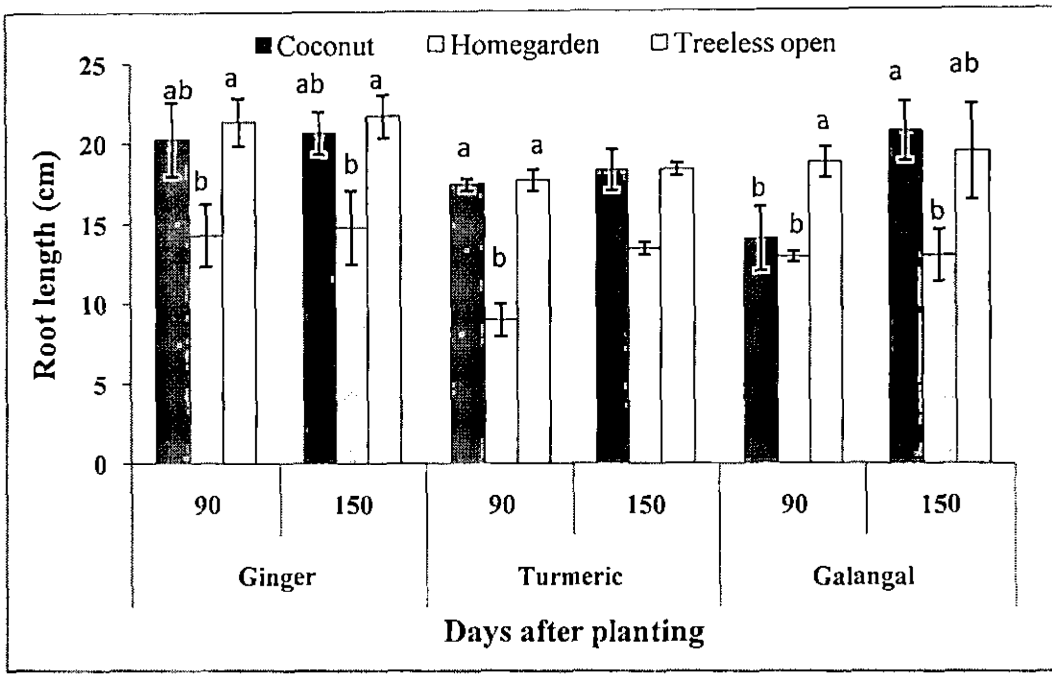


Figure 4. Root length of various medicinal herbs grown under different landuse systems at Vellanikkara, Kerala

4.5 NUMBER OF TILLERS

Observations on tiller production in ginger, turmeric and galangal during different growth stages as influenced by different landuse systems are given in the Table 5.

Variation in tiller production during the initial sampling was found to be non-significant across the different land uses. However, apparently higher number of tillers was associated with treeless open (6.5) followed by homegarden (4.96) and coconut (4.79). Nevertheless, number of tillers were significantly higher for treeless open at 150 DAP (14) followed by coconut (9.88). Contrary to the plant height growth trends, homegarden recorded lowest tiller production (7.04) at 150 DAP. Despite the wide variability in tiller production among the land use system, the number of tillers for ginger almost doubled at 150 DAP compared to 90 DAP for all the land use systems.

In general tiller production for turmeric was considerably lower compared to ginger for all landuse regimes. Also the changes were marginal across the land use systems. Even though changes were not appreciable amongst cropping systems, it appears that tiller growth was marginally higher for the treeless open

Tiller production for galangal during the two sampling periods did not yield any predictable trend. It was however, better under homegarden (4.5) compared to coconut and open which were on par at 90 DAP. The trends were however variable at 150 DAP with higher tiller production from the open. At 150 DAP the number of tillers in homegarden and coconut was lower by 26.56 and 16.99 % compared to treeless open. An appreciable observation during the period is the substantial increase in the tiller production during the successive sampling periods (90 and 150 DAP). For instance, treeless open showed an increase in number of tillers to the tune of 203.49 % followed by coconut (151.94 %) and homegarden (72.22 %).

4.6 NUMBER OF LEAVES

The data on number of leaves in ginger, turmeric and galangal during different growth stages as influenced by different landuse systems are given in the Table 6.

4.6.1 Ginger

Ginger exhibited no significant variation in number of leaves at 90 DAP. However, homegarden grown ginger performed better in terms of leaf number (16.08) followed by coconut (15.46) and treeless open (13.08). Trends were however variable at the final observation with highest number of leaves for ginger from coconut (19.17) and least in treeless open (14.58) whereas homegarden showed statistically similar value with coconut and treeless open. Moreover, ginger in homegarden at final sampling showed a stabilization in leaf production as observed by the marginal increase compared to the previous sampling (90 DAP)

Table 5. Number of tillers of various medicinal herbs grown under different landuse systems at Vellanikkara, Kerala

Landuse type	Number of tillers					
	Ginger		Turmeric		Galangal	
	90 DAP	150 DAP	90 DAP	150 DAP	90 DAP	150 DAP
Coconut	4.79 (0.77)	9.88[b] (0.46)	1.46 (0.18)	1.38 (0.26)	2.58[b] (0.04)	6.50 (0.19)
Homegarden	4.96 (0.44)	7.04[b] (1.35)	1.83 (0.15)	1.42 (0.22)	4.50[a] (0.54)	5.75 (1.51)
Treeless open	6.50 (0.38)	14.00[a] (0.50)	2.04 (0.85)	2.33 (0.44)	2.58[b] (0.11)	7.83 (2.61)
F	2.860	16.052	0.333	2.881	11.821	0.365
p	0.134	0.004	0.729	0.133	0.008	0.709

Values with same superscript do not differ significantly
Values in the parenthesis represent standard error of the mean
DAP – Days After Planting

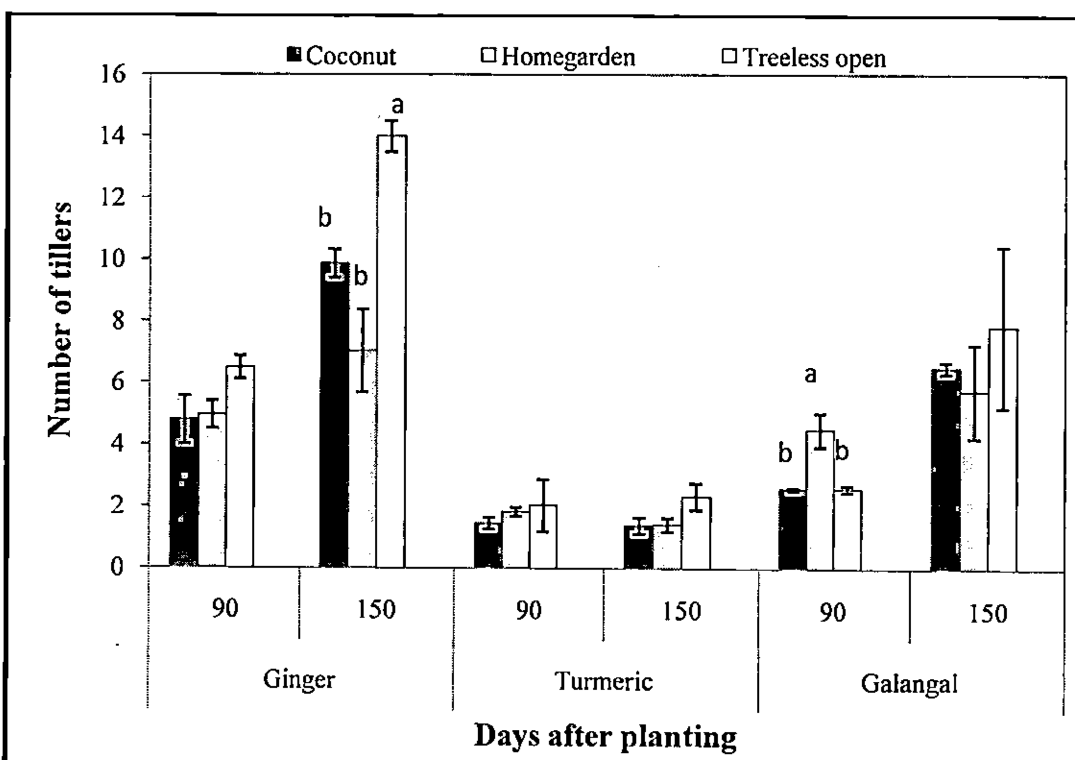


Figure 5. Number of tillers of various medicinal herbs grown under different landuse systems at Vellanikkara, Kerala

4.6.2 Turmeric

Number of leaves per tiller for turmeric was almost uniform among all the three landuse regimes during the initial sampling period. Turmeric in general tends to retain or reduce leaf production at advanced stage of sampling. However, leaf production was better under tree less open (8.29) during the second sampling period (150 DAP) followed by coconut (6.63) and homegarden (5.63).

4.6.3 Galangal

Analysis of variance revealed significant difference in number of leaves for galangal under different land use regimes during both the sampling periods. At 90 DAP, leaf production under coconut and homegarden were on par. Galangal leaf number was distinctly higher (4.5) in the open condition at 90 DAP, while the trends were not predictable during the second sampling period (150 DAP). It appears that leaf production in galangal get stabilised much easier as compared to ginger and turmeric. At 150 DAP, treeless open is on par with coconut and homegarden in terms of leaf production.

Table 6. Number of leaves per tiller per plant of various medicinal herbs under different landuse systems at Vellanikkara, Kerala

Landuse type	Number of leaves					
	Ginger		Turmeric		Galangal	
	90 DAP	150 DAP	90 DAP	150 DAP	90 DAP	150 DAP
Coconut	15.46 (0.72)	19.17[a] (0.58)	7.67 (0.21)	6.63[b] (0.14)	2.79[b] (0.41)	2.29[a] (0.42)
Homegarden	16.08 (1.41)	16.21[ab] (1.35)	7.17 (0.34)	5.63[c] (0.14)	2.58[b] (0.15)	2.00[b] (0.00)
Treeless open	13.08 (0.61)	14.58[b] (0.30)	7.00 (0.38)	8.29[a] (0.37)	4.54[a] (0.29)	2.25[ab] (0.13)
F	2.600	7.150	1.202	30.447	12.572	5.300
p	0.154	0.026	0.364	0.001	0.007	0.049

Values with same superscript do not differ significantly
Values in the parenthesis represent standard error of the mean
DAP – Days After Planting

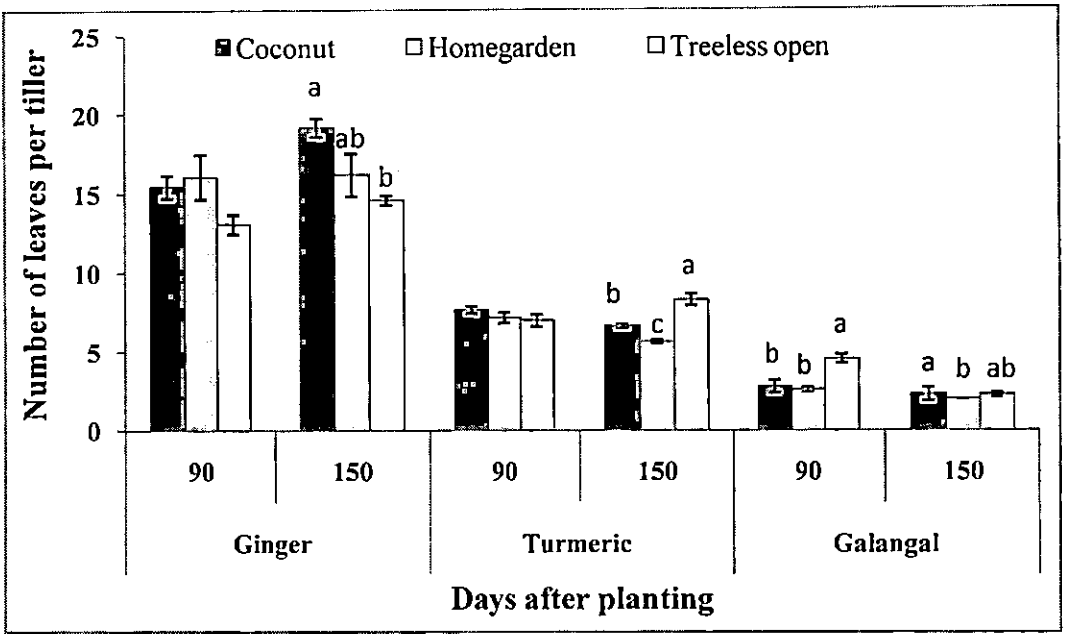


Figure 6. Number of leaves per tiller of various medicinal herbs grown under different landuse systems at Vellanikkara, Kerala

4.7 FRESH ABOVEGROUND BIOMASS

Biometric observation on the intercrop performance was done at two periodic intervals both for aboveground and belowground plant parts. The data on fresh aboveground biomass per plant for ginger, turmeric and galangal during different growth stages as influenced by different landuse systems are given in the Table 7.

4.7.1 Ginger

Unlike the variable plant growth characteristics, the aboveground biomass showed distinct trends for ginger. The aboveground biomass was consistently higher for ginger for both the sampling periods. Especially visible trends were discernible during the second sampling. For instance, the mean per plant aboveground fresh weight was distinctly higher for treeless open (163.93g) followed by coconut and the least by homegarden. Observations indicate considerable reduction in aboveground biomass in both the intercropping scenarios. For *e.g.* the higher reduction in biomass was observed for homegarden (75.85 %) compared to open grown ginger while the reduction was about 37 % under coconut. Yet another observation is the many fold increase in ginger biomass both in coconut (219.13 %) and open (264.27 %) during the sampling intervals.

4.7.2 Turmeric

Similar trends were discernible in aboveground biomass production for turmeric across the intercropping regimes with consistent results during both the sampling periods. Invariably the biomass production was higher in the treeless open condition, 109.52 and 146.88 g per plant during 90 and 150 DAP respectively. Among the landuse system, the turmeric showed consistently better performance in the mature coconut plantation while reduction was observed under homegarden.

4.7.3 Galangal

Coconut and homegarden grown galangal biomass were on par at 90 DAP. The highest value was observed in treeless open with 62.28 g. During the final observation at 150 DAP, there was no significant variation in fresh aboveground biomass though, treeless open grown galangal recorded highest value. The reduction in fresh aboveground biomass during 150 DAP has been observed compared to 90 DAP probably due to the difference in moisture content.

Table 7. Fresh aboveground biomass per plant of various medicinal herbs under different landuse systems at Vellanikkara, Kerala

Landuse type	Fresh aboveground biomass (g plant^{-1})					
	Ginger		Turmeric		Galangal	
	90 DAP	150 DAP	90 DAP	150 DAP	90 DAP	150 DAP
Coconut	32.20 (3.70)	102.76^{b} (12.55)	107.29^{a} (8.11)	88.02^{b} (13.07)	35.95^{b} (7.77)	28.77 (5.67)
Homegarden	32.54 (7.81)	39.56^{c} (9.86)	41.86^{b} (0.34)	19.44^{c} (4.07)	40.94^{b} (2.14)	18.26 (10.39)
Treeless open	45.01 (4.53)	163.93^{a} (11.56)	109.52^{a} (10.44)	146.88^{a} (8.00)	62.28^{a} (6.24)	53.70 (32.04)
F	1.304	33.389	25.346	48.537	5.652	2.758
P	0.339	0.001	0.001	0.000	0.042	0.141

Values with same superscript do not differ significantly
Values in the parenthesis represent standard error of the mean
DAP – Days After Planting

4.8 ABOVEGROUND DRY BIOMASS

The data on dry aboveground biomass per plant in ginger, turmeric and galangal during different growth stages as influenced by different landuse s are given in the Table 8.

4.8.1 Ginger

During the first sampling period (90 DAP), variation in aboveground dry biomass in ginger was not significant (p=0.154) under various landuse systems, However treeless open showed highest value (8.62 g) and least by coconut (4.45 g). At 150 DAP, the dry aboveground biomass production were in tune with the fresh weight trends with highest production attached to treeless open grown ginger (21.25 g) followed by coconut (12.47 g) and lowest by homegarden (6.31 g). Conspicuous reduction in above ground dry biomass observed was observed for homegarden (70.31 %) as compared to treeless open while the reduction was moderate under coconut (41.31 %). As against the fresh biomass reduction, the increase in dry aboveground biomass production in the landuse systems were marginal across the sampling intervals, implying the probable variation in plant moisture content as the major reason for such observation.

4.8.2 Turmeric

Turmeric also displayed similar trends in dry aboveground biomass yield. For *e.g.* treeless open grown turmeric showed higher dry aboveground biomass (15.91 g) followed by coconut (14.15 g) which however were on par at 90 DAP. The lowest dry aboveground biomass was observed in homegarden with value of 7.79 g per plant. At 150 DAP treeless open grown plants had significant higher weight compared to coconut and homegarden. Overall homegarden registered lower dry aboveground biomass throughout the study period.

4.8.2 Galangal

At 90 DAP, highest value (5.23 g) was attributed to treeless open grown galangal followed by homegarden and coconut with on par values. During the final observation there was no statistical difference among various land uses in galangal dry aboveground weight, despite the marginal difference with maximum in treeless open and minimum in the coconut plot.

Table 8. Aboveground dry biomass per plant of various medicinal herbs under different landuse systems at Vellanikkara, Kerala

Landuse type	Aboveground dry biomass (g plant^{-1})					
	Ginger		Turmeric		Galangal	
	90 DAP	150 DAP	90 DAP	150 DAP	90 DAP	150 DAP
Coconut	4.45 (0.58)	12.47^{b} (1.63)	14.15^{a} (0.94)	13.15^{b} (2.28)	2.63^{b} (0.55)	2.13 (0.38)
Homegarden	4.92 (1.01)	6.31^{c} (1.37)	7.79^{b} (0.32)	6.14^{c} (0.58)	3.07^{b} (0.07)	2.81 (0.73)
Treeless open	8.62 (2.16)	21.25^{a} (1.19)	15.91^{a} (1.93)	21.57^{a} (1.55)	5.23^{a} (0.65)	3.95 (2.54)
F	2.597	28.460	20.350	22.486	7.926	0.929
p	0.154	0.001	0.002	0.002	0.021	0.445

Values with same superscript do not differ significantly
Values in the parenthesis represent standard error of the mean
DAP – Days After Planting

4.9 FRESH BELOWGROUND BIOMASS

Belowground biomass production assures greater importance in intercrop growth studies as they contribute to the economical yield. The data on fresh belowground biomass per plant in ginger, turmeric and galangal during different growth stages as influenced by different landuse systems are given in the Table 9.

4.9.1 Ginger

Available growth information suggests that there exist a consistent trend for belowground fresh biomass yield in differently raised ginger plants. At 90 DAP, highest belowground fresh biomass was observed for control plot (104.81 g) followed by coconut and homegarden which however were on par. More consistent results were observed during the subsequent sampling periods. For instance, the open grown ginger yielded consistently higher fresh belowground biomass during both the successive sampling periods with a production of 198 and 216 g plant^{-1} at 150 and 230 DAP respectively. As observed earlier ginger fresh biomass yield was significantly higher under coconut during all the sampling dates

(90, 150 and 230 DAP) as compared to modest production under homegarden. Yield reduction basis was 48.21 %, 20.02 % and 23.42 % for coconut while same was 52.65 %, 69.11 % and 63.68 % for homegarden compared to yield in the open during the successive sampling periods (90, 150 and 230 DAP).

4.9.2 Turmeric

Belowground fresh biomass production for turmeric was by and large comparable with ginger yields (Table 9). Consistent increase in belowground biomass has been observed during all the sampling dates. Probably the increase in biomass production is more during the first sampling interval (*i.e.*, between 90 and 150 DAP) while the increase was modest during second sampling period for all the three growth regimes. As observed earlier, turmeric belowground fresh biomass yields were highest in the open condition with values ranging from 96 to 238 g plant^{-1} between first and third sampling. Among the intercropped plots again, turmeric belowground yield under coconut was far higher than that from homegarden.

4.9.3 Galangal

Generally, galangal showed better performance in fresh belowground biomass in treeless open during all the sampling periods. At 90 DAP, coconut and homegarden were on par while the highest fresh belowground biomass was discernible in treeless open. At 230 DAP, treeless open galangal showed highest fresh belowground biomass (116.15 g) followed by coconut and homegarden with 68.15 and 65.67 grams respectively. Despite the fluctuation in fresh belowground biomass production across the sampling periods, homegarden showed fairly higher yields at final sampling date which was on par with the galangal fresh yield under coconut.

4.10 BELOWGROUND DRY BIOMASS

The data on dry belowground biomass per plant in ginger, turmeric and galangal during different growth stages as influenced by different landuses are given in the Table 10.

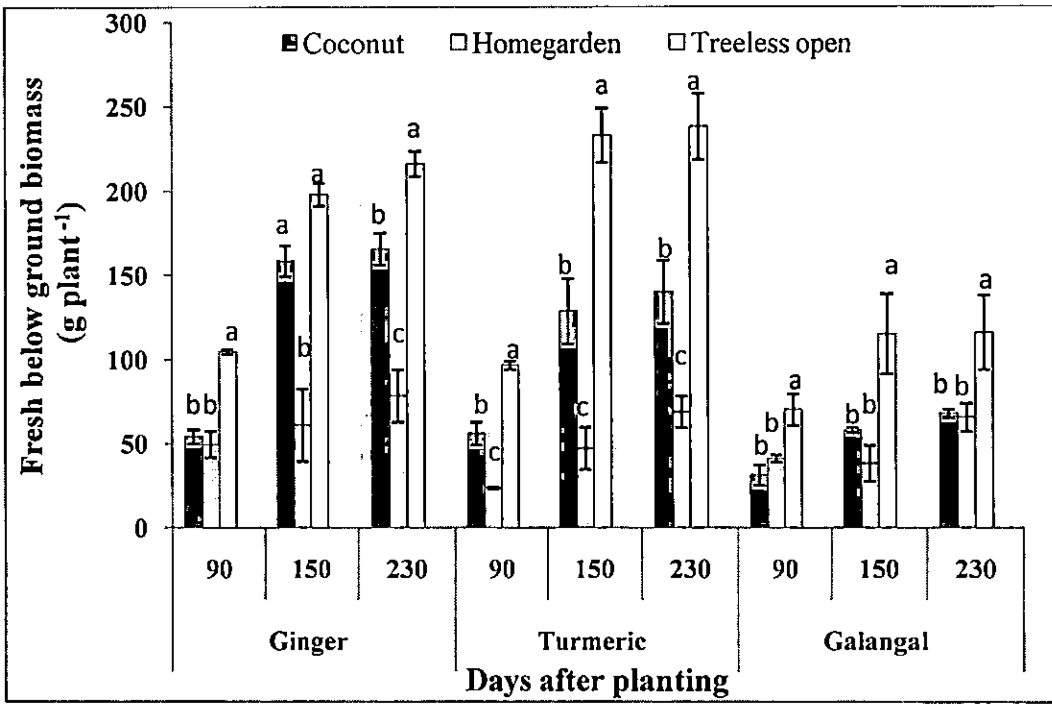


Figure 7. Fresh belowground biomass per plant of various medicinal herbs under different landuse systems at Vellanikkara, Kerala

4.10.1 Ginger

Dry belowground yields during the 3 sampling periods showed significant difference among the landuse systems. In brief ginger production was lower in homegarden during all the growth stages. At 90 DAP, significantly higher belowground dry biomass production per plant was observed in control plot (8.95 g) compared to coconut (4.72 g) and homegarden (4.24 g) which however were on par. The trends were more consistent during the subsequent sampling dates. For instance, at 150 DAP, treeless open recorded highest biomass of 18.86 g followed by coconut and lowest by homegarden. At 230 DAP, again the highest dry belowground biomass was observed in treeless open (21.62 g) followed by coconut (17.9 g) and homegarden (9.99 g). As compared to treeless open grown ginger at 230 DAP, the reduction in belowground dry biomass was 17.21 % and 53.79 % for coconut and homegarden respectively. Across the growth period from 90 to 230 DAP rhizome dry weight per plant showed highest increment in coconut grown ginger (279.24 %) while an increase of 141.56 % and 135.61 % was noticed in treeless open and homegarden respectively.

4.10.2 Turmeric

Among the selected intercrops probably belowground dry matter production for turmeric was considerably lower giving considerable yield reduction under the intercropped scenario. Generally turmeric performed well in control plot over the different growth periods. At 90 DAP, turmeric in treeless open recorded highest belowground biomass of 15.02 g whereas coconut (6.03 g) and homegarden (2.86) were on par. At 150 and 230 DAP, treeless open grown turmeric showed higher dry belowground biomass (40.95 g at 150 DAP and 43.86 g at 230 DAP) followed by coconut and least in homegarden. Compared to treeless open grown turmeric at 230 DAP, the coconut and homegarden registered 39.72 % and 74.83 % reduction. Furthermore over the growth period from 90 to 230 DAP rhizome dry weight per plant showed highest increment (338.47 %) per plant in coconut grown turmeric while an increase of 286.01 and 192.01 per cent was noticed in homegarden and treeless open respectively.

4.10.3 Galangal

Periodic changes in belowground dry weights suggest that generally galangal also performed well in open control plot like ginger and turmeric. At 90 DAP, galangal from the control plot recorded highest dry belowground biomass (8.71 g) while coconut and homegarden showed lower production which however were on par. Trends were similar at 150 DAP as well with open control plot giving higher dry belowground biomass. At final harvest treeless open grown galangal showed again higher dry belowground biomass (19.12 g) while homegarden and coconut showed values on par. A comparison with treeless open grown galangal at 230 DAP suggest a decrease of 29.86 % and 33.32 % rhizome dry weight per plant for coconut and homegarden respectively. During the growth period from 90 to 230 DAP rhizome dry weight per plant showed highest increment per plant (241.22 %) in coconut grown galangal while an increase of 160.2 and 119.52 % was noticed in homegarden and treeless open respectively.

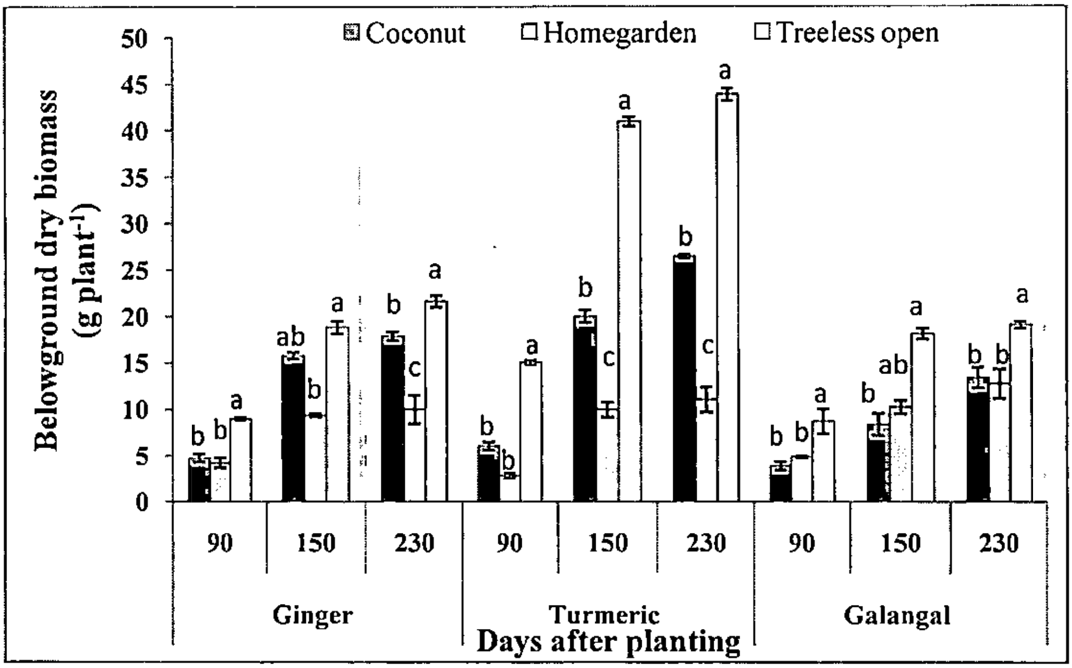


Figure 8. Belowground dry biomass per plant of various medicinal herbs under different landuse systems at Vellanikkara, Kerala

4.11 RHIZOME PRODUCTION ON HECTARE BASIS

4.11.1 Ginger

Dry rhizome yield on unit area basis for ginger varied considerably across the land management system (Table 11). Observations revealed an amount of 1.43 Mg ha^{-1} of rhizome yield in treeless open while 0.76 and 0.68 Mg ha^{-1} in coconut and homegarden respectively during first sampling stage. At 150 DAP significant increase in rhizome yield were noticed with treeless open recording 3.02 Mg ha^{-1} followed by coconut (2.52 Mg ha^{-1}) and homegarden (1.6 Mg ha^{-1}). During the final sampling stage maximum rhizome yield amounted to 3.46 Mg ha^{-1} in treeless open while 2.86 and 1.49 Mg ha^{-1} in coconut and homegarden respectively with relatively consistent changes. Conspicuous reduction in belowground dry weight was observed for homegarden (56.93 %) as compared to treeless open while the reduction was moderate under coconut (17.34 %).

4.11.2 Turmeric

Rhizome production for turmeric also showed appreciable change especially during first sampling stage (Table 11). Considerable differences in rhizome yield were observed at the first sampling stage. The highest amount of turmeric rhizome yield (2.40 Mg ha^{-1}) was recorded in treeless open followed by coconut (0.96 Mg ha^{-1}) and homegarden (0.46 Mg ha^{-1}) respectively at 90 DAP. During second observational time treeless open recorded the maximum yield of 6.55 Mg ha^{-1} whereas coconut and homegarden recorded 3.21 and 1.59 Mg ha^{-1} respectively. Treeless open continued the higher rhizome yield at final sampling stage (7.02 Mg ha^{-1}) followed by coconut and homegarden with 4.23 and 1.77 Mg ha^{-1} respectively. Conspicuous reduction in belowground dry weight was observed for homegarden (74.78 %) as compared to treeless open while the reduction under coconut was (39.74 %).

4.11.3 Galangal

Following trends of ginger and turmeric during the first sampling stage (90 DAP) galangal also showed significantly higher rhizome yield (1.39 Mg ha^{-1}) from treeless open. However, galangal yields under homegarden were marginally higher than that from coconut at 90 and 150 DAP. At 150 DAP treeless open again showed a maximum rhizome yield of 2.90 Mg ha^{-1}. This was followed by homegarden and coconut recording 1.64 and 1.34 Mg ha^{-1} respectively. During final sampling stage treeless open was noticed to produce a yield of 3.06 Mg ha^{-1} whereas coconut and homegarden recorded comparatively lower values of 2.15 and 2.04 Mg ha^{-1} respectively. Significant reduction in belowground dry weight was observed for homegarden (33.33 %) and coconut (29.73 %) as compared to treeless open.

4.12 NET PRODUCTIVITY OF RHIZOME

Variation in net productivity of rhizome was observed among the intercrops for different landuse systems. Obviously the highest net rhizome yield was observed for the treeless open for all the three intercrops with 2.2, 4.46 and 1.94 Mg ha^{-1} for ginger, turmeric and galangal respectively. Also intercrop performance was better under coconut while lowest under homegarden. Despite the lower productivity for the ginger in the coconut and homegarden the changes were not significant.

Table 9. Fresh belowground biomass per plant of various medicinal herbs under different landuse systems at Vellanikkara, Kerala

Landuse type	Fresh belowground biomass (g plant^{-1})								
	Ginger			Turmeric			Galangal		
	90 DAP	150 DAP	230 DAP	90 DAP	150 DAP	230 DAP	90 DAP	150 DAP	230 DAP
Coconut	54.28^{b} (4.09)	158.38^{a} (9.23)	165.65^{b} (9.66)	56.23^{b} (6.66)	128.69^{b} (19.33)	140.25^{b} (18.71)	31.46^{b} (6.05)	58.27^{b} (1.43)	68.15^{b} (2.57)
Homegarden	49.63^{b} (7.80)	61.17^{b} (21.59)	78.56^{c} (15.60)	23.74^{c} (0.64)	47.40^{c} (12.60)	69.11^{c} (9.27)	41.29^{b} (2.18)	38.30^{b} (10.80)	65.87^{b} (8.38)
Treeless open	104.81^{a} (1.28)	198.03^{a} (6.71)	216.33^{a} (7.55)	96.82^{a} (2.37)	233.16^{a} (15.91)	238.33^{a} (19.59)	70.32^{a} (9.51)	115.29^{a} (23.87)	116.15^{a} (22.03)
F	35.428	24.948	36.986	79.884	33.111	26.422	9.289	6.955	6.302
p	0.000	0.001	0.000	0.000	0.001	0.001	0.015	0.027	0.039

Table 10. Belowground dry biomass per plant of various medicinal herbs under different landuse systems at Vellanikkara, Kerala

Landuse type	Belowground dry biomass (g plant^{-1})								
	Ginger			Turmeric			Galangal		
	90 DAP	150 DAP	230 DAP	90 DAP	150 DAP	230 DAP	90 DAP	150 DAP	230 DAP
Coconut	4.72^{b} (0.41)	15.76^{ab} (0.36)	17.9^{b} (0.48)	6.03^{b} (0.45)	20.04^{b} (0.67)	26.44^{b} (0.21)	3.93^{b} (0.45)	8.38^{b} (1.18)	13.41^{b} (1.11)
Homegarden	4.24^{b} (0.54)	9.33^{b} (0.16)	9.99^{c} (1.53)	2.86^{b} (0.25)	9.95^{c} (0.81)	11.04^{c} (1.36)	4.90^{b} (0.10)	10.23^{ab} (0.72)	12.75^{b} (1.58)
Treeless open	8.95^{a} (0.16)	18.86^{a} (0.69)	21.62^{a} (0.63)	15.02^{a} (0.24)	40.95^{a} (0.49)	43.86^{a} (0.69)	8.71^{a} (1.37)	18.15^{a} (0.60)	19.12^{a} (0.35)
F	10.604	10.427	40.388	22.726	51.497	57.857	9.119	13.721	7.15
p	0.011	0.022	0.000	0.002	0.000	0.000	0.015	0.039	0.026

Values with same superscript do not differ significantly
Values in the parenthesis represent standard error of the mean
DAP – Days After Planting

Table 11. Belowground dry weight of intercrops as influenced by various landuse systems at Vellanikkara, Kerala

Landuse type	Belowground dry weight rhizome yield (Mg ha^{-1})								
	Ginger			Turmeric			Galangal		
	90 DAP	150 DAP	230 DAP	90 DAP	150 DAP	230 DAP	90 DAP	150 DAP	230 DAP
Coconut	0.76^{b} (0.06)	2.52^{ab} (0.16)	2.86^{b} (0.28)	0.96^{b} (0.08)	3.21^{b} (0.49)	4.23^{b} (0.28)	0.63^{b} (0.09)	1.34^{b} (0.21)	2.15^{b} (0.19)
Homegarden	0.68^{b} (0.05)	1.60^{b} (0.11)	1.49^{c} (0.16)	0.46^{b} (0.05)	1.59^{c} (0.27)	1.77^{c} (0.14)	0.78^{b} (0.04)	1.64^{ab} (0.12)	2.04^{b} (0.24)
Treeless open	1.43^{a} (0.12)	3.02^{a} (0.23)	3.46^{a} (0.35)	2.40^{a} (0.12)	6.55^{a} (0.52)	7.02^{a} (0.61)	1.39^{a} (0.24)	2.90^{a} (0.76)	3.06^{a} (0.44)
F	10.604	10.427	40.388	22.726	51.497	57.857	9.119	13.721	7.15
p	0.011	0.022	0.000	0.002	0.000	0.000	0.015	0.039	0.026

Values with same superscript do not differ significantly
Values in the parenthesis represent standard error of the mean
DAP – Days After Planting

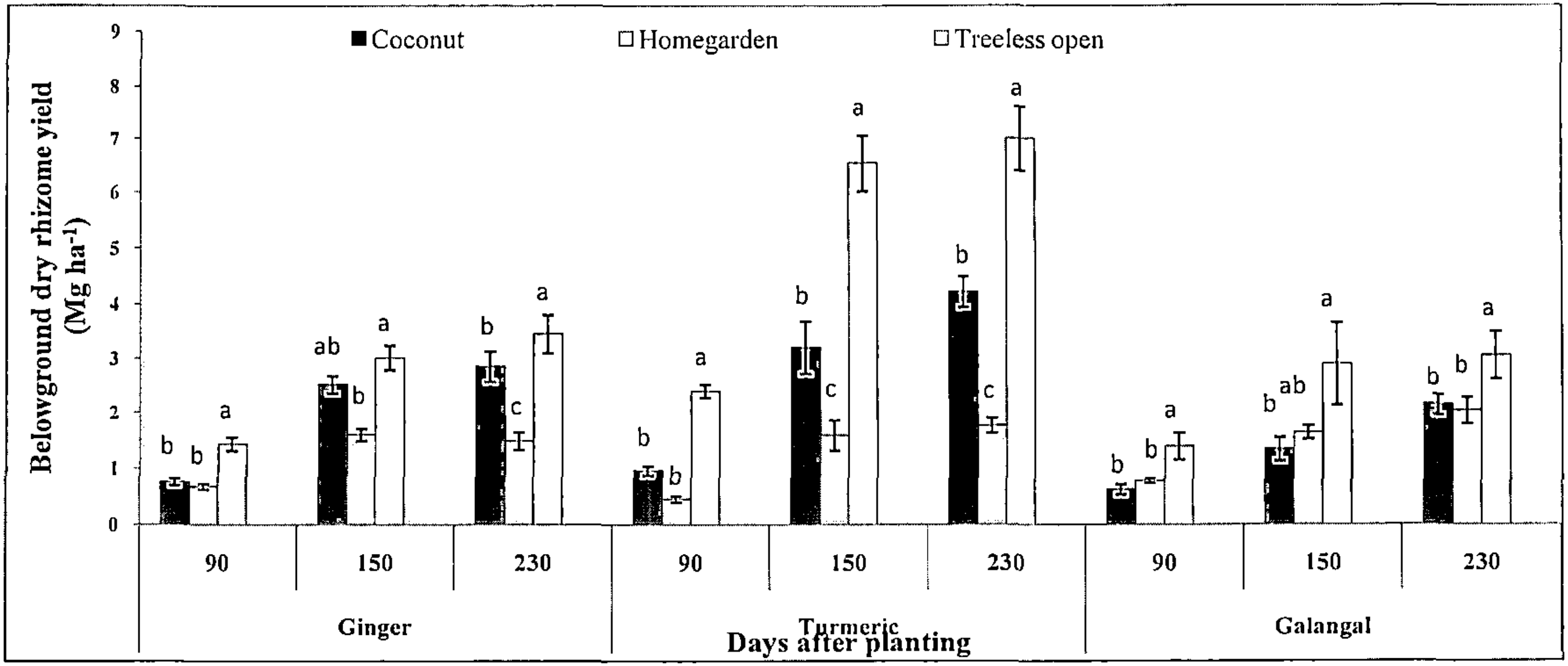


Figure 9. Belowground dry rhizome yield of various medicinal herbs under different landuse systems at Vellanikkara, Kerala

In general yield reduction compared to open control was highest for turmeric (83.81 % reduction under coconut and 97.75 % under homegarden) followed by galangal (80.41 % reduction under coconut and 93.81 % under homegarden) and ginger (76.82 % reduction under coconut and 95.91 % under homegarden).

Table 12. Changes in net productivity among the of intercrops as influenced by various landuse systems at Vellanikkara, Kerala

Landuse type	Net productivity of rhizome (Mg ha^{1})		
	230 DAP		
	Ginger	Turmeric	Galangal
Coconut	0.51	0.75^{b}	0.38^{b}
Homegarden	0.09	0.10^{c}	0.12^{b}
Treeless open	2.20	4.46^{a}	1.94^{a}
F	2.893	5.21	6.56
p	0.124	0.047	0.031

Values with same superscript do not differ significantly
DAP – Days After Planting

4.13 RHIZOME QUALITY

Oleoresin content is an important quality parameter for which rhizomatous plants such as ginger, turmeric and galangal are valued. Generally oleoresin content was increased with increasing understorey shade levels. Among the intercrops, average oleoresin content was highest for turmeric (10.53 %) followed by ginger (4.27 %) and galangal (2.51 %). Among the various land use systems, the oleoresin content appeared higher in the homegarden for all the three intercrops, despite poor statistical significance. Similarly, the herbaceous crops showed marginally lower oleoresin content in the treeless open condition for ginger, turmeric and galangal.

Table 13. Oleoresin content of various intercrops as influenced by different landuse systems at Vellanikkara, Kerala

Landuse type	Oleoresin content (%)		
	Ginger	Turmeric	Galangal
Coconut	4.14 (0.12)	10.57 (0.76)	2.48 (0.20)
Homegarden	4.64 (0.49)	11.05 (0.97)	2.80 (0.35)
Treeless open	4.02 (0.07)	9.92 (0.32)	2.26 (0.17)
F	1.253	0.591	1.185
p	0.351	0.583	0.368

Values in the parenthesis represent standard error of the mean

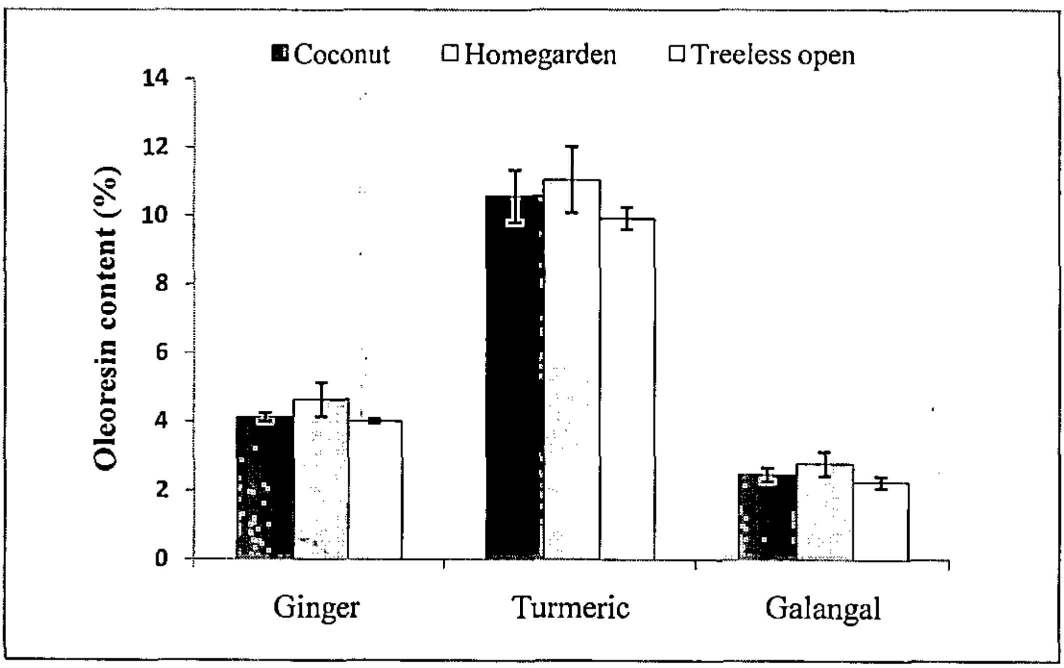


Figure 10. Oleoresin content of various intercrops as influenced by different landuse systems at Vellanikkara, Kerala

Ginger

Turmeric

Galangal

Plate 11. Rhizome yield of various medicinal plants grown at different locations of Vellanikkara, Thrissur

4.14 TOTAL CHLOROPHYLL CONTENT

Similar to the trends observed for oleoresin content, the chlorophyll content in the leaves of the medicinal plants were lowest in the treeless open while the highest content was reported for homegardens. Despite the statistical insignificance ginger recorded highest total chlorophyll (mg g^{-1}) content in homegarden (2.54) and least in treeless open (1.95). However, significant variation in chlorophyll content was observed for turmeric among various landuse systems. For instance, the chlorophyll content (mg g^{-1}) was recorded highest for homegarden (2.41 mg g^{-1}) and least in treeless open (1.39 mg g^{-1}) which was on par with coconut. Similar to the trends for turmeric, galangal also showed marked variation in chlorophyll content when grown under various selected landuse systems. Highest content (mg g^{-1}) was noted for homegarden (1.33) and least in treeless open (0.70) which was on par with coconut. The percentage increase was highest for homegarden with 73.38 % for turmeric and 90 % of galangal as compared to control. As compared to control the percentage increase in total chlorophyll content for coconut was 17.98 % for turmeric and 14.28 % for galangal.

Table 14. Total chlorophyll content of various intercrops as influenced by different landuse systems at Vellanikkara, Kerala

Landuse type	Total chlorophyll content (mg g^{-1})		
	Ginger	Turmeric	Galangal
Coconut	2.16 (0.25)	1.64[b] (0.20)	0.80[b] (0.02)
Homegarden	2.54 (0.08)	2.41[a] (0.20)	1.33[a] (0.15)
Treeless open	1.95 (0.25)	1.39[b] (0.19)	0.70[b] (0.05)
F	2.009	6.952	13.332
p	0.215	0.027	0.006

Values with same superscript do not differ significantly
Values in the parenthesis represent standard error of the mean
DAP – Days After Planting

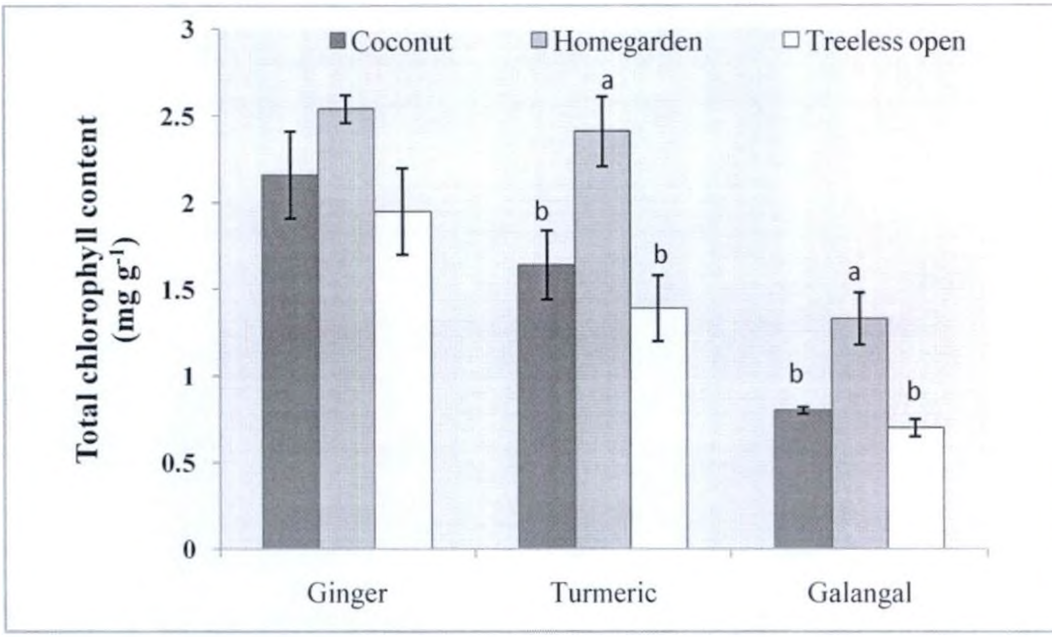


Figure 11. Total chlorophyll content of various intercrops as influenced by different landuse systems at Vellanikkara, Kerala

4.15 PLANT NUTRIENT CONTENT

4.15.1 Aboveground nutrient content

The data on the plant nutrient content recorded in the aboveground portions of ginger, turmeric and galangal are presented in Table 15.

4.15.1.1 Ginger

In general consistent increase in aboveground nutrient content has been observed during successive sampling dates for all the intercrops except for the initial sampling period (90 DAP). The significant changes in N, P and K were observed among the intercrops under different cropping systems. At 90 DAP the aboveground plant nitrogen content was statistically similar across various land uses. However at 150 DAP, homegarden grown ginger showed lowest N content in the aboveground biomass compared to treeless open and coconut which were on par. Phosphorus concentration at initial sampling stage was significantly higher in treeless open (0.35 %) followed by homegarden and coconut which were statistically similar. At final sampling period similar trend was followed with highest P concentration in treeless open (0.73 %). Aboveground potassium concentration for ginger was significantly higher in treeless open during initial observation while least in homegarden. At 150 DAP, lowest K concentration was observed in the homegarden (4.97 %) raised ginger which however was on par with coconut.

4.15.1.2 Turmeric

Similar to ginger, turmeric also showed consistent increase in plant nutrient concentration with planting dates. Nitrogen concentration in turmeric did not vary appreciably during the first sampling period, however treeless open recorded higher N concentration. At 150 DAP, nitrogen concentration was significantly higher in treeless open (2.32 %). This was followed by coconut and homegarden which were on par with each other. Phosphorus concentration in aboveground biomass was found to be highest in treeless open grown turmeric (p=0.01) during both the sampling periods (0.51 % at 90 DAP and 0.66 % at 150 DAP). This was followed by coconut and least in homegarden throughout the sampling periods. Potassium concentration showed higher values in treeless open grown turmeric (3.59 %) at 90 DAP. This was followed by coconut and homegarden which were on par with each other. Trends were similar for subsequent sampling date also. At 150 DAP, lowest K concentration was recorded from homegarden (4.69 %) while treeless open grown turmeric recorded highest K concentration followed by coconut.

4.15.1.3 Galangal

Galangal also exhibited significant difference in nutrient concentration in the aboveground biomass. At 90 DAP, nitrogen concentration was found significantly higher in open (2.01 %) grown galangal. This was followed by coconut and homegarden which were statistically on par with each other. Open grown galangal recorded higher N concentration at 150 DAP also though differences were not appreciable. Phosphorus concentration recorded significantly higher in treeless open at 90 DAP (0.44 %) and at 150 DAP (0.73

%). This was followed by coconut and homegarden which were on par with each other. Potassium content varied marginally during the two sampling periods. Treeless open raised galangal recorded significantly highest K concentration (3.48 %) which was followed by galangal in the coconut and homegarden. Interestingly, the galangal in the homegarden (5.27 %) showed higher K content in the aboveground biomass at 150 DAP while the differences were non-significant.

Table 15. Aboveground plant nutrient concentration in ginger under various landuse systems at Vellanikkara, Kerala

Landuse type	Aboveground plant nutrient concentration (%)					
	N		P		K	
	90 DAP	150 DAP	90 DAP	150 DAP	90 DAP	150 DAP
Coconut	1.77 (0.13)	2.03[a] (0.06)	0.31[b] (0.04)	0.62[b] (0.03)	3.18[a] (0.06)	5.09[ab] (0.39)
Homegarden	1.93 (0.13)	1.94[b] (0.17)	0.32[b] (0.01)	0.58[b] (0.03)	3.01[b] (0.24)	4.97[b] (0.16)
Treeless open	2.0 (0.11)	2.19[a] (0.12)	0.35[a] (0.02)	0.73[a] (0.08)	3.27[a] (0.05)	5.11[a] (0.13)
F	0.626	5.993	5.564	26.790	7.401	4.464
p	0.566	0.0357	0.033	0.001	0.024	0.045

Table 16. Aboveground plant nutrient concentration in turmeric under various landuse systems at Vellanikkara, Kerala

Landuse type	Aboveground plant nutrient concentration (%)					
	N		P		K	
	90 DAP	150 DAP	90 DAP	150 DAP	90 DAP	150 DAP
Coconut	1.93 (0.16)	2.02[b] (0.22)	0.46[b] (0.01)	0.59[b] (0.04)	3.34[b] (0.03)	4.82[b] (0.15)
Homegarden	1.83 (0.07)	1.95[b] (0.37)	0.35[c] (0.03)	0.41[c] (0.06)	3.29[b] (0.15)	4.69[c] (0.07)
Treeless open	2.08 (0.08)	2.32[a] (0.09)	0.51[a] (0.02)	0.66[a] (0.15)	3.59[a] (0.02)	4.92[a] (0.16)
F	0.313	8.881	17.728	7.796	7.228	5.612
p	0.743	0.016	0.003	0.029	0.035	0.042

Values with same superscript do not differ significantly
Values in the parenthesis represent standard error of the mean
DAP – Days After Planting

Table 17. Aboveground plant nutrient concentration in galangal under various landuse systems at Vellanikkara, Kerala

Landuse type	Aboveground plant nutrient concentration (%)					
	N		P		K	
	90 DAP	150 DAP	90 DAP	150 DAP	90 DAP	150 DAP
Coconut	1.93^{b} (0.02)	2.01 (0.23)	0.39^{a} (0.02)	0.33^{b} (0.01)	3.26^{b} (0.1)	4.96 (0.04)
Homegarden	1.85^{b} (0.11)	1.97 (0.38)	0.35^{b} (0.03)	0.42^{b} (0.14)	3.29^{b} (0.08)	5.27 (0.48)
Treeless open	2.01^{a} (0.09)	2.18 (0.07)	0.44^{a} (0.03)	0.73^{a} (0.08)	3.48^{a} (0.0)	5.12 (0.29)
F	5.367	3.553	5.854	7.163	6.452	4.596
p	0.024	0.096	0.020	0.005	0.008	0.062

Values with same superscript do not differ significantly
Values in the parenthesis represent standard error of the mean
DAP – Days After Planting

4.15.2 Belowground plant nutrient content

The plant nutrient concentration in the belowground portions of ginger, turmeric and galangal for varied cropping systems are presented in Table 18.

4.15.2.1 Ginger

Nitrogen concentration in ginger belowground biomass did not vary appreciable during the first two sampling period, despite marginally higher values attached to open grown ginger. At 230 DAP, treeless open recorded significantly higher nitrogen concentration (1.55 %) followed by coconut and homegarden. Initial phosphorus concentration did not vary considerably in ginger, though treeless open recorded highest. Last two sampling showed almost similar trend with treeless open having significantly higher phosphorus concentration (0.31 % at 150 DAP and 0.43 at 230 DAP) whereas homegarden and coconut showed lower values which were on par. An appreciable change in the potassium concentration has been observed for ginger across landuse system throughout the sampling period. Homegarden grown ginger recorded significantly lowest potassium concentration in the belowground biomass. In general, nitrogen content in belowground biomass was highest for open grown ginger followed by ginger in the coconut and lowest in homegarden.

4.15.2.2 Turmeric

Nutrient concentration in turmeric also was found to vary among the intercrop regimes. Nitrogen concentration in turmeric did not vary appreciably during the first sampling period, however treeless open recorded higher N concentration. The changes were more significant during the subsequent sampling periods with higher values attached with belowground biomass for open grown turmeric followed by turmeric from coconut and lowest by turmeric in the homegarden. Phosphorous concentration also showed similar changes for turmeric as that of ginger. Turmeric showed significantly higher phosphorus in treeless open during the entire sampling period. Except for the last sampling period (230 DAP), homegarden showed lower phosphorus concentration than coconut. Potassium concentration during the first two sampling periods were non-significant however, treeless open recorded maximum.

4.15.2.3 Galangal

Unlike the ginger and turmeric the changes in nutrient concentration for galangal were variable especially for P and K. Galangal showed significantly higher nitrogen content in the treeless open during the entire sampling period. During the first two sampling periods coconut and homegarden showed closer values whereas at 230 DAP, coconut grown galangal showed higher nitrogen concentration (1.35 %) than homegarden (1 %). During first two sampling period galangal showed non-significant values for phosphorus despite marginally higher values for homegarden. At 230 DAP, phosphorus concentration was clearly higher in homegarden (0.44 %) followed by galangal in the open area. Potassium exhibited variable trend across different landuse regimes. Interestingly, galangal K concentration was higher in the homegarden for all the three sampling periods which was followed by galangal from open area and least in the coconut garden. It was initially not significant but last two observations were significant.

4.16 ABOVEGROUND NUTRIENT ACCUMULATION

Changes in aboveground nutrient accumulation for various intercrops under different management regimes are showed in Table 21.

4.16.1 Ginger

Nitrogen accumulation trends in ginger were not prominent at initial sampling (90 DAP) while it was found to be significant at 150 DAP. Highest accumulation of nitrogen was shown by treeless open grown plants at both the stages. i.e. 16.55 and 44.68 kg ha^{-1} at 90 and 150 DAP respectively.

Phosphorus accumulation was also observed more in treeless open grown ginger at both the stages of observation. Although the changes were marginal at 150 DAP, significant differences were noticed at 90 DAP. At second stage of sampling highest phosphorus content (14.89 kg ha^{-1}) was found for treeless open followed by coconut (7.42 kg ha^{-1}) and homegarden (3.51 kg ha^{-1}).

Potassium uptake did not vary considerably over the first sampling period across the land use systems. Yet the trends suggest considerable increase in uptake from first to second stage of sampling. During both the stages highest K content was found in treeless open grown ginger. The K content at 150 DAP was highest for open grown ginger (104.24 $kgha^{-1}$) followed by coconut (60.93 $kgha^{-1}$) and homegarden (30.11 $kgha^{-1}$). The K accumulation in coconut grown ginger was almost double and in the open grown ginger almost 3.5 times as compared to homegarden.

Table 18. Belowground plant nutrient concentration in ginger under various landuse systems at Vellanikkara, Kerala

Landuse type	Belowground plant nutrient concentration (%)								
	N			P			K		
	90 DAP	150 DAP	230 DAP	90 DAP	150 DAP	230 DAP	90 DAP	150 DAP	230 DAP
Coconut	0.58 (0.13)	0.97 (0.05)	1.21[b] (0.05)	0.16 (0.04)	0.27[b] (0.02)	0.33[b] (0.07)	0.45[b] (0.03)	0.95[b] (0.07)	1.11[b] (0.23)
Homegarden	0.59 (0.16)	0.75 (0.09)	1.08[c] (0.04)	0.11 (0.01)	0.21[b] (0.02)	0.31[b] (0.04)	0.39[c] (0.06)	0.82[c] (0.08)	1.01[c] (0.15)
Treeless open	0.87 (0.11)	1.18 (0.08)	1.55[a] (0.29)	0.24 (0.01)	0.31[a] (0.01)	0.43[a] (0.11)	0.56[a] (0.18)	1.01[a] (0.17)	1.41[a] (0.20)
F	0.159	3.094	6.178	2.829	5.689	5.628	14.162	5.457	6.457
p	0.857	0.076	0.035	0.136	0.041	0.043	0.005	0.045	0.032

Values with same superscript do not differ significantly
Values in the parenthesis represent standard error of the mean
DAP – Days After Planting

Table 19. Belowground plant nutrient concentration in turmeric under various landuse systems at Vellanikkara, Kerala

Landuse type	Belowground plant nutrient concentration (%)								
	N			P			K		
	90 DAP	150 DAP	230 DAP	90 DAP	150 DAP	230 DAP	90 DAP	150 DAP	230 DAP
Coconut	0.59 (0.13)	0.66[b] (0.06)	1.06[b] (0.33)	0.11[a] (0.01)	0.26[a] (0.03)	0.28[b] (0.02)	0.33 (0.14)	0.72 (0.19)	1.15[b] (0.13)
Homegarden	0.35 (0.04)	0.51[b] (0.13)	1.01[b] (0.04)	0.07[b] (0.01)	0.13[b] (0.03)	0.28[b] (0.01)	0.26 (0.04)	0.66 (0.18)	0.95[b] (0.18)
Treeless open	0.69 (0.08)	0.78[a] (0.12)	1.29[a] (0.26)	0.13[a] (0.01)	0.26[a] (0.04)	0.31[a] (0.02)	0.41 (0.1)	0.78 (0.12)	1.22[a] (0.13)
F	3.118	4.832	4.899	5.542	5.016	9.866	1.215	0.189	4.816
p	0.118	0.047	0.049	0.033	0.042	0.002	0.360	0.833	0.047

Values with same superscript do not differ significantly
Values in the parenthesis represent standard error of the mean
DAP – Days After Planting

Table 20. Belowground plant nutrient concentration in galangal under various landuse systems at Vellanikkara, Kerala

Landuse type	Belowground plant nutrient concentration (%)								
	N			P			K		
	90 DAP	150 DAP	230 DAP	90 DAP	150 DAP	230 DAP	90 DAP	150 DAP	230 DAP
Coconut	0.77[b] (0.07)	0.91[b] (0.12)	1.35[b] (0.34)	0.16 (0.02)	0.17 (0.02)	0.25[b] (0.16)	0.62 (0.13)	0.93[b] (0.09)	1.01[b] (0.06)
Homegarden	0.84[b] (0.05)	0.95[b] (0.33)	1.00[c] (0.08)	0.26 (0.02)	0.29 (0.01)	0.44[a] (0.13)	0.77 (0.11)	0.95[b] (0.21)	1.34[a] (0.36)
Treeless open	0.92[a] (0.19)	1.04[a] (0.13)	1.42[a] (0.18)	0.21 (0.03)	0.27 (0.02)	0.32[b] (0.01)	0.66 (0.22)	1.09[a] (0.12)	1.37[a] (0.04)
F	4.241	9.63	5.925	3.109	1.516	5.206	0.235	5.886	4.857
p	0.049	0.002	0.040	0.063	0.370	0.036	0.798	0.041	0.049

Values with same superscript do not differ significantly
Values in the parenthesis represent standard error of the mean
DAP – Days After Planting

Table 21. Aboveground plant nutrient accumulation in ginger under various landuse systems at Vellanikkara, Kerala

Landuse type	Aboveground plant nutrient accumulation (kg ha^{-1})					
	N		P		K	
	90 DAP	150 DAP	90 DAP	150 DAP	90 DAP	150 DAP
Coconut	7.56 (0.36)	24.30^{b} (0.67)	1.32^{b} (0.05)	7.42 (1.08)	13.58 (0.42)	60.93^{b} (2.86)
Homegarden	9.12 (0.41)	11.75^{b} (1.01)	1.51^{b} (0.09)	3.51 (0.16)	14.22 (0.29)	30.11^{c} (2.15)
Treeless open	16.55 (2.67)	44.68^{a} (0.15)	2.90^{a} (0.54)	14.89 (0.21)	27.06 (0.15)	104.24^{a} (3.74)
F	0.626	5.993	5.564	1.516	1.203	4.464
p	0.566	0.037	0.041	0.27	0.36	0.045

Values with same superscript do not differ significantly
Values in the parenthesis represent standard error of the mean
DAP – Days After Planting

4.16.2 Turmeric

Fairly higher nutrient accumulation was observed in turmeric aboveground biomass under different systems. For instance highest nitrogen uptake was recorded in treeless open grown plants (31.77 kg ha^{-1}) at 90 DAP and at 150 DAP (48.04 kg ha^{-1}). Lowest content was found in homegarden grown plants (13.69 and 14.49 kg ha^{-1} at 90 and 150 DAP respectively). The N accumulation in open grown turmeric was almost 4 times higher as compared to the N accumulation for homegarden turmeric.

Phosphorus uptake at 90 DAP also showed highest value in treeless open grown plants (7.79 kg ha^{-1}) which was on par with coconut grown plants and significantly different from homegarden grown turmeric. The observations at second sampling phase however did not reveal any significant difference.

Potassium accumulation varied considerably during both the observational periods. Treeless open grown plants recorded significantly higher K (54.83 and 101.88 kg ha^{-1} at 90 and 150 DAP respectively) uptake followed by coconut and homegarden during both the sampling periods. All the nutrients showed highest accumulation in the open grown turmeric irrespective of the sampling periods.

Table 22. Aboveground plant nutrient accumulation in turmeric under various landuse systems at Vellanikkara, Kerala

Landuse type	Aboveground plant nutrient accumulation (kg ha^{-1})					
	N		P		K	
	90 DAP	150 DAP	90 DAP	150 DAP	90 DAP	150 DAP
Coconut	26.22 (0.97)	28.50^{b} (0.08)	6.25^{a} (0.09)	7.45 (0.52)	45.37^{b} (1.06)	60.85^{b} (0.44)
Homegarden	13.69 (0.71)	14.49^{c} (0.29)	2.62^{b} (0.41)	2.69 (0.19)	24.60^{c} (0.64)	27.64^{c} (0.13)
Treeless open	31.77 (0.42)	48.04^{a} (0.24)	7.79^{a} (0.29)	13.67 (0.52)	54.83^{a} (1.87)	101.88^{a} (0.26)
F	0.626	5.993	5.564	3.818	7.401	4.464
p	0.566	0.037	0.043	0.079	0.024	0.045

Values with same superscript do not differ significantly
Values in the parenthesis represent standard error of the mean
DAP – Days After Planting

4.16.3 Galangal

Galangal also showed highest nutrient accumulation in the open condition followed by homegarden and lowest in the coconut. Nitrogen accumulation varied inconsistently at 90 DAP however, nitrogen content was recorded maximum in treeless open followed by homegarden and coconut. At 150 DAP significantly higher N content (10.27 kg ha^{-1}) was found in treeless open grown plants which was significantly higher than homegarden (5.31 kg ha^{-1}) which was on par with coconut (4.91 kg ha^{-1}).

Observations revealed highest P content at 90 DAP in treeless open grown plants (2.21 kg ha^{-1}) followed by homegarden and coconut. No appreciable change was found at 150 DAP for phosphorus uptake in galangal. The reduction in P accumulation in the intercrops was almost 50 % in the homegarden and coconut.

Potassium uptake recorded significant changes during both observational periods across landuse systems. The highest content was registered in treeless open grown galangal at both the observational periods with 17.47 and 19.42 kg ha^{-1} respectively. However, the galangal K uptake in the homegarden and coconut were considerably lower (14.22 and 10.14 kg ha^{-1} respectively) as against 19.42 kg ha^{-1} for open grown galangal.

Table 23. Aboveground plant nutrient accumulation in galangal under various landuse systems at Vellanikkara, Kerala

Landuse type	Aboveground plant nutrient accumulation (kg ha^{-1})					
	N		P		K	
	90	150	90	150	90	150
Coconut	4.87 (0.44)	4.91^b (0.46)	0.88^b (0.07)	0.97 (0.14)	8.23^b (0.28)	10.14^b (0.11)
Homegarden	5.45 (0.18)	5.51^b (0.15)	1.03^b (0.31)	1.13 (0.26)	9.70^b (0.86)	14.22^b (0.51)
Treeless open	10.09 (0.54)	10.27^a (0.74)	2.21^a (0.19)	2.77 (0.51)	17.47^a (0.94)	19.42^a (0.54)
F	0.626	5.993	5.564	1.820	7.401	4.464
p	0.566	0.037	0.041	0.241	0.024	0.048

Values with same superscript do not differ significantly
Values in the parenthesis represent standard error of the mean
DAP – Days After Planting

4.17 BELOWGROUND NUTRIENT ACCUMULATION

4.17.1 Ginger

Belowground nutrient accumulation trends for ginger grown under different system suggested strong variation. In general, the open grown ginger stored higher nutrient in the belowground biomass followed by coconut and lowest in the homegarden. Nitrogen uptake during first sampling stage varied marginally. However, highest nitrogen (7.48 kg ha^{-1}) uptake was recorded in treeless open grown ginger rhizome. At 150 and 230 DAP highest nitrogen uptake again observed in the treeless open grown ginger rhizome (21.36 and 32.17 kg ha^{-1} at 150 DAP and 230 DAP respectively) which was significantly higher from coconut and homegarden. The nitrogen uptake increased with the advancement of growth. The reduction in N accumulation in the homegarden and coconut compared to open at 230 DAP was 69.94 % and 35.37 % respectively.

Phosphorus accumulation in ginger rhizomes did not vary appreciably during at first two sampling stages, despite marginally higher value for treeless open and homegarden the lowest. The observations during the last sampling period revealed significant changes in P accumulation with maximum value (8.92 kg ha^{-1}) in treeless open with an appreciable reduction for coconut (36.43 %) and homegarden (68.83 %).

Results revealed no prominent change in rhizome K uptake at 90 DAP (2.07 kg ha^{-1}). Treeless open grown ginger rhizomes however recorded highest K content compared to coconut and homegarden. At subsequent sampling stage (150 DAP) also differences were non-significant. Treeless open recorded highest (18.29 kg ha^{-1}) K uptake in rhizome followed by coconut (14.37 kg ha^{-1}) and homegarden (7.86 kg ha^{-1}). At 230 DAP the open grown ginger showed enhanced N uptake (29.26 kg ha^{-1}) while the uptake trend remained same for coconut and homegarden. Probably the reduction in K accumulation is as much as 69.07 % and 34.82 % for homegarden and coconut respectively at 230 DAP, compared to treeless open.

4.17.2 Turmeric

Similar to the nutrient uptake trends for ginger, the turmeric also showed highest nutrient accumulation in the open condition. During the first two sampling stages nitrogen uptake varied marginally showing highest value in treeless open (9.95 and 30.66 kg ha^{-1} at 90 and 150 DAP respectively) followed by coconut and homegarden. However significant variation was noticed during last sampling stage, with highest N accumulation (54.32 kg ha^{-1}) was attached to turmeric from treeless open which was significantly higher than coconut (26.91 kg ha^{-1}) and homegarden (10.7 kg ha^{-1}). The percentage reduction in N accumulation for homegarden was 80.3 % and for coconut 43.17 %, compared to open grown turmeric.

Phosphorus uptake by turmeric rhizomes showed non significant differences during first sampling stage (90 DAP) with modestly higher P content (1.87 kg ha^{-1}) attached to treeless open grown rhizomes. Further, at 150 DAP higher nutrient stocks was recorded by treeless open grown turmeric (10.22 kg ha^{-1}) which was significantly lower for coconut (5 kg ha^{-1}) as well as homegarden (1.24 kg ha^{-1}). Trends were similar during the final sampling (230 DAP) as well with treeless open (13.05 kg ha^{-1}) showing significantly higher phosphorus uptake which was at par with coconut but significantly different from homegarden. The percentage reduction in P content in the homegarden and coconut compared to open at 230 DAP was 79.69 % and 45.51 % respectively.

Potassium uptake showed moderate changes among the landuse systems during first sampling stage. Notwithstanding this, highest K content was found in treeless open grown turmeric and least in homegarden rhizomes. Further at 150 DAP and last sampling appreciable changes were observed in K content. At 230 DAP, treeless open grown turmeric exhibited significantly highest (51.37 kg ha^{-1}) nutrient content followed by coconut (29.19 kg ha^{-1}) and homegarden (10.07 kg ha^{-1}). Probably the reduction in K accumulation is as much as 89.39 % and 43.17 % for homegarden and coconut respectively at 230 DAP.

4.17.3 Galangal

Galangal also exhibited consistently higher nutrient stocks in the rhizome of open grown condition. In the intercropping scenario, galangal nutrient accumulation was higher under coconut while the lowest uptake was under homegarden. For instance, at 150 and 230 DAP significantly higher nitrogen uptake was observed in the open grown ginger rhizome (18.12 and 26.06 kg ha^{-1} at 150 and 230 DAP respectively). This indicates that N accumulation under the coconut and homegarden were considerably reduced to the tune of 33.3 % and 53.01 %.

Similarly, treeless open grown galangal recorded highest rhizomatous phosphorus uptake during various stages of growth. The changes were more prominent during 150 and 230 DAP. The percentage reduction in P content in the homegarden and coconut compared to open at 230 DAP was 0.08 % and 45.14 % respectively.

Potassium content in the galangal also suggested higher nutrient accumulation from open grown plants. However contrary to trends for other nutrients, the K accumulation in the homegarden galangal was fairly better as compared to coconut. The trends were more prominent at 230 DAP. The percentage reduction in K content in the homegarden and coconut compared to open at 230 DAP was 34.79 % and 48.31 % respectively.

4.18 SPECIFIC LEAF AREA

Specific leaf area provides information about the net leaf area available for photosynthesis. In the present study the specific leaf area varied significantly among the intercrops and their cropping regimes. Contrary to the growth trends the specific leaf area was highest under homegarden grown ginger (174.51 cm^2 g^{-1}) followed by coconut and lowest in the open condition. The trends were similar for galangal too with homegarden giving highest specific leaf area (180.01 cm^2 g^{-1}) while galangal in the open condition recorded lowest value. Specific leaf area pattern in turmeric showed different pattern in comparison with ginger and galangal. Coconut grown turmeric showed higher specific leaf area (170.09 cm^2 g^{-1}) followed by open with 139.66 cm^2 g^{-1} and homegarden with 106.52 cm^2 g^{-1}.

Table 24. Belowground plant nutrient accumulation in ginger under various landuse systems at Vellanikkara, Kerala

Landuse type	Belowground plant nutrient accumulation (kg ha^{-1})								
	N			P			K		
	90 DAP	150 DAP	230 DAP	90 DAP	150 DAP	230 DAP	90 DAP	150 DAP	230 DAP
Coconut	2.63 (0.06)	14.68[b] (0.17)	20.79[b] (1.11)	0.72 (0.05)	4.08 (0.87)	5.67[b] (0.24)	2.04 (0.5)	14.37 (0.93)	19.07[b] (0.88)
Homegarden	2.40 (0.23)	7.19[b] (0.16)	9.67[b] (0.94)	0.45 (0.08)	2.01 (0.09)	2.78[c] (0.28)	1.59 (0.21)	7.86 (0.13)	9.05[c] (0.31)
Treeless open	7.48 (0.44)	21.36[a] (0.28)	32.17[a] (0.68)	2.06 (0.16)	5.61 (0.27)	8.92[a] (0.19)	4.81 (0.08)	18.29 (0.11)	29.26[a] (0.78)
F	0.159	4.094	6.178	2.829	2.311	4.628	2.774	4.457	6.457
p	0.857	0.046	0.035	0.136	0.12	.043	0.087	.065	.032

Values with same superscript do not differ significantly
Values in the parenthesis represent standard error of the mean
DAP – Days After Planting

Table 25. Belowground plant nutrient accumulation in turmeric under various landuse systems at Vellanikkara, Kerala

Landuse type	Belowground plant nutrient accumulation (kg ha^{-1})								
	N			N			N		
	90 DAP	150 DAP	230 DAP	90 DAP	150 DAP	230 DAP	90 DAP	150 DAP	230 DAP
Coconut	3.42 (0.22)	12.70 (0.84)	26.91^{b} (0.14)	0.64 (0.05)	5.00^{b} (0.46)	7.11^{a} (0.74)	1.91 (0.11)	13.85^{b} (0.21)	29.19^{b} (1.74)
Homegarden	0.96 (0.08)	4.87 (0.44)	10.70^{c} (0.09)	0.19 (0.05)	1.24^{c} (0.13)	2.65^{b} (0.04)	0.71 (0.06)	6.30^{c} (0.07)	10.07^{c} (0.9)
Treeless open	9.95 (0.04)	30.66 (0.32)	54.32^{a} (0.19)	1.87 (0.1)	10.22^{a} (0.87)	13.05^{a} (0.54)	5.91 (0.64)	30.66^{a} (1.02)	51.37^{a} (1.83)
F	0.159	2.426	6.178	2.829	5.689	4.628	2.792	4.457	6.457
p	0.857	0.117	0.035	0.136	0.041	0.043	0.139	0.045	0.032

Values with same superscript do not differ significantly
Values in the parenthesis represent standard error of the mean
DAP – Days After Planting

Table 26. Belowground plant nutrient accumulation in galangal under various landuse systems at Vellanikkara

Landuse type	Belowground plant nutrient accumulation (kg ha^{-1})								
	N			N			N		
	90 DAP	150 DAP	230 DAP	90 DAP	150 DAP	230 DAP	90 DAP	150 DAP	230 DAP
Coconut	2.91 (0.15)	7.32^{b} (0.21)	17.38^{b} (0.87)	0.60 (0.09)	1.37^{b} (0.12)	3.22^{b} (0.19)	2.34 (0.13)	7.48 (0.73)	13.00^{c} (0.84)
Homegarden	3.95 (0.24)	9.33^{b} (0.45)	12.24^{b} (0.96)	1.22 (0.05)	2.85^{b} (0.16)	5.39^{a} (0.31)	3.62 (0.09)	9.33 (0.44)	16.40^{b} (0.69)
Treeless open	7.69 (0.61)	18.12^{a} (0.19)	26.06^{a} (0.64)	1.76 (0.14)	4.70^{a} (0.41)	5.87^{a} (0.07)	5.52 (0.45)	18.99 (1.01)	25.15^{a} (0.78)
F	0.159	4.094	6.178	2.829	5.689	4.628	2.033	0.365	6.457
p	0.857	0.046	0.035	0.136	0.041	0.043	0.212	0.709	0.032

Values with same superscript do not differ significantly
Values in the parenthesis represent standard error of the mean
DAP – Days After Planting

Table 27. Specific leaf area of ginger, turmeric and galangal in various landuse regimes at Vellanikkara, Kerala

Landuse type	Specific leaf area ($cm^2 g^{-1}$)		
	Ginger	Turmeric	Galangal
Coconut	124.29^b (6.13)	170.09^a (12.05)	178.79^a (9.46)
Homegarden	174.51^a (11.03)	106.52^b (8.54)	180.01^a (13.04)
Treeless open	91.05^b (9.87)	139.66^b (12.07)	151.16^b (8.04)
F	9.2	5.2	6.2
p	0.001	0.046	0.035

Values with same superscript do not differ significantly
Values in the parenthesis represent standard error of the mean
DAP – Days After Planting

4.19 STAND LEAF AREA INDEX

Stand leaf area is an important determinant of understorey productivity in polyculture systems. Figure 12 shows the changes in stand leaf area index under coconut and homegarden. LAI varied between the homegarden and coconut considerably. Results clearly indicate that homegarden system had more stand leaf area index (3.84) while the same for pure coconut plantation was considerably low (2.21).

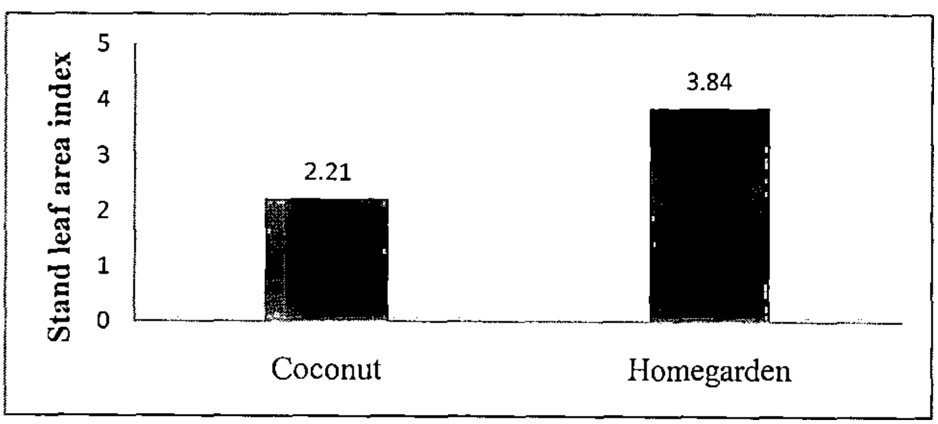


Figure 12. Stand leaf area index under coconut and homegarden at Vellanikkara, Thrissur

4.20 PHOTOSYNTHETICALLY ACTIVE RADIATION

Diurnal changes in understorey PAR in various land use systems showed distinct variability (Table 28). Mean photosynthetic photon flux density (PPFD) above the canopy ranged from 212 μ moles m^{-2} s^{-1} (8 am) to 1774 μ moles m^{-2} s^{-1} (1-2 pm). Mean mid-day (12 – 13 hrs) understorey photosynthetic Photon Flux Density (PPFD) levels ranged from 398 to 765 μmoles m^{-2} s^{-1}. The average mid-day PAR under the homegarden and coconut canopies ranged from 17 to 37 % of the incident PAR above the canopy. Lowest PAR was associated with homegarden (17 %).

4.21 SOIL NUTRIENT CONTENT

4.21.1 Initial soil nutrients and pH

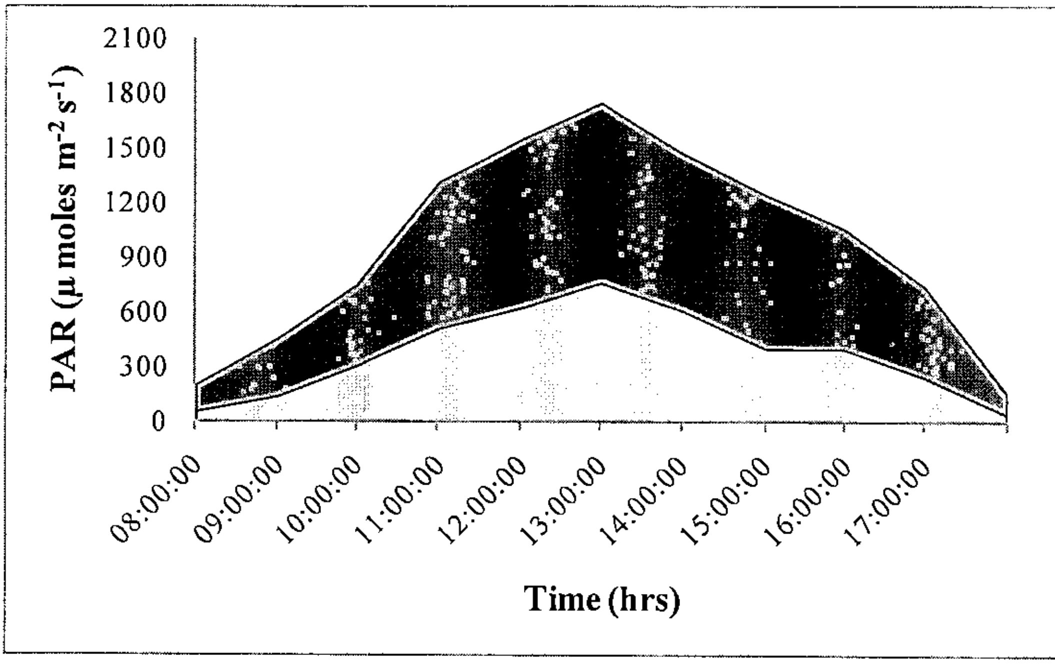
The data on initial soil nutrients (sampled prior to intercropping) and soil ph in different landuse systems are presented in the Table 29.

In general homegarden soil showed better physico-chemical attributes while open soil giving lower values. Higher pH was observed in homegarden (6.01) followed by coconut (5.39) and least in open tree less control (4.88). Among the systems organic carbon recorded highest value in homegarden (0.78 %) which was on par with coconut (0.71 %). The lowest organic content was in open soil (0.63 %). The highest soil nitrogen content was observed in the homegarden with 228.34 kg ha^{-1}. Nitrogen content in the coconut was on par with homegarden whereas treeless open soils recorded the lowest value (146.43 kg ha^{-1}).

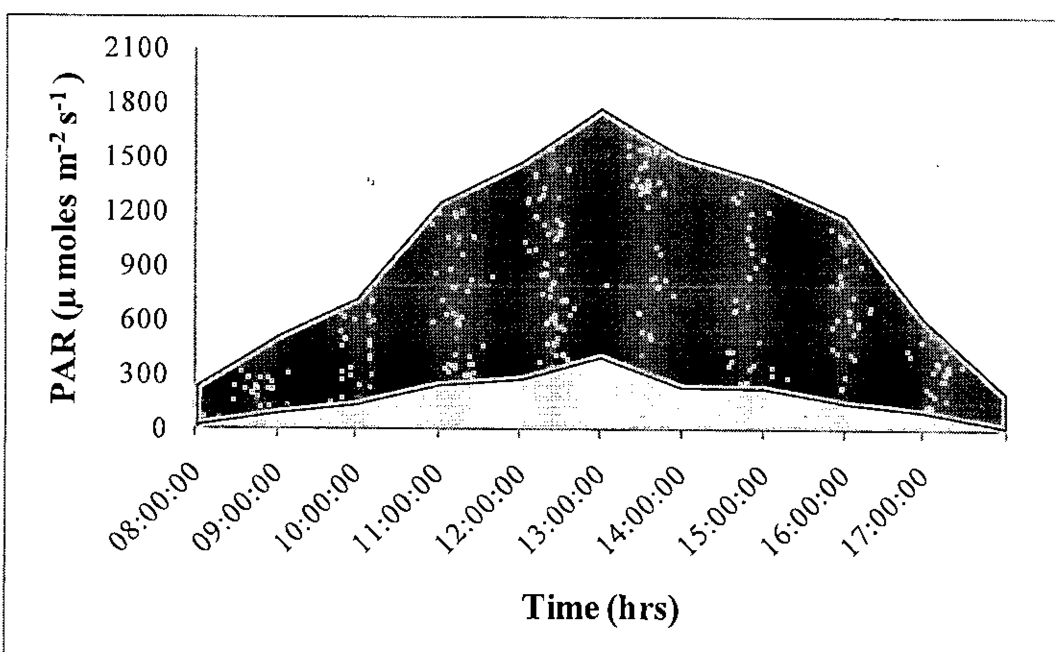
Soil phosphorus content varied significantly in all the landuse with highest content recorded in homegarden (65.29 kg ha^{-1}) and least in treeless open condition (31.62 kg ha^{-1}). Significant changes were noticed for soil potassium content having a trend similar to nitrogen and phosphorus with homegarden (223.76 kg ha^{-1}) registering highest and treeless open soil giving lowest value 125.21 kg ha^{-1}.

Table 28. Diurnal variation in understorey PAR transmission for homegarden and coconut at Vellanikkara, Kerala

Time (Hours)	**Coconut**			**Homegarden**		
	I_1 (μ moles $m^{-2} s^{-1}$)	**I_2** (μmoles $m^{-2} s^{-1}$)	**Transmittance** (%)	**I_1** (μmoles $m^{-2} s^{-1}$)	**I_2** (μmoles $m^{-2} s^{-1}$)	**Transmittance** (%)
08:00:00	212	65	30.66	248	31	12.50
09:00:00	465	146	31.40	521	96	18.43
10:00:00	759	312	41.11	725	142	19.59
11:00:00	1326	515	38.84	1254	245	19.54
12:00:00	1562	629	40.27	1481	279	18.84
13:00:00	1760	765	43.47	1774	398	22.44
14:00:00	1486	614	41.32	1515	236	15.58
15:00:00	1256	408	32.48	1378	229	16.62
16:00:00	1065	402	37.75	1185	152	12.83
17:00:00	753	253	33.60	624	106	16.99



a) Coconut



b) Homegarden

Figure 13. Diurnal variation in understorey PAR transmission for a) Coconut and b) Homegarden at Vellanikkara, Kerala

Table 29. Nutrient status and pH in the soils prior to the field trial at Vellanikkara, Kerala

Landuse type	pH	Org C (%)	N ($kg\ ha^{-1}$)	P ($kg\ ha^{-1}$)	K ($kg\ ha^{-1}$)
Coconut	5.39^{b} (0.14)	0.71^{ab} (0.03)	196.42^{a} (5.6)	57.84^{a} (3.98)	151.99^{b} (1.85)
Homegarden	6.01^{a} (0.23)	0.78^{a} (0.02)	228.34^{a} (5.35)	65.29^{a} (9.44)	223.76^{a} (2.81)
Treeless open	4.88^{b} (0.08)	0.63^{b} (0.05)	146.43^{b} (10.93)	31.62^{b} (7.82)	125.21^{b} (13.28)
F	11.875	4.949	13.225	5.653	22.635
p	0.008	0.04	0.006	0.042	0.002

Values with same superscript do not differ significantly
Values in the parenthesis represent standard error of the mean

4.21.2 Soil nutrients at 150 and 230 DAP

The data on soil nutrients in ginger beds as influenced by different landuse at 150 and 230 DAP are given in the Table 30.

Comparison of the Tables 29 and 30 suggest that intercropping improved the soil nutrient status. For instance N, P and K content in the soil at final crop harvest was considerably higher compared to the initial soil samples.

4.21.2.1 Ginger

Nitrogen content in the ginger beds varied considerably over time. Generally nitrogen content in the bed reduced at final harvest. In both the observational times homegarden recorded higher nitrogen content (257.61 kg ha^{-1} at 150 DAP and 247.67 kg ha^{-1} at 230 DAP) followed by coconut and treeless open. Likewise phosphorous also showed the same pattern with a value of 166.49 kg ha^{-1} at 150 DAP and lower value of 133.85 kg ha^{-1} at 230 DAP in homegarden. Treeless open exhibit lowest value of phosphorous content (61.87 kg ha^{-1} at 150 DAP and 55.43 kg ha^{-1} at 230 DAP) which on par with coconut. The potassium content in the ginger bed also suggested high value associated with homegarden followed by coconut which is on par with treeless open. At 230 DAP, homegarden soil recorded slightly lower value of 243.9 kg ha^{-1}. Nevertheless, both treeless open and coconut showed almost the similar values.

Table 30. Soil nutrient status in ginger beds at various landuse regime of Vellanikkara, Kerala

Landuse type	Soil nutrient status (kg ha^{-1})					
	N		P		K	
	150 DAP	230 DAP	150 DAP	230 DAP	150 DAP	230 DAP
Coconut	232.56^{b} (8.63)	225.32^{ab} (5.26)	82.85^{b} (12.23)	74.31^{b} (4.39)	192.86^{b} (4.66)	146.48^{b} (6.91)
Homegarden	257.6^{a} (12.01)	247.67^{a} (13.73)	166.49^{a} (12.54)	133.85^{a} (15.54)	271.24^{a} (17.13)	243.9^{a} (16.62)
Treeless open	191.8^{c} (6.74)	178.67^{b} (9.94)	61.87^{b} (7.76)	55.43^{b} (2.9)	173.09^{b} (16.95)	146.02^{b} (19.49)
F	11.232	4.628	25.037	18.629	14.028	6.909
p	0.008	0.043	0.00	0.003	0.005	0.028

Values with same superscript do not differ significantly
Values in the parenthesis represent standard error of the mean
DAP – Days After Planting

4.21.2.2 Turmeric

Comparatively smaller changes were observed in nitrogen content during both the stages of sampling in the turmeric beds. Nitrogen content in the homegarden soil showed the highest value of 314.13 kg ha^{-1} and 311.42kg ha^{-1} at 150 DAP and 230 DAP. It was then followed by coconut and treeless open. In case of phosphorous and potassium a common trend was seen, with homegarden marking a peak value of 153.81 kg ha^{-1} and 121.36 kg ha^{-1} at 150 DAP and 230 DAP respectively for phosphorous. Similarly homegarden showed characteristically higher K content in the soil (257.16 kg ha^{-1} and 249.47 kg ha^{-1} at 150 DAP and 230 DAP). In both the cases, treeless open showed the lowest content on par with coconut.

Table 31. Soil nutrient status in turmeric beds at various landuse regime of Vellanikkara, Kerala

Landuse type	Soil nutrient status (kg ha^{-1})					
	N		P		K	
	150 DAP	230 DAP	150 DAP	230 DAP	150 DAP	230 DAP
Coconut	240.45^{b} (5.68)	231.22^{b} (16.17)	79.36^{b} (7.51)	60.83^{b} (6.91)	172.68^{b} (14.75)	153.1^{b} (9.95)
Homegarden	314.13^{a} (10.01)	311.42^{a} (8.15)	153.81^{a} (15.74)	121.36^{a} (14.16)	257.16^{a} (12.21)	249.47^{a} (17.97)
Treeless open	180.39^{c} (11.62)	169.19^{c} (11.63)	59.75^{b} (4.33)	44.06^{b} (3.15)	161.96^{b} (18.84)	118.85^{b} (6.99)
F	5.219	32.937	22.883	19.219	5.584	29.248
P	0.049	0.00	0.00	0.002	0.043	0.00

Values with same superscript do not differ significantly
Values in the parenthesis represent standard error of the mean
DAP – Days After Planting

4.21.2.3 Galangal

Nitrogen content in galangal bed had a marked changes at 150 DAP varying from a minimum value of 192.85 kg ha^{-1} in treeless open, 296.81kg ha^{-1} in coconut and a maximum value of 337.99 kg ha^{-1}in homegarden. A similar trend exist in 230 DAP also. Significantly highest nitrogen content (kg ha^{-1}) was observed in homegarden, followed by coconut (285.59 kg ha^{-1}) and lowest in treeless open (177.6 kg ha^{-1}). Perceptible changes were found in soil phosphorous content in the galangal beds at different landuse. In both the sampling stages, phosphorous content changed in a predictable pattern. At 150 DAP, homegarden exhibited highest value of 168.4 kg ha^{-1} and treeless open exhibited lowest value of 61.63 kg ha^{-1} which was on par with coconut (89.95 kg ha^{-1}). At 230 DAP, highest P content was again showed by homegarden, and the lowest by treeless open soil. Potassium content in the galangal bed was observed to be maximum in homegarden in both the sampling stages (244.63 kg ha^{-1} at 150 DAP and 240.12 kg ha^{-1} at 230 DAP). At 150 DAP, coconut showed the minimum value of 183.94 kg ha^{-1} which was on par with treeless open (188.66 kg ha^{-1}). Where as in the second sampling stage of 150 DAP, treeless open exhibited the lowest value of 134.32 kg ha^{-1} which was on par with coconut

Table 32. Soil nutrient status in galangal beds at various landuse regime of Vellanikkara, Kerala

Landuse type	Soil nutrient status (kg ha^{-1})					
	N		P		K	
	150 DAP	230 DAP	150 DAP	230 DAP	150 DAP	230 DAP
Coconut	296.81^{b} (9.29)	285.59^{b} (3)	89.95^{b} (5.06)	76.99^{b} (2.81)	183.94^{b} (4.09)	143.37^{b} (13.42)
Homegarden	337.99^{a} (6.25)	334.87^{a} (5.72)	168.4^{a} (13.83)	166.04^{a} (12.76)	244.63^{a} (7.92)	240.12^{a} (14.32)
Treeless open	192.85^{c} (7.76)	177.6^{c} (5.48)	61.63^{b} (6.3)	47.93^{b} (8.62)	188.66^{b} (10.32)	134.32^{b} (3.61)
F	5.653	5.584	35.766	46.339	18.393	8.950
p	0.042	0.043	0.000	0.000	0.003	0.016

Values with same superscript do not differ significantly
Values in the parenthesis represent standard error of the mean
DAP – Days After Planting

4.21.2.4 Soil nutrient status in the non-intercropped area

Nitrogen content in the fields without inter crops exhibited a different trend in both the sampling stages. At 150 DAP, nitrogen content were found to be maximum at homegarden with 247.96 kg ha^{-1} followed by coconut (218.99 kg ha^{-1}) which was on par with homegarden and considerably different from treeless open. However, relatively different values of nitrogen content were observed at 230 DAP. Homegarden (255.37 kg ha^{-1}) recorded significantly highest content followed by coconut and lowest in treeless open (156.13 kg ha^{-1}). Phosphorous content did not vary considerably in both the sampling stages. Yet 150 DAP, it varied from 69.33 kg ha^{-1} in homegarden to 36.67 kg ha^{-1} in treeless open. At 230 DAP also, these landuse were reported with similar values in the soil phosphorous content. It varied from 64.3 kg ha^{-1} in homegarden, 55.07 kg ha^{-1} in coconut and 37.2 kg ha^{-1} in treeless open. Potassium content at 150 DAP was observed to be maximum in homegarden (219.35 kg ha^{-1}) and minimum in treeless open (139.13kg ha^{-1}) which was in par with coconut (156.17 kg ha^{-1}). At 230 DAP, homegarden was observed to be with highest potassium content of 238.93 kg ha^{-1} followed by coconut which was on par with treeless open.

Table 33. Soil nutrient status of the landuse regime area devoid of medicinal plants at Vellanikkara, Kerala

Landuse type	Soil nutrient status (kg ha^{-1})					
	N		P		K	
	150 DAP	230 DAP	150 DAP	230 DAP	150 DAP	230 DAP
Coconut	218.99[a] (8.48)	221.74[b] (9.31)	52.93 (12.23)	55.07[b] (19.81)	156.17[b] (11.26)	158.55[b] (9.83)
Homegarden	247.96[a] (14.91)	255.37[a] (6.29)	69.33 (13.49)	64.3[a] (6.07)	219.35[a] (11.75)	238.93[a] (15.8)
Treeless open	153.93[b] (7)	156.13[c] (3.91)	36.67 (4.8)	37.2[c] (5.85)	139.13[b] (2.55)	140.85[b] (18.59)
F	20.270	53.977	2.256	4.422	8.984	11.841
p	0.002	0.000	0.186	0.052	0.016	0.008

Values with same superscript do not differ significantly
Values in the parenthesis represent standard error of the mean
DAP – Days After Planting

4.22 BULK DENSITY

Soil bulk density varied significantly across the soil depth as well as between the landuse systems. Generally bulk density showed a increasing trend with the increase in soil depth up to 1m from the surface layer. In coconut, bulk density varied from 1.12 at 0-20 cm to 1.28 at 81-100 cm. Similar trends were observed for homegarden also, with a value ranging from 1.05 at 0-20 cm to 1.2 at 81-100 cm.

Bulk density of the soils in the treeless open areas registered high values while homegarden represented lower bulk density throughout the soil profile varied from 1.17 at 0-20 cm to 1.35 at 81-100 cm depth. There was a percentage increase of 15.38 % from first layer to the lowest layer.

Table 34. Variation in bulk density as a function of soil depth for selected landuse regimes at Vellanikkara, Kerala

Depth (cm)	Bulk density ($g\ cm^{-3}$)			Depth mean
	Coconut	Homegarden	Open	
0-20	1.12^{c} (0.14)	1.05^{c} (0.12)	1.17^{d} (0.19)	1.13
21-40	1.14^{b} (0.04)	1.12^{c} (0.8)	1.23^{c} (0.45)	1.16
41-60	1.2^{b} (0.08)	1.16^{b} (0.18)	1.29^{b} (0.86)	1.22
61-80	1.23^{ab} (0.06)	1.19^{a} (0.08)	1.34^{a} (0.29)	1.25
81-100	1.28^{a} (0.08)	1.2^{a} (0.09)	1.35^{a} (0.86)	1.28
Treatment mean	1.19	1.15	1.28	

Values with same superscript do not differ significantly
Values in the parenthesis represent standard error of the mean
DAP – Days After Planting

4.23 ORGANIC CARBON

Organic carbon percentage followed exactly the similar trend as that of organic matter percentage. The values showed a decreasing trend with increase in soil depth. In case of coconut, the topmost layer of 0-20 cm recorded 0.73 %, 21-40m as 0.38 %, 41-60 cm as 0.49 %, 61-80 cm as 0.52 % and the lower most layer as 0.41 %. A similar trend existed in homegarden also with maximum value of 0.78 % in the top most layer and minimum value of 0.39 % in the lower most layer whereas, in the treeless open plot the percentage organic carbon content varies from 0.65 to 0.27 %.

As we compare the systems, the highest value lies in homegarden at a depth of 0-20 cm and the lowest value is exhibited in treeless open plot at a depth of 61-80 cm which was observed as 0.27 %.

Table 35. Variation in organic carbon as a function of soil depth for selected landuse regimes at Vellanikkara, Kerala

Depth (cm)	Organic carbon (%)			Depth mean
	Coconut	Homegarden	Open	
0-20	0.73 (0.08)	0.78[a] (0.09)	0.55[b] (0.05)	0.69
21-40	0.38 (0.15)	0.7[a] (0.09)	0.65[a] (0.08)	0.58
41-60	0.49 (0.1)	0.63[b] (0.06)	0.42[c] (0.07)	0.51
61-80	0.52 (0.08)	0.46[c] (0.09)	0.27[d] (0.08)	0.42
81-100	0.41 (0.05)	0.39[d] (0.06)	0.31[d] (0.08)	0.37
Treatment mean	0.51	0.59	0.44	

Values with same superscript do not differ significantly
Values in the parenthesis represent standard error of the mean
DAP – Days After Planting

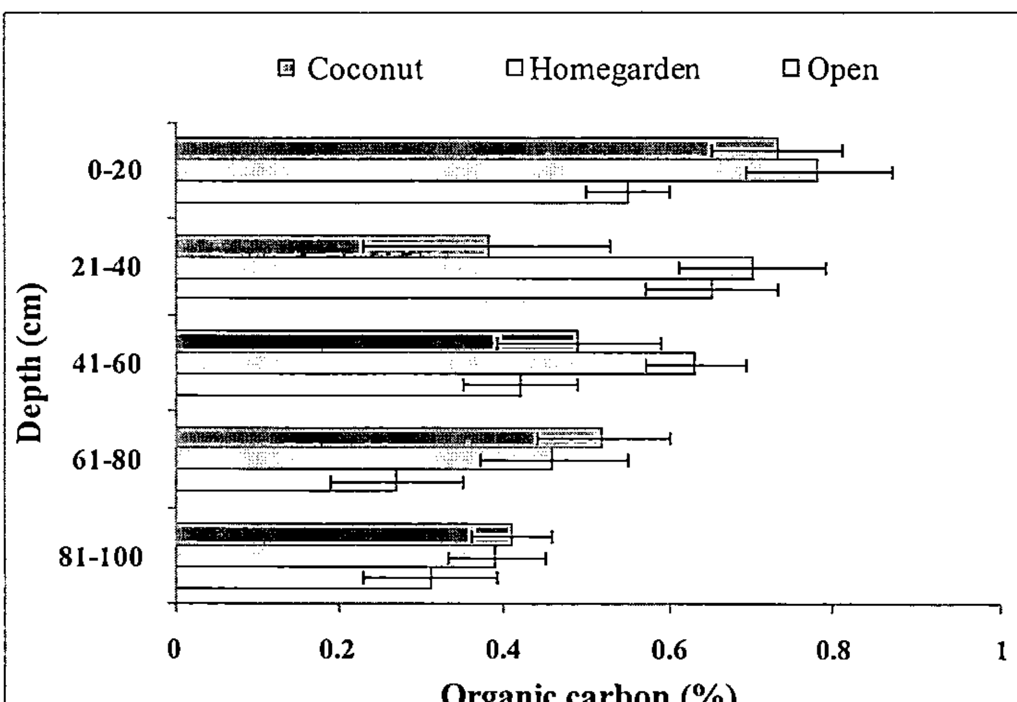


Figure 14. Variation in organic carbon as a function of soil depth for selected landuse regimes at Vellanikkara, Kerala

4.24 ORGANIC MATTER

Among the landuse system, higher soil organic matter content was found associated with homegarden (1.34 %) and lowest by soil in the treeless open condition. The organic matter content also showed consistent decline with increasing soil depth. Interestingly both the woody systems maintained fairly good organic matter at deepest horizon (0.7 and 0.67 % for coconut and homegarden respectively at 81-100 cm depth). Nonetheless, treeless open showed lowest organic matter content at farthest soil depths.

Table 36. Variation in organic matter as a function of soil depth for selected landuse regimes at Vellanikkara, Kerala

Depth (cm)	Organic matter (%)			Depth mean
	Coconut	Homegarden	Open	
0-20	1.25 (0.09)	1.34^{a} (0.1)	0.94^{b} (0.05)	1.18
21-40	0.65 (0.06)	1.2^{a} (0.08)	1.11^{a} (0.13)	0.99
41-60	0.84 (0.08)	1.08^{b} (0.21)	0.72^{c} (0.17)	0.88
61-80	0.89 (0.1)	0.79^{c} (0.17)	0.46^{d} (0.08)	0.71
81-100	0.7 (0.04)	0.67^{d} (0.9)	0.53^{d} (0.06)	0.63
Treatment mean	0.87	1.02	0.75	

4.25 MEAN SOIL ORGANIC CARBON CONTENT

Vertical distribution of soil organic carbon showed a constant decline with increasing depth for all the land use systems. Accordingly, the surface soil horizon recorded highest carbon content of 16.21, 17.39 and 12.83 Mg ha^{-1} respectively for coconut, homegarden and open. Among the two wooded ecosystems, homegarden maintained higher carbon for all soil horizons. Convincingly, treeless open soil showed lowest carbon content at all soil depths. The percentage reduction in carbon content at the deepest sample layer (81-100 cm) was 35.9, 46.34 and 34.84 % of the carbon at surface horizon for coconut, homegarden and treeless open respectively. Irrespective of horizon the average soil organic carbon content followed the order 11.93, 13.49 and 11.02 Mg ha^{-1} for coconut, homegarden and treeless open respectively.

Table 37. Variation in mean soil organic carbon content as a function of soil depth for selected landuse regimes at Vellanikkara, Kerala

Depth (cm)	Mean soil organic carbon content (Mg ha^{-1})			Depth mean
	Coconut	Homegarden	Open	
0-20	16.21 (1.11)	17.39^{a} (0.85)	12.83^{ab} (0.78)	15.48
21-40	8.63 (0.85)	15.31^{a} (1.08)	15.91^{a} (0.94)	13.28
41-60	11.67 (0.46)	14.55^{b} (1.46)	10.81^{b} (0.24)	12.34
61-80	12.75 (0.25)	10.87^{c} (1.19)	7.19^{c} (0.93)	10.27
81-100	10.39 (0.18)	9.33^{d} (0.42)	8.36^{c} (0.16)	9.36
Treatment mean	11.93	13.49	11.02	

Values with same superscript do not differ significantly
Values in the parenthesis represent standard error of the mean
DAP – Days After Planting

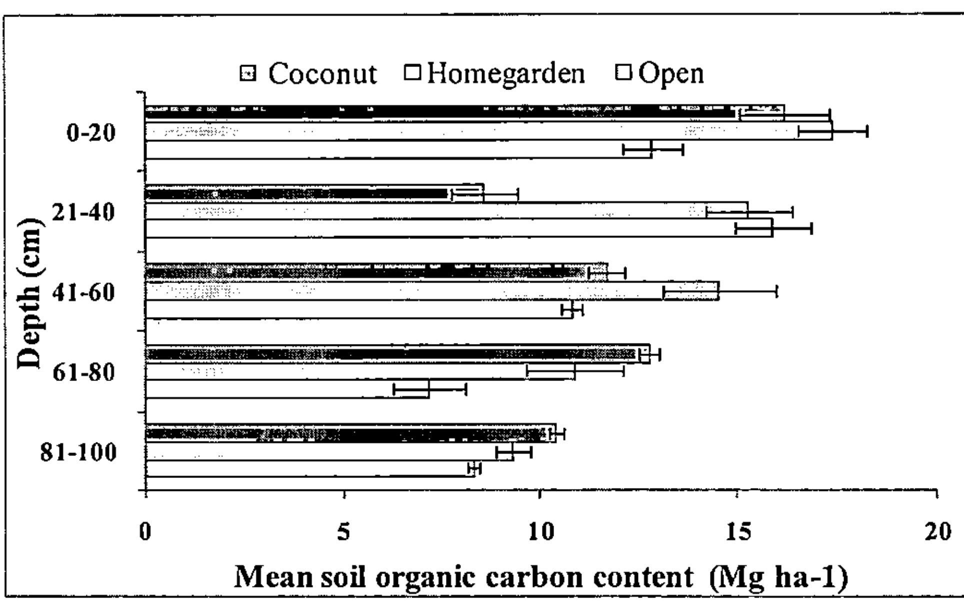


Figure 15. Variation in mean soil organic carbon content as a function of soil depth for selected landuse regimes at Vellanikkara, Kerala

4.26 Allometric models

Regression equation relating PAR with rhizome yields showed statistical soundness with high coefficient of determination (r^2) values (Table 38). Linear, quadratic and logarithmic models were the best predictors of understorey productivity for the selected intercrops. Considering correlation between ginger yield and understorey PAR (r^2=0.63 to 0.99), regression equations were developed linking these two variables. Linear, quadratic and logarithmic equations gave good fit with high r^2 values 0.63, 0.99 and 0.84 respectively. Though, all of the equations were statistically not significant for ginger. In case of turmeric the correlation was sound and linear, quadratic and logarithmic equations gave good fit with high r^2 values 0.86 to 0.98. Except for simple linear equation statistical soundness were observed with all. Correlation in galangal was sound with high r^2 values 0.94 to 0.99. Except for quadratic equation statistical soundness were observed with rest of the equations. Simple linear equation may be more acceptable on account of its simplicity in use compared to quadratic and logarithmic equations. These models will help to predict the intercrop productivity under various land management systems as a function of understorey PAR availability.

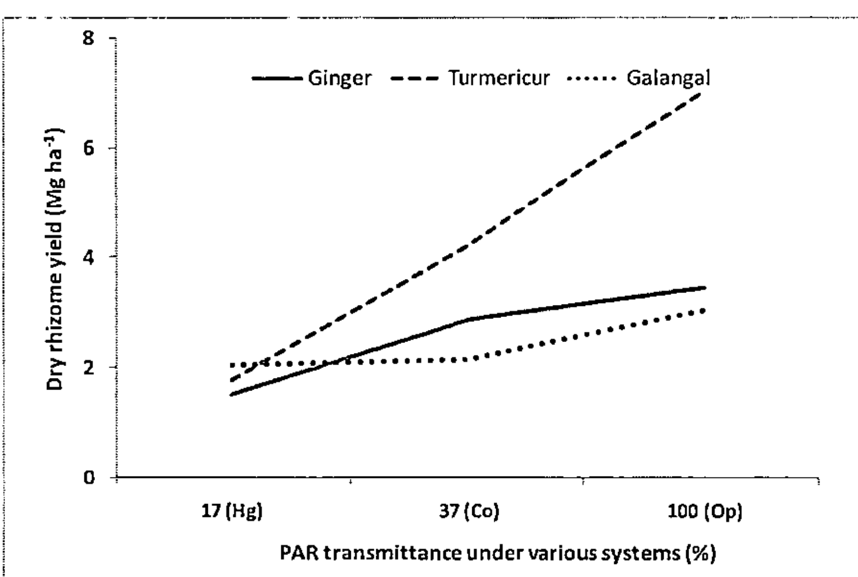


Figure 16. Understorey PAR and rhizome yield under various land management systems

Table 38. Allometric models for rhizome yield and understorey PAR transmittance for various herbaceous crops at Vellanikkara, Kerala

Sl. No	Model	Coefficients a_0	a_1	a_2	r^2
		Ginger			
1	$Y = a_0 + a_1*D$	1.955^{ns}	0.016^{ns}	-	0.63
2	$Y = a_0 + a_1*D + a_2*D^2$	0.367^{ns}	0.171^{ns}	-0.001	0.99
3	$\ln Y = a_0 + a_1* \ln D$	0.472^{ns}	0.682^{ns}	-	0.84
		Turmeric			
1	$Y = a_0 + a_1*D$	2.371^{ns}	0.048^{ns}		0.86
2	$Y = a_0 + a_1*D + a_2*D^2$	-0.231^{ns}	0.301^{ns}	-0.002	0.99
3	$\ln Y = a_0 + a_1* \ln D$	-1.660^{*}	1.917^{*}		0.98
		Galangal			
1	$Y = a_0 + a_1*D$	1.961**	.011**		0.97
2	$Y = a_0 + a_1*D + a_2*D^2$	1.967^{ns}	0.01^{ns}	4.809E-006 ^{ns}	0.99
3	$\ln Y = a_0 + a_1* \ln D$	1.157**	0.402**		0.94

Equation models: 1= Linear with one independent variable, 2=Quadratic; 3=Logarithmic.

Y= mean rhizome yield, D= PAR transmittance (%); ns = not significant at 0.05 level; * significant at 0.05 level; ** significant at 0.01 level.

Discussion

DISCUSSION

The one year long field study has been undertaken to optimize understorey productivity of selected medicinal herbs in the prominent land management systems of Kerala *viz.* mature coconut garden and homegarden. The intercrop growth attributes and the biophysical factors that regulate understorey productivity were evaluated critically as part of the study. The salient findings are discussed hereunder.

5.1 GROWTH PERFORMANCE OF THE INTERCROPS

5.1.1 Plant height

One of the primary requisites that decide the possibility of intercropping in polyculture system is the availability of light which depends on the extent of interception by their canopies. Plant height has been reported as a growth variable sensitive to shading. In the present study ginger and turmeric performed better in terms of plant height under coconut. Galangal also exhibited increased (30.15 cm) leaf spread in coconut field (Table 1). Despite the weak statistical significance in ginger height growth among the various woody systems at 150 DAP, in general the medicinal crop height growth was better under woody cover as compared to treeless open. However, intense shade may inhibit the plant height and leaf spread as observed in homegarden for galangal. Probably, under shaded conditions plants compete each other for the vertical advantage in light acquisition resulting in better height growth under shaded conditions. According to Meyer and Anderson (1952) high irradiance may result in high rates of transpiration which are likely to result in internal deficiencies of water and a consequent retardation of cell division or cell enlargement, ultimately resulting in low height in plants grown under treeless open condition. However the poor height for turmeric in the homegarden suggesting the species difference in intercrop performance under varying light regimes (Kumar *et al.* 2001).

The general effect of shading on plants was studied by Ross (1976) and reported that plants under shaded conditions exhibited increased growth of main axis. Aclan and Quisumbing (1976) reported that ginger plants grown under full sunlight were found to be shorter compared to shaded plants. Similar positive influence of shading on plant height has been reported for ginger, coleus and sweet potato (Bai and Nair, 1982). In yet another study, Verghese (1989) reported that in ginger plant height increased with increase in shade intensity from zero to 75 per cent at 60 DAP only, after which plants grown at 25 per cent shade had the highest plant height, whereas in turmeric, with increase in shade, plant height increased up to medium shade of 50 per cent and then decreased. Many published reports are available on the Increase in plant height with increasing shade intensities in ginger (Jayachandran *et al.*1991; Ancy, 1992; Ajithkumar, 1990; Sreekala, 1999; Amin *et al*, 2010; Bhuiyan *et al*, 2012). Such height sensitivity to shade level has been reported for other intercrops as well.

5.1.2 Tiller production

Observations revealed highest tiller production was in treeless open grown ginger and turmeric plants (Table 5). The reduction in ginger tiller production was almost half for homegarden whereas in coconut grown ginger showed about 30 % reduction. Homegarden represented lowest ginger tiller production during both the sampling periods which incidentally had the lowest light availability. Such lowering in tiller production with reduction in understorey light has been reported earlier for ginger and turmeric (Verghese, 1989). However weak response on tiller production with varying light levels also has been observed. For instance, Moursi *et al.* (1976) in wheat and Prameela (1990) in colocasia observed non significant effect of shade on tiller production. Reduced tiller production under shade may be due to the low Red: Far-red ratio at the base of the plants caused by the shade (Ancy, 1992). A limitation in energy supply resulting from the decreased proportion of incident radiation available per tiller may also be partly responsible for the decrease in tiller formation (Attridge, 1990). Furthermore, at high shade intensity the limited biomass production will be allocated more towards increase in plant height and this may have delayed the allocation for tiller production. Thus the reduced photosynthetic activity under heavy shade may be suppressing the growth and development of tillers (Sreekala, 1999). Galangal also produced more tiller in treeless open condition (7.83). Contrary to these observations there are reports that suggest increased tiller production for ginger under tree cover managed under shaded conditions compared to growth in treeless open (Wilson and Ovid, 1992; Jaswal *et al.*, 1993; Newman *et al.*, 1998).

5.1.3 Leaf production

Observations revealed highest leaf production was in shaded conditions for ginger as in coconut followed by homegarden and lowest under treeless open (Table 6). Such lower leaf production for ginger in full sunlight has been reported from many studies (Ancy, 1992; Aclan and Quisumbing, 1976). The increase in leaf production may be due to decrease in the number of tillers and vice versa. In case of turmeric there was marginal reduction in number of leaves under coconut and homegarden whereas galangal showed highest leaf production in coconut. Observations in general suggest that leaf production is more of species dependent though shade influences leaf production as reported. For instance, a decrease in number of leaves with increase in shade intensity was observed in ginger (Verghese 1989; Sreekala 1999). A clear cut trend in leaf production was not discernible for turmeric despite a moderate increase in treeless open conditions. However, in turmeric lowest number of leaves per tiller grown under full sunlight has been observed compared to shade grown plants. Similar result were reported by Bhuiyan *et al.*, 2012. Galangal at 90 DAP showed higher leaf production in the open condition though, the difference were marginal at 150 DAP. Similar results has been obtained for galangal for example, Latha (1994) found more leaf production in open grown galangal. Kumar *et al.* (2005) found vegetative growth of galangal was greater in the open, implying a favourable effect of high radiation intensity.

5.1.4 Root production

Mean root length of medicinal plants was fairly high in treeless open plots except for galangal. At 150 DAP, coconut and homegarden displayed 4.8 and

31.93 per cent reduction in root length for ginger in contrast to open control (Table 4). At 150 DAP, turmeric root length showed marginal variation among cropping system. It was better in control plot (18.33 cm) followed by coconut (18.29 cm) and homegarden (13.42 cm). Galangal root growth during the two sampling periods suggest only marginal increase except for coconut which registered about 47 % increase during 90 to 150 DAP. Root development in plants is very much influenced by the species. Also the soil resource availability decides the root production and distribution patterns especially in tree bases ecosystems. The intercrop roots may stretch the root system to more soil volume in the open condition in search of water and minerals which are often limited in open soil compared to wooded ecosystem. The restricted root production in homegarden could be attributed to the intense below ground competition for resources. Conversely this could also be attributed to the ample availability of resources at shallow depths in the homegardens rendering the plants not to stretch the roots to higher soil depths.

5.2 OLEORESIN CONTENT

Oleoresin content is an important parameter for which rhizomatous plants such as ginger, turmeric and galangal are valued. The species dependence on oleoresin content is evident from the study. Among the three intercrops average oleoresin content was highest for turmeric (11.05 %) followed by ginger (4.62 %) and galangal (2.80 %). Oleoresin content in all the crops was invariably highest in homegarden and lowest in treeless open plot, despite poor statistical differences (Table 13). In ginger it varied from 4.02 % in treeless open to 4.62 % in homegarden, in turmeric from 9.92 in treeless open to 11.05 % in homegarden and in galangal the oleoresin content varied from 2.26 in treeless open to 2.80 % in homegarden. The relatively more oleoresin content in homegarden and coconut compared to treeless open may be explained as a function of understorey PAR availability. Essential oil and oleoresin contents were also greater in the rhizomes of the intercropped galangal (Maheswarappa *et al.*, 1998) compared to open grown galangal. Shade can influence the production of secondary metabolites and reduce the oxidation of other biochemical activities resulting in high oleoresin content (Zachariah and Gopalan, 1987). Shade influence on secondary metabolites in ginger has been reported by Ravishankar and Muthuswamy, 1988). However few studies relating insensitivity of shade levels on oleoresin yield (Latha,1994). Similar observations were also noticed by Kumar *et al.* (2001) in ginger and Sureshkumar (1997) in galangal. Other factors that influence oleoresin content of rhizomes are variety, maturity and environment while shade exerts major influence (Kumar *et al.*, 2005).

5.3 CHLOROPHYLL CONTENT

Chlorophyll is vital for photosynthesis, which allows plants to absorb energy from light. Chlorophyll content in all selected intercrops was recorded consistently highest in homegarden followed by coconut while lowest in treeless open in the present study (Table 14). Differences were significant in turmeric and galangal. As compared to control the percentage increase in total chlorophyll content for coconut was 17.98 % for turmeric and 14.28 % for galangal. The percentage increase was highest for homegarden with 73.38 % for turmeric and 90 % of galangal respectively as compared to control. The influence of shade on leaf chlorophyll content appeared to be very much prominent which varied with land use systems.

Most scientists have quoted positive effect of shading on chlorophyll content in plants. In ginger and turmeric, an increase in chlorophyll content with increase in shade intensity has been reported (Verghese, 1989; Ancy, 1992). Gardener *et al.* (1952) and Bjorkman and Holmgren (1963) observed that the concentration of chlorophyll per unit weight of leaf increased with decreasing light intensities until the intensity was so low that it hazarded the survival of plants. Ravisankar and Muthuswamy (1988) observed higher content of total chlorophyll and its components in ginger in two-year and six-year old arecanut plantations compared to those grown in the treeless open.

This increase in chlorophyll under shaded conditions is an adaptive mechanism commonly observed in plants to maintain the photosynthetic efficiency (Attridge, 1990). It may be because shade leaves need to invest more energy for improving the photosynthetic efficiency than plants growing under open conditions, thus increasing chlorophyll content. The lower chlorophyll content in sun leaves may be attributed to faster light compensation point under intense light conditions (Kochar, 1978). It appears that relatively low temperature combined with low light intensity contributes to development of more chlorophyll in ginger (Sreekala and Jayachandran, 2001).

5.4 PHOTOSYNTHETICALLY ACTIVE RADIATION (PAR)

Competition for light often determines the success of a component in mixed cropping scenario. A variation in height could profoundly affect the yield of shorter component (Trenbath, 1976). In agroforestry systems, the amount of light available at the ground level depends primarily on the nature of the tree species, their spacing/planting geometry and age (Payne, 1985; Mathew *et al.*, 1992). The spectral quality of radiation will change with depth of penetration into plant canopies because leaves absorb solar radiation differently. PAR, one of the requirements for productive growth of plants is used to evaluate the growth potential of understorey component in agroforestry systems. The important factor to be considered is the light use efficiency. The biomass yield limit is set by the available light, its efficiency with which intercepted light is converted into biomass (Long *et al.*, 2006).

In the present study light availability (PAR) was 17 and 37 % in homegarden and coconut fields respectively. Such wide variability in understorey light regimes has been reported for multi species- multi strata agroforestry systems (Kumar *et al*, 2005). Manjunath *et al.* (2002) reported that mean transmission of PAR in 12 years old coconut plantation varied from 23.1 to 36.6 per cent of the open light depending on the period of year (season). Kasturibai *et al.* (1991) reported on the reduction in light intensity reaching canopy of intercrops due to interception by coconut canopy under coconut based intercropping system. It is obvious that density of vegetation in the homegarden favoured the reduction in PAR. Implicit in this marked reduction in understorey light availability is the interception of substantial portion of incoming solar radiation depending upon the nature of tree crowns. Probably the high canopy density contributed by the multistrata combination of diverse plant components (trees, herbs and shrubs) in the homegarden leads to substantial light interception at the various strata leading to reduction in the understorey PAR. The coconut canopy also captured sizable quantum of PAR may be on account of the lower mean palm heights (8-10 m) and close spatial spread of the coconut leaves. PAR levels under coconut may improve with palm maturity (Nelliat, *et al.*, 1974; Nair, 1993).

Generally the mid growth phase (8-25 years) is the intense growth period in coconut plantation limiting understorey PAR availability while period up to 8 year and beyond 25 year facilitate intercropping under coconut. This could be the reason for the moderate understorey production. As regards crown characteristics, leaf density and leaf angle had positive curvilinear relationships with understorey light intensity (Agetsuma, 1989). Sampson and Smith (1993) simulated the effects of changing canopy architecture on light infiltration and found that the order of importance on light penetration was leaf area index, foliage aggregation, average leaf inclination angle and vertical distribution of foliage. Wider spacing in bamboo intercepted less solar radiation by canopy and allowed more solar radiation to reach the ground which might have stimulated the understorey growth and resulted in more understorey dry matter production.

PAR of 62 to 82 % resulted in better turmeric and ginger dry matter production and rhizome yield (Bhimappa, 2014). In the present study PAR of 37 % resulted in the better yield of ginger, turmeric and galangal. Kasanga and Monsi (1954) also revealed that the understorey growth rate is proportional to the amount of radiation intercepted by the canopy. Kunhamu *et al* (2008) reported that ginger yield increased linearly with increasing PAR in *Acacia mangium* based intercropping. The reduced yield of intercrops in close spacing's may be due to competition of light, in which larger plants have disproportionate advantage of shading smaller ones (Casper and Jackson, 1997). Preferably, closer spacing and the multitier crown characteristics contributed to the distinct variation in understorey PAR for homegarden compared to coconut.

5.5 DRY MATTER PRODUCTION

Maximum aboveground dry biomass was observed at 150 DAP for all medicinal plants except for galangal. The dry spell and reduction in number of functional leaves may account for the reduction in dry weight during the final stages of observation for galangal (Table 8). As regards belowground biomass yield (rhizome) over time it essentially followed a linear trend (Table 10). Dry belowground yields during the three sampling periods showed significant difference among the landuse systems. In brief ginger production was lower in homegarden during all the growth stages. At final harvest, as compared to open grown ginger the reduction in dry biomass was 17.21 % and 53.79 % for coconut and homegarden respectively.

In general, the overall growth performance of ginger was better under mature coconut plantation compared to homegarden. Better performance of ginger grown under mature coconut plantation has been reported earlier (Sujatha *et al.*, 1994). Coconut root spread normally confined to 2 m radius around the tree giving almost 3 m less competitive zone between primary rows of coconut palm (Nelliat *et al.*, 1974). This competitive advantage probably facilitates growth of ginger as an intercrop under coconut (Reynolds, 1988). Generally turmeric performed well in control plot over the different growth periods. Compared to treeless open grown turmeric at 230 DAP, the coconut and homegarden registered 39.72 % and 74.83 % reduction in rhizome yield. Periodic changes in belowground dry weights suggest that galangal also performed well in open control like ginger and turmeric. As compared to treeless open grown galangal at 230 DAP, a reduction in rhizome dry weight to the tune of 29.86 % and 33.32 % per plant were observed in coconut and homegarden respectively.

The biomass production potential is primarily a function of available light, its efficiency with which intercepted light is converted into biomass (Long *et al.*, 2006). Kasanga and Monsi (1954) also revealed that the understorey growth rate is proportional to the amount of radiation intercepted by the canopy. Kunhamu *et al* (2008) reported higher ginger rhizome yield increased with increasing intensity of thinning which suggest strong influence of canopy regulation on ginger yield. Similar observations were reported for poplar-ginger based system managed under varying tree densities by Jaswal *et al.* (1993). Amin *et al,* (2010) observed ginger-mango partnership having 50 ± 5 % shade resulted the plant growth of medium status but had the topmost yield of ginger (12.42 Mg ha^{-1}, which was 2.45 fold better than the least yield (5.07 Mg ha^{-1}) of the ginger-guava coalition and 119.65 times higher even from the open field. Ghosh and Hore (2007) found among five different spacing's (20 × 15 cm, 20 × 20 cm, 25 × 20 cm, 25 × 25 cm and 30 × 25 cm) and two rhizome size (15-20 and 25-30 g) of ginger, the closest spacing (20 × 15 cm) in combination with bigger seed rhizome (25-30 g) produced highest yield (15.39 kg from three m^2). Kumar (2005) found that ginger grown as intercrop in tamarind plantation recorded higher yield (173.89 g/plant) compared to sole crop in open area (117.17 g/plant).

The important aspects governing the crop productivity are the type of photosynthesis it exhibits *i.e.* whether C_3 or C_4 and influence of shade or the amount of incident PAR. Since Zingiberaceae family exhibits C_3 pathway it is interesting to note the relationship between productivity and PAR in tree based systems. C_3 plants become light saturated at approximately 50 % of full sunlight whereas C_4 plants become light saturated at near full sunlight. If shading by the tree crop does not reduce light levels below the threshold of light saturation, then no reduction in photosynthesis (net assimilation), or ultimately crop growth or yield, should occur. In simple words it means an overstorey tree species that reduces light levels by no more than 50 % of full sunlight should allow an understorey C_3 species to operate at full photosynthetic potential, with no appreciable loss of crop yield compared with the same plants grown in full sunlight (Reynolds *et al.*, 2007). By contrast, C_4 plants are highly sensitive to understorey light regime and exhibit considerable reduction of photosynthesis even for slight reduction in light levels. Crops respond differently to depressed light levels. In the present study lowest rhizome yield of all the three crops in homegarden consequence to lower understorey PAR (17 %) is in line with this observation. The rhizome yield of all intercrops was relatively more in coconut plot compared to in homegarden.

For continuous growth, plant requires regular and balanced access to the plant requirements, *viz.*, moisture, nutrient, space in addition to light, which are adequately available under sole cropping than intercropping. There was delay in attaining maturity and senescence in intercropping. There are reports about different values with respect to optimum shade requirement of ginger. For instance many workers have reported that inanimate shade of 25 per cent (illumination level of 75 %) promotes ginger yield (Bai, 1981; Jayachandran *et al.*, 1991; Verghese, 1989; George, 1992). Ghosh *et al.* (2006) reported the yield of ginger was significantly high in the treeless open field compared to plots under agroforestry system. Vikram and Hegde (2014) found significantly highest yield of turmeric in treeless open conditions compared to cashew intercropping. Geetha (2004) reported maximum yield of galangal at 50 per cent shade. These findings suggest 50 % tolerance level may not be generalized for all the C_3 crops which further depend on other factors such as crop variety.

Although ginger is generally regarded as a shade tolerant crop, the higher ginger yield in tree-less plot can be partly based on varietal differences also. For instance 'Varada' ginger variety has been reported to be less shade tolerant (Kunhamu, 2006) while 'Kuruppampady' ginger variety performed better under shade (Kumar *et al.* 2001). Potty *et al.,* (1979), found out among nine varieties of turmeric tried as intercrop in coconut, 'Sugantham', 'Wynad local' and 'T. Sunder' performed well yielding 18.9, 18.1 and 17.4 Mg $ha^{-1}$of fresh rhizomes under rainfed condition. Kumar *et al* (2005) revealed that galangal was not affected by light interception levels by the upper storey canopy up to 82 % of the open. A number of medicinal and aromatic crops that are traditionally grown outside forest also withstand deeper shade (Jha and Gupta, 1991).

The average mid day PAR recorded in coconut and homegarden was 37 and 17 % respectively. The lower understorey productivity under homegarden despite of better soil physico-chemical attributes is a clear indication of heavy shade in the selected homegarden. Ecologically and economically viable judicious efforts are needed to improve the understorey light regimes in homegardens. This demands Kerala homegardens to maintain a stand structure that is compatible for intercropping. Probably, we need to critically examine the present species density and diversity and the possible stand management options to regulate them such as judicious removal of certain trees/shrubs. Also it calls for tree management practices such as pruning, lopping etc to improve the understorey light regimes.

5.6 STAND LEAF AREA INDEX (LAI)

Maximizing the use of available resources and minimizing competition between trees and crops are central to improving yields and overall productivity in any agroforestry system (Cannell *et al.*, 1983). Trees minimize the amount of solar radiation reaching to understorey crops through shading. The extent of shade varies according to crown dimensions, tree phenology and leaf density. In the present study, the spacing in coconut plantations was 7.5 m × 7.5 m and in homegarden various tree species are placed densely resulting in close spacing. In agroforestry practices, factors like LAI and crown development are of utmost importance for standardization of spacing. The stand leaf area index recorded was 2.21 and 3.84 in coconut and homegarden. Findings in the present study are consistent with the findings of many authors (Srinivasan, 2006; Kumar *et al.*, 2005 and Kumar *et al.*, 2001). Stand density regulation may also influence the stand LAI. For instance, *Dendrocalamus strictus* reported lowest LAI in widest spacing (12 m × 12 m) and highest in closer spacing (4 m × 4 m) (Bhimappa (2014). In monoculture systems, the competition between plants is mainly for light, but in polyculture systems the plant competitive interaction is experienced for both belowground and aboveground resources (Faget *et al.*, 2012).

The higher LAI may distress the understorey crop growth in tree based systems. This was substantiated by lesser dry matter production and rhizome yield in coconut and homegarden compared to treeless open plot. On the similar lines Bhimappa (2014) noticed lesser dry matter production and rhizome yield in close spacing's compared to wide spacing's of bamboo (*Dendrocalamus strictus*). Nissen *et al.* (1999) reported that both shading and belowground competition decreased the yield of *Brasicca oloracea* in a eucalyptus based alley cropping system in Philippines. Greater light extinction when stand LAI is more has been reported by Kumar *et al.* (2001). LAI is primarily a function of overstorey tree species. The leaf spread and phyllotaxy significantly influence the net light availability in the understorey. Results converge to the generalization that information on factors such as PAR and LAI are indispensable for optimizing understorey productivity in polyculture systems.

5.7 NUTRIENT ACCUMULATION

The growth and development of understorey crops may depend on overstorey species, soil health and the accumulation of nutrients from the soil. Further, the process of nutrient accumulation at different growth stages is a function of climate, soil properties and crop variety (Thomas, 1998). Several studies reveal that understorey crop nutrient accumulation is strongly correlated with overstorey stand density, understorey PAR and the amount of plant nutrient demand (Rowe *et al.*, 2001; and Goa *et al.*, 2013). In general, maximum accumulation of nutrients was exhibited in open followed by coconut and least by homegarden except for few variations. The wider spacing in coconut (7.5 m x 7.5 m) and higher PAR (37 %) may be the reason for coconut grown intercrops showing relatively more accumulation than that from homegarden where tree density and shade were highest (PAR = 17 %).

Enhanced accumulation of nutrients in the rhizome is evident for most of the intercrops grown in open condition. It could be by and large attributed to the far better light conditions and the sub-optimal levels of belowground competition for minerals in the open soil. The apparent increase in nutrient accumulation in the open soil could be a temporary phenomenon contributed by the higher rate of mineralization due to exposure. However, this will decline in due course with repeated intercropping. Since the nutrient turnover in open system is very much limited compared to wooden system, there could be consistent decline in nutrient content in open soils over time. However, the better nutrient cycling contributed by perennial trees ensures continued nutrient build-up in wooded systems ensuring sustained availability of nutrients to the intercrop.

Higher accumulation of N, P and K may also be due to higher root growth and biomass of understorey crops in open. The root length in all crops was invariably highest in treeless open except for mature galangal. Vandenbeldt *et al.* (1990) reported that soil nutrition and competition for soil water is dependent on root distribution pattern. Plants with deep root system generally decrease competition whereas shorter thick roots quickly deplete adjacent nutrient pools, promoting steep and extensive nutrient gradients (Gillespie, 1989). Similarly higher biomass productivity associated with treeless open grown crops also reported. Ingestad and Agren (1988) noticed that root growth has larger effect on nutrient accumulation leading to strong soil-plantation interaction. Similar results were reported by Bhimappa (2014) in wide spacing of bamboo compared to close spacing. In contrast, Bai (1981) observed an increase in N, P and K content in the biomass with increasing intensities of shade. Similar observations were noted by Sureshkumar (1997) in galangal. In the present study also galangal showed higher nutrient accumulation in homegarden compared to coconut.

Total nutrient accumulation is primarily a function of nutrient concentration and biomass production that explain the higher nutrient accumulation in open grown crops. Generally nutrient concentrations in the foliage and rhizome of all the crops followed the order of K>N>P. A similar trend was noticed by Kunhamu (2006) in case of ginger. The foliar as well as rhizome nutrient concentrations peaked with growing season, which corresponds to the period of maximum vegetative growth.

5.7 SOIL CARBON SEQUESTRATION

Contrary to the intercrop growth trends, the total soil carbon stock corresponding to one meter soil depth was found highest in homegarden (67.45 Mg ha^{-1}) followed by coconut (59.65 Mg ha^{-1}) and lowest in the treeless open plot (55.1 Mg ha^{-1}) respectively. Depth wise soil carbon stock showed decreasing trend with increase in depth for 1 m soil profile. In open it varied from 12.83 Mg ha^{-1} at 0-20 cm depth to 8.36 Mg ha^{-1} at 81-100 cm soil depth. In the same order it varied from 17.39 to 9.33 Mg ha^{-1} in homegarden and 16.21 to 10.39 Mg ha^{-1} in coconut garden. Tree based land use systems have greater potential of soil carbon sequestration than agronomic crops. A comparison study of soil carbon stock under different land use system in Kerala reported higher soil organic carbon stocks under tree based system like Forest (177 Mg ha^{-1}), Homegarden (119 Mg ha^{-1}), Rubber plantation (119Mg ha^{-1}), and Coconut (91 Mg ha^{-1}) compared to Rice (54 Mg ha^{-1}; Saha *et al.*, 2010).

The Influence of tree on soil C storage differs among different tree species, which differ in biomass production, tissue nutrient concentrations and their effects on soil quality (Post and Kwon, 2000). Srinivasan *et al.* (2010) estimated the soil carbon stock in three MPTs interplanted coconut plot registered highest soil carbon levels under *Leucaena* followed by *Casuarina* and *Ailanthus* interplanted plots. Moreover surface soil showed highest organic carbon percentage as compared to soil from deeper layers.

With respect to bulk density in the present study, there was an increase with the increase in soil depth both in tree based landuse systems (homegarden and coconut) and treeless open plots (Table 34). Bulk density at 0-20 cm depth for homegarden, coconut open was 1.05, 1.12 and 1.17 g cm^{-3} which correspondingly increased to 1.2, 1.28 and 1.35 at 81-100 cm soil depth. Many reports suggest such increase in bulk density with soil depth (Lemma *et al.*, 2006; Jangra *et al.*, 2010, Singh *et al.*, 2010, Tumwebaze *et al.*, 2012, Samritika, 2013). The top soil in tropical areas us usually low in bulk density owing to the highly weathered soil rich in litter and organic matter which turns harden with increasing soil depth. Such improvement in bulk density in wooded systems is a regular feature owing to the long-term addition of organic matter to the soil and root activity (Chandra *et al.*, 2010). Above observation is strongly validated by the higher organic matter content in the soil under rubber and cashew compared to open in the present study.

The consistent decline in organic matter content with soil depth is also evident in the study, which is closely in tune with the bulk density changes. This suggests a negative correlation between bulk density and organic content in wooded soils. Similar results were corroborated by Samritika (2013) and Tumwebaze *et al.*, (2012) and they observed increase in mean bulk density with soil depth and inversely with SOC. Pandey and Pathak (1975) stressed on higher compaction and defloculation of soil particles (which considerably restricts the capillary pore) to be an important reason for higher bulk densities in the treeless control site. In addition to aboveground biomass additions, the belowground roots contribute substantially in enriching the organic matter content of the soils (Young, 1989). Factors like litter quality, quantity as well as litter dynamics are the probable reasons behind differences in organic matter addition under different species (Garg, 1998; Russell *et al.*, 2007).

In general, soil organic carbon (SOC) concentration was highest at 0-20 cm depth and thereafter it showed a decline in all the land use systems (Table 35). A similar result was observed by Jangra *et al.* (2010) and Samritika (2013) in *Grevelia robusta* plantation where SOC concentration was found to be highest at top layer of soil and then decline with increase in depth. Gupta *et al.* (2009) and Srinivasan *et al.* (2010) also observed the same trend in poplar based agroforestry system and coconut inter planted with MPTs respectively. Similar results were observed by Tumwebaze *et al.* (2012) under *Grevillea robusta, Casuarina, Maesopsis and Markhamia* where the SOC at 0-25 cm depth was found to be highest and least was observed at 50-100 cm for all the species. The higher SOC in the shallow superficial soil may be ascribed to the higher litter fall and litter decomposition in the surface soil of plantations which subsequently declined with soil depth.

Among the two wooded ecosystems, homegarden maintained higher carbon for all soil horizons. Presence of high carbon stocks in polyculture systems with multi-tier tree structure is evident in the present study too. However presence of relatively higher carbon and nutrient contents in the farther soil depths in the homegarden suggest the potential influence of trees in enriching deep soils layers in wooded systems. Many reports also suggest higher soil C content at subsequent soil depths. For instance, Hansen (1993) found that the soil carbon gain was most significant in the 30-50 cm layer, which may be on account of variable root distribution patterns (Kumar *et al.*, 1999). The soil carbon sequestration findings of present study validate the influence of trees in building organic matter and carbon stocks, making tree-based systems more relevant for understorey productivity.

Summary

6. SUMMARY

The research work entitled "Performance of selected medicinal herbs under typical homegarden and pure coconut plantation" was undertaken during 2014-15 at Kerala Agricultural University, Vellanikkara to assess the understorey productivity of the two tree based land management systems through intercropping with three herbaceous medicinal crops *viz. Zingiber officinale* (ginger), *Curcuma longa* (turmeric) and *Kaempferia galanga* (Lesser galangal). The salient findings are summarized below.

1. Growth observations at final stages revealed maximum plant heights of ginger and turmeric in shaded condition than treeless open. On similar lines, lowest pseudostem length of ginger and turmeric was in treeless open. With respect to leaf spread galangal performed well in the coconut plot followed by homegarden and treeless open.
2. Root length of all the intercrops exhibited maximum values in open plot except galangal for which coconut was the best. Invariably root production was lowest in homegarden.
3. Tiller production at final stages showed highest in treeless open. Contrary to the plant height growth trends, homegarden recorded lowest tiller production at final stages.
4. Highest number of leaves for ginger was observed from coconut and least in treeless open. Turmeric and galangal showed lowest leaf production in homegarden.
5. Specific leaf area varied significantly among the intercrops across their cropping regimes. Contrary to the growth trends the specific leaf area was highest under homegarden grown ginger (174.51 cm^2 g^{-1}) followed by coconut and lowest in the open condition. The trends were similar for galangal too with homegarden giving highest specific leaf area (180.01 cm^2 g^{-1}) while galangal in the open condition recorded lowest value. Coconut grown turmeric showed higher specific leaf area (170.09 cm^2 g^{-1}) followed by open with 139.66 cm^2 g^{-1} and homegarden with 106.52 cm^2 g^{-1}.

6. Aboveground fresh weight was highest in open grown medicinal herbs across the land use systems. Aboveground dry weight also followed the same trend with maximum in open grown sole crops.
7. Fresh and dry rhizome yields per plant, was highest in treeless open for all the land use systems. However, within the intercropped scenario all the crops recorded higher fresh and dry rhizome weight per plant in coconut and the lowest in homegarden.
8. The rhizome yield of ginger at the final harvest was higher in open (3.46 Mg ha^{-1}) followed by coconut (2.86 Mg ha^{-1}) and homegarden (1.49 Mg ha^{-1}). Conspicuous reduction in belowground dry weight was observed for homegarden (56.93 %) as compared to treeless open while the reduction was moderate under coconut (17.34 %).
9. Treeless open continued the higher rhizome yield for turmeric at final sampling stage (7.02 Mg ha^{-1}) followed by coconut and homegarden with 4.23 and 1.77 Mg ha^{-1} respectively. Conspicuous reduction in belowground dry weight was observed for homegarden (74.78 %) as compared to treeless open while the reduction under coconut was 39.74 %.
10. Galangal yields at final harvesting was consistently higher in the treeless open (3.06 Mg ha^{-1}) whereas coconut and homegarden recorded comparatively lower values to the tune of 2.15 and 2.04 Mg ha^{-1} respectively. Significant reduction in belowground dry weight was observed for homegarden (33 %) and coconut (29 %) as compared to treeless open.
11. Variation in net productivity was observed among the intercrops for different landuse systems. Obviously the highest net rhizome yield was observed for the treeless open for all the three intercrops with 2.2, 4.46 and 1.94 Mg ha^{-1} for ginger, turmeric and galangal respectively. Also intercrop performance was better under coconut while lowest under homegarden.
12. Mean photosynthetic photon flux density (PPFD) above the canopy ranged from 212 μ moles $m^{-2}s^{-1}$ (8 am) to 1774 μ moles $m^{-2}s^{-1}$ (1-2 pm). Mean

mid-day (12–13 hrs) understorey PAR levels ranged from 398 to 765 μmoles $m^{-2} s^{-1}$

13. The average mid-day PAR transmittance under the homegarden and coconut canopies ranged from 17 to 37 % of the incident PAR above the canopy.
14. LAI varied between the homegarden and coconut considerably with homegarden giving more stand leaf area index (3.84) while the same for pure coconut plantation was considerably low (2.21).
15. The oleoresin concentration in all the intercrops was found to be highest in homegarden followed by coconut and open. Among the intercrops, average oleoresin content was highest for turmeric (10.53 %) followed by ginger (4.27 %) and galangal (2.51 %).
16. The chlorophyll content in all intercrops was invariably highest in homegarden followed by coconut and the lowest in open plots.
17. Nutrient concentration (N, P & K) in the aboveground biomass for all intercrops was consistently highest in open grown plants during all the sampling stages except K in galangal at final stage, which was higher in homegarden.
18. Bulk density showed an increasing trend with the increase in depth up to 1m from the surface layer. Among the landuse systems, desirable lower bulk density was found associated with homegarden with an increasing trend from coconut to open soil.
19. The soil organic matter content was highest in homegarden (1.02 %) followed by coconut (0.87 %) and the lowest open plot (0.75 %) Soil organic carbon percentage also followed the same trend as that of organic matter content.
20. Total soil carbon sequestration at one meter soil depth was highest for homegarden soil (67.45 Mg ha^{-1}) followed by coconut (59.65 Mg ha^{-1}) and lowest in the treeless open soil (55.1 Mg ha^{-1}). Generally, soil carbon stocks in treeless open plot reduced with increase in soil depths. The

average soil organic carbon content followed the order 11.93, 13.49 and 11.02 Mg ha^{-1} for coconut, homegarden and treeless open respectively.

21. The intercropping studies converges to the generalization that there is fairly good scope for enhancing understorey productivity in mature stable cropping systems in humid tropics such as coconut and homegardens. However, judicious management practices at stand level and tree level are necessary for improving the combined productivity in polyculture systems especially homegardens.

References

REFERENCE

Abou-Hadid, A. F., El- Saeid, H. M. and El-Beltagy, A. S. 1988. Factors affecting transpiration of protected vegetables in North Nile Delta Region. *Egyptian J. Hort.* 15: 13-21.

Aclan, F. and Queisumbing, E. C. 1976. Fertilizer requirement, mulch and light attenuation on the yield and quality of ginger. *Phill. Agricst.* 60: 183-191

Agetsuma, N. 1989. Leaf inclination of *Abies firma* Zucc. responding to light condition. Ecol. Rev. 21(4): 289-292

Ajithkumar, K. 1990. Production dynamic of ginger (Zingiber officinale R.) under varying levels of shade, nutrients and triazole. Ph.D thesis, Kerala Agricultural University, Thrissur, 266 p.

Allen, L. H. J. 1975. Shade cloth microclimate of soya beans. *Agron. J.* 67: 175-181.

Amin, M. R., Ikbal, T. M. T., Miah, M. M. U, Hakim., M. A. and Amanulla, A. S. M. 2010. Performance of ginger under agroforestry system. *Bangl. Res. Publi. J.* 4(3): 208-217

Ancy, J. 1992. Nutrient requirement of ginger under shade. M.Sc. (Hort.) Thesis, Kerala Agricultural University, Thrissur, 104 p.

Aneesh, S. 2014. Biomass production and nutrient dynamics in a multipurpose tree based black pepper production systems. M.Sc. (For.) thesis, Kerala Agricultural University, Vellanikkara, Thrissur, 100 p.

Arnon, D.I. 1949. Copper enzymes in isolated chloroplast polyphenol oxidase in *Beta vulgaris*. Plant physiol., 24:1-15.

Asandhi, A. A. and Suryadi, M. 1982. Effect of shading by maize plants and mulching on the yield of potatoes. *Bulchin Penelition Horticultura,* 9:105

Attridge, T. H. 1990. *Light and Plant Responses*. Hodder and Stoughtton Ltd., Great Britain, 101p.

Babu, P. 1993. Effect of shade and mulch on the yield of ginger (*Zingiber officinale* R.). M.Sc. (Hort.) thesis, Kerala Agricultural University, Thrissur,. 112 p.

Babu, R. C. and Nagarajan, M. 1993. Growth and Development of Soybean (*Glycine max* [L.] Merr.) Cultivars under Shade in Coconut Garden. *J. Agron and Crop Sci.*171(4): 217–288.

Bai, E. K. L. and Nair, R. V. 1982. Shade response of some common rain fed intercrops. *Proc. Fifth Ann. Symp. Pln. Crops*, Indian Society for Plantation Crops, pp. 394-401

Bai, L. E. K. 1981. Shade response of common rainfed intercrops of coconut. M.Sc. (Ag.) thesis, Kerala Agricultural University, Thrissur, 161p.

Baldochhi, D. and Collineau, S. 1994. The physical nature of solar radiation in heterogeneous canopies: spatial and temporal attributes. In: Exploitation of Environmental Heterogeneity by Plants: Ecophysiological Progresses Above and Belowground. Caldwell M. M, Pear, R. W (Eds.), Academic Press, San Diego, CA, pp. 21-64

Bandyopadhyay, A., Ghosh, D., and Hore, J. K., 2003, Performance of different turmeric
germplasm as intercrop in young arecanut plantation. *The Orissa J. Hort.*, 31(1) : 22-25.

Bavappa, K. V. A. 1990. An up-to-date research profile on coconut based farming system. In: Coco tech Meeting on Coconut Based Farming Systems, Manila, Philippines, 25-29 June 1990, In : Proceedings of the Meeting, pp. 90-102

Bellamy, P. H., Loveland, P. J., Bradley, R. I., Lark, R. M., and Kirk, G. J. D. 2005. Carbon losses from all soils across England and Wales. *Nature* 437: 245-248.

Bhatt, J. G. and Ramanujam, T. 1975. Response of the cotton plant to the variation of in the intensities of natural light. *Turrialba*. 25: 440-444.

Bhimappa, K. 2014. Bamboo (*Dendrocalamus strictus* Roxb) based agroforestry system: planting density effects on biomass accumulation, carbon sequestration, root distribution pattern and understorey crop productivity. Ph. D thesis, Kerala Agricultural University, Thrissur 122 p.

Bhuiyan, M.M. R., Roy, S., Sharma, P.C.D., Rashid, M.H.A., and Bala, P. 2012. Impact of multistoreyed agro-forestry systems on growth and yield of turmeric and ginger at mymensingh, Bangladesh. *Sci J. Crop Prod.* 01:19-23.

Bjorkman, O. 1968. Further studies on differentiation on photosynthetic properties in sun and shade ecotypes of *Solidago virgaurea. Pl. Physiol.* 21: 84-99.

Bjorkman, O. and Holmgren, P. 1963. Adaptability of the photosynthetic apparatus to light intensity in ecotypes from exposed and shaded habitats. *Pl. Physiol.* 16: 889-914.

Blackman, G. E. and Wilson, G. L. 1951. The constancy for different species of a logarithmic relationship between net assimilation rate and light intensity and its ecological significance. *Ann. Bot.* 15: 63-94.

Cannell, M. G. R. 1983. Plant population and yield of tree and herbaceous crops. In: *Plant Research and Agroforestry,.* (Ed. P A Huxley) ICRAF Nairobi. pp. 455-502

Cartechini, A and Palliotti, A. 1995. Effect of shading on vine morphology, productivity and leaf gas exchange characteristics in grapevines in the field. *Am. J. Enol. Viticulture*, 46: 227-234.

Casper, B. B. and Jackson, R. B. 1997. Plant competition underground. *Annual Rev. Ecol. Syst.* 28: 545-570.

Chandler P. 1994. Adaptive ecology of traditionally derived agroforestry in *China. Hum Ecol.* 22: 415-442.

Chandra, K. K., Kumar, N., Verma, A., and Saxena, A. K. 2010. Influence of tree plantations on physico-chemical properties and microflora of soil. *Indian J. Agroforest.* 12(1): 84-90.

Chopra, R. N., Chopra, I. C., Handa, K. L., and Kapur, L. D. 1958. *Indigenous Drugs of India* (2nd ed.). U. N. Dhur and Sons, Calcutta, 617 p.

Cooper, C. S. 1966. Response of bird's foot trefoil and alfalfa to various levels of shade. *Crop Sci.* 6: 63-66

Copper, C. S. and Qualls, M. 1967. Morphology and chlorophyll content of shade and sun leaves of two legumes. *Crop Sci.* 7: 672-673

Crockston, R. K., Trecharue, K. J., Lcidford, P. and Ozhun, J. L. 1975. Response of beans to shading. *Crop Sci.* 15: 412-416

Crossman S. M. A., Palada M. C and Davis A. M. 1999. Performance of West Indian hot pepper cultivars in the Virgin Islands. Proceedings Caribbean Food Crops Society 35: 169-176.

Devdas, M. 1997. Nutritional requirements of bush pepper under different light intensities, M.Sc. (Agri.) thesis, Kerala Agricultural University, Thrissur 104 p.

Faget, M., Kerestin, Nage, A., Walter, A., Juan, M., Herrera., Jahnke, S., Schurr, U., and Temperton, V. M. 2012. Root-root interactions: extending our perspective to be more inclusive of the range of theories in ecology and agriculture using in-vivo analyses. *Anna. Bot.* 1-14.

Fisher, R. A. 1975. Yield potential in a dwarf spring wheat and the effect of shade. *Crops Sci.* 15: 607-609

Frydrych, J. 1970. Photosynthetic characteristics of diploid and tetraploid forms of *Brassica olaracea* var. gongyloides grown under different irradiance. *Photosynthetica* 4: 139-145.

Gao, L., Xu, H., Mail, B. H., Xi, W., Bao, B., Wang, X., Bi, C. and Chang, Y. 2013. Intercropping competition between apple trees and crops in the agroforestry systems on the Loess Plateau of China. *PLoS ONE* 8(7): 70739

Gardener, V. R., Bradford, E. C. and Hooker, H. D (Jr.). 1952. *The Fundamentals of Fruit Production.* Mc Graw Hill Book Company. New York, 552 p.

Garg, V. K. 1998. Interaction of tree crops with a sodic soil environment: potential for rehabilitation of degraded environments. *Ld. Degradation Deve.* 9: 81-83.

Garrity, D. and Mercado, A. 1994. Reforestation through agroforestry. Market driven small holder timber production on the frontier. In: *Marketing of Multipurpose Tree Products In Asia*: Raintree, J. B., Francisco, H. A. (Eds.).

proc. of an international workshop in Baguio City, phillippines, 6-9 December, 1993. Wingrock International, Bangok, Thailand, pp. 265-268

Geetha, V. 2004. Shade response and nutrient requirement of common rainfed intercrops of coconut. M. Sc. (Ag.) thesis, Kerala Agricultural University, Thrissur, 216 p.

George, S, J., Kumar, B, M., Wahid, P. A., and Kamalam, N. V. 1996. Root competition for phosphorous between the tree and herbaceous components in silvopastoral systems in Kerala. *Plant Soil* 179(2): 189-196.

George, S. 1982. Shade response of common rainfed intercrops of coconut Part II. Legumes. M.Sc. (Ag.) Thesis, Kerala Agricultural University, Thrissur p. 114

George, S. J. 1993. Biomass production and resource portioning in silvi-pastoral systems. M. Sc. (For) thesis, Kerala Agricultural University, Thrissur, p. 136-139

Ghosh, D. K and Bandopadhyay, A. 2011. Productivity and profitability of coconut based cropping systems with fruits and black pepper in West Bengal, *J. of Crop and Weed.* 7(2), 134-137.

Ghosh, D. K. and Hore, J. K. 2007. Economics of different coconut based cropping models under alluvial plains of West Bengal. *Indian Coc. J.*, 37: 9-13.

Ghosh, K. K., Vinoy, T., and Saha, D. 2006. Performance of ginger under agroforestry system. *Journal of Interacademicia* 10(3): 337-341.

Gillespie, A. R. 1989. Modelling nutrient flux and interspecies root competition in agroforestry interpolatings. *Agrofor. Syst.* 8: 257-265

Goa, L., Xu, H., Mail., B. H., Xi, W., Bao, B., Wang, X., Bi, C., and Chang, Y. 2013. Intercropping competition between apple trees and crops in agroforestry systems on the Loess Plateau of China. *PLoS ONE,* (8): 70739.

Gopinathan, R. 1981. Effect of shade and moisture regimes on the growth of cocoa seedling. M.Sc. (Ag.) thesis, Kerala Agricultural University, Thrissur, 125 p.

Gupta, N., Kukal, S. S., Bawa, S. S., and Dhaliwal, G. S. 2009. Soil organic carbon and aggregation under Poplar based agroforestry sytems in relation to tree age and soil type. *Agroforest. Syst.* 76 (1): 27-35.

Gupta, R. 1964. Effect of drying Japanese mint on yield and quality of essential oil. *Res. Ind.* 9: 196-197

Haile, S. J., Nair, P. K. R., and Nair, V. D. 2008. Carbon storage of different soil size fractions in Florida silvopastoral systems. *J. Environ. Qual.* 37: 1789-1797.

Hansen, E. A. 1993. Soil carbon sequestration beneath hybrid poplar plantation in the north central United States. *Biomass Bioenergy.* 5(6): 431-436.

Hazra, C. R. and Tripathi, S. B. 1986. Soil properties micro-metereological parameters, forage yield and phosphorous uptake of berseem as influenced by phosphate application under agroforestry system of production. *J. Agron. and Crop Sci.* 156: 145-152

Hedge, N. K., Sulikeri, G. S., and Rethinam, B. P. 2000. Distribution of photosynthetically active radiation (PAR) and performance of ginger under arecanut shade. *Indian. J. Arecanut. Spices. Med. Pl.* 2: 107-112

Hegde, N. K., 1998. Crop diversification studies in arecanut (Areca catechu L.) plantation. Ph. D. Thesis, Univ. Agri. Sci., Dharwad, Karnataka.

Huxley, P. A. 1985. The prediction of biological productivity and sustainability of tree crop mixtures. *Trop. Agric.* 63 (1): 68-70

Ingestad, Agren, G. I. 1988. Nutrient uptake and allocation at steady-state nutrition. *Physiologia Plantarum* 72: 450-459.

Jackson, M. L. 1958. Soil Chemical Analysis. Asia Publishing House, New Delhi, India, pp. 498

Jackson, M. L. 1973. Soil Chemical Analysis (II edition). Prentice Hall of India Pvt. Ltd, New Delhi, India, pp. 12-498

Jackson. J. E., Reifsnyder, W. S., and Darnhofer, T. O. 1989. Tree and crop selection and management to optimise overall system productivity, especially light utilisation, in agroforestry. *Proceedings of An International*

Workshop on the Application of Metereology to Agroforestry System, Planning and Management, Nairobi, 9-13 Feb, 1987: 163-173

Jamaludheen, V. 1994. Biomass production and root distribution pattern of selected fast growing multipurpose tree species. M. Sc. (For) thesis, Kerala Agricultural University, Thrissur, p. 109

Jangra, R., Gupta, S. R., Kumar, R., and Singh, G. 2010. Carbon sequestration in the *Grevellia robusta* plantation on a reclaimed sodic soil at Karnal in northern India. *Int. J. Ecol. Environ. Sci.* 36(1): 75-86.

Jaswal S. C., Mishra V. K., and Verma K. S. 1993. Intercropping ginger and turmeric with poplar (*Populus deltoides* 'G-3' Marsh). *Agroforest. Syst.* 22: 111-117

Jayachandran, B. K., Bai, M., Salam, A. M., Mammen, M. K. and Kunjama, P. 1991. Performance of ginger under shade and open conditions. *Indian Cocoa, Arecanut and Spices J.* 15(2): 40-41

Jayachandran, B. K., Meerabai, M., Mammen, M. K., and Mathew, K. P. 1992. Influence of shade on growth and productivity of turmeric. *Spice India* 3 (4): 2-9.

Jha, K. K and Gupta, C. 1991. Intercropping of medicinal plants with poplar and their phenology. *India For.* 117: 535-544

Jung, H. B., Ito, T., and Maruo, T. 1994. Effect of shading and NO_3: NH_4 ratios in the nutrient solutions on the growth and yield of pepper plants in nutrient film technique culture. *J. Jap. Soc. Hort. Sci.* 63: 371-377

Kasanga, K. and Monsi, M. 1954. Light transmission of leaves and its meaning for the production of matter in plant communities. *Jap. J. Bot.* 14: 304-324.

Kasturibai, K. V., Voleti, S. R., Ramdasan, A., and Kailasam, C. 1991. Growth and dry matter production in the component crops under high-density multispecies cropping systems. *J. Plant. Crops* 18:151-155

KAU. (Kerala Agricultural University). 1992. Final research report of ICAR ad-hoc scheme as studies on coconut based intercropping situations. KAU, Thrissur, 37 p.

KAU. (Kerala Agricultural University). 2011. Package of practice of recommendations: Crops, 14th edition, Thrissur 360 p.

Khadse, V. M. and Bharath, G. M. 1996. Performance of annual crops under canopy *of Hardwickiabinnata* in agroforestry systems. *J. Soil and Crops*. 6: 151-153

Kochar, P. L. 1978. *A text book of Plant Physiology*.Atma and Sons, Delhi,218 p.

Kohli, A. and Saini, B. C. 2003. Microclimate modification and response of wheat planted under trees in fan design in northern India. *Agrofor. Syst*. 58: 109-117.

Korikanthimath V.S. and Hegde R. 1994. Cardamom and arecanut mixed-cropping systems. *Indian Cocoa, Arecanut and Spices J* .18(4): 109-112.

Kraybill, H. R. 1922. Effects of shading on some horticultural crops. *Proc. Amer. Soc. Hort. Sci*. 97: 152-154

Krishnankutty, N. K. 1983. Shade response of common rain fed intercrops of coconut. Part III- Vegetables. M. Sc. (Ag.) thesis, Kerala Agricultural University, Thrissur, 124 p.

Kulasgaram, S. and Kathvetpillai, A. 1980. Effect of level of shade and nitrogen on growth of young tea (*Camellia sinensis* L.). *Tea Quarterly* 49 (3 & 4): 112-124.

Kumar K. and Gupta C. 1991. Intercropping of medicinal plants with poplar and their phenology. *Indian Forester*: 535–544.

Kumar, B. M., George, S. J. and Suresh, T. K. 2001. Fodder grass productivity and soil fertility changes under four grass + tree association in Kerala, India. *Agrofor. Syst*. 52: 91-106

Kumar, B. M., Kumar, S. S. and Fisher, F. F. 2005. Galangal growth and productivity related to light transmission in single –strata, multistrata and no-over-canopy systems. *J. New Seeds.* 7(2): 111-126.

Kumar, B. M., Thomas, J., and Fisher, R.F. 2001. *Ailanthus triphysa* at different density and fertiliser levels in Kerala, India: tree growth, light transmittance and understorey ginger yield. *Agroforest. Syst*., 52 (2): 133–144.

Kumar, R. D. 2005. Intercropping studies in tamarind (*Tamarindus indica* L.) plantation. M. Sc. thesis, Univ. Agri. Sci., Dharwad, Karnataka.

Kumar, S. S., Kumar, B. M., Wahid, P. A., Kamalam, N. V., and Fischer. R. F. 1999. Root competition for phosphorus between coconut, multipurpose tree and kacholam (*Kaempferia galanga* L.) in Kerala, India. *Agroforest. Syst.* 46(2): 131-146.

Kunhamu, T. K. 2006. Stand density manipulation and pruning of *Acacia mangium* willd. to optimise productivity in an agrisilvicultural system. Ph. D thesis. Institute of Forest Genetics and Tree Breeding, Coimbatore. 187 p.

Kunhamu, T.K., Kumar, B.M., Viswanath, S., and Sureshkumar, P. 2008. Thinning promotes understorey ginger productivity in *Acacia mangium* Willd. stands of Kerala, India. *Proc. Internat. Agroforestry Conf.*. Yahya, A.Z., Ngah, M.L., Md. Ariff, F.F., Rahman, Z.A., Abdullah, M.Z., Philip, E., and Chik, S.W. (eds). Trans. of the Malaysian Society of Plant Physiology, vol. 15, Forest Research Institute, Kuala Lumpur, Malaysia, pp 47–60.

Lakshmamma, P. and Rao, J. V. S. 1996. Response of black gram (*Vignum mungo*) to shade and naphthalene acetic acid. *Indian J. Pl. Physiol.* 1: 63-64

Lal, R. 2002. Carbon sequestration in dryland ecosystems of West Asia and North Africa. *Lnd. Deg. and Dev.* 13: 45-59.

Lal, R. 2004. Soil Carbon Sequestration Impacts on Global Climate Change and Food Security. *Science* 304(5677): 1623-1627.

Latha, E.V. 1994. Evaluation of kacholam (Kaempferia galanga) types fro morphological variability and yield. M.Sc. (Agri.) Thesis submitted to Kerala Agricultural University, pp. 93-96.

Latha, P., Giridharan, M. P. and Naik, B. J. 1995. Performance of turmeric (Curcuma longa L.) cultivars in open and partially shaded conditions under coconut. *J. Spices and Aromatic Crops*, 4 : 139-144.

Laura, B., Roberts, N. L. B., Ferguson, T. V., and Wilson, L. 1986. Response of four sweet potato cultivars to different levels of shade. *Trop. Agric.* 63(63): 265.

Lemma, B., Kleja, D. B., Nilsson, I., and Olsson, M. 2006. Soil carbon sequestration under different exotic species in the south western islands of Ethiopia. *Geoderma* 136: 886-898.

Long, S. P., Zhu, G. X., Naidu, S. L., Ort, D. R. 2006. Can improvement in photosynthesis increase crop yields? *Plant, Cell and Environ.* 29: 315-330.

Lott, J. E., Ong, C. K. and Black, C. R. 2009. Understorey microclimate and crop performance in *grevillea robusta* based agroforestry system in semi arid Kenya. *Agr. For. Meteorol.* 149: 1140-1151

Lyiange, M. D. S., Thejawani, K. G. and Nair, P. K. R. 1985. Intercropping under coconut in Srilanka. Agrofor. Syst. 2: 215-228

Maheshwarappa, H. P., Hegde, M. R. and Nanjappa, H. V. 2000. Arrowroot (Maranta arundinacea L.) and potential intercrops in coconut garden. *Indian coconut J.* 32: 89-91.

Maheswarappa, H. P ., Hegde, M. R.; Dhanapal, R. and Biddappa, C. C. 1998. Mixed farming in coconut garden - Its impact on soil physical, chemical properties coconut nutrition and yield. *J. Plantn. Crops*, 26 : 139-43

Maheswari S. K., Dhantonde B.N., Yadav S., and Gangrade, S. K. 1985. Intercropping of *Rauvolfia serpentina* for higher monetary returns. *Indian J Agri Sci.* 58: 108–111.

Maliphant, G. K. 1959. Manurial and cultural experiments on cocoa VII. River estate, Trinidad- Shade, spacing times and rates of fertilizer application experiment. Regional Research Centre, Trinidad, pp. 83-86

Manjunath, B. L., Singh, S. P., and Sundaram, R. N. S., 2002, Performance of grainsforage legume mixtures as intercrops in coconut garden. *J. Plantation Crops* 30 (2): 26-29.

Mathai, C. K. and Sasthry, S. K. 1988. Productivity of black pepper vines (*Piper nigrum* L.) as influenced by the light availability during pre-flowering stage. *Physiol. Ecol.* 13: 97-102.

Mathew, T., Kumar, B. M., Sureshbabu, K. V. and Umamaheshwaran, K. 1992. Comparative performance of four multipurpose trees associated with four grass species in the humid regions of southern India. *Agrofor. Syst.* 17: 205-218

Mathew, T., Kumarm B. M., Babu, K. V. S, and Umamaheshwaran, K. 1992. Comparative performance of four multipurpose trees associated with four grass species in the humid regions of southern India. *Agrofor. Syst.*, 17: 205-218.

Meadows A. B., Olorunda A. O., and Aina TO. 2005. Oleoresin yield and 6 Gingerol in Two varieties of Nigerian Ginger (*Zingiberis officinale*, Roscoe) at Various Maturity Stages. *Nig. Food J.* 23:91-105.

Menon, M. V., Krishnankutty, J. and Pushpalatha, P. B. 2013. Identification and Evaluation of Selected Underutilized Leafy Plant Species in the Homesteads of Kerala, India. *II International Symposium on Underutilized Plant Species: Crops for the Future - Beyond Food Security*, 625-630.

Meyer, B. S. and Andrson, D. B. 1952. *Plant Physiology*. D. Von Nostrand Company, INC. pp. 624-627

Minami, K., Lucchesi, A., and Filho, V. R. 1981. Effect of environment on the quality of tomato transplants. *Anasis da Escola Superior de Agriculture Luiz do Qerroz* 38: 113- 120.

Mishra R. K. and Pandey V. K. 1998. Intercropping of turmeric under different tree species and their planting pattern in agroforestry systems. *Range Manag. Agroforest.* 19: 199-202.

Misra, R., Singh, J. S., and Singh, K. P. 1968. Dry matter production in sun and shade leaves and simple method for the measurement of primary productivity. *Curr. Sci.* 37(11): 306-307.

Montith, J. L. 1969. Light interception and radioactive exchange in crop stands. *Physiological Aspects of Crop Yield* (eds. Easten, J. O., Haskins, F. A., Sullivan, C. Y. And Van Bavel, C. H. M). Wisconsin, pp. 89-110

Moss, D. N. and Stinson, H. T. 1961. Differential response of corn hybrids to shade. *Crop Sci.* 1: 416-418.

Moursi, M. A., El-Gawad, A. A. A., Ell- Din, N. A. N., Ashour, N. I. And Yokout, G. M. 1976. Effect of shading and nitrogen fertilizer on photosynthetic pigments and nitrogen contents of wheat blades. *Egyptian J. Agron.* 1: 171-198

Mullakoya, P. 1982. Shade tolerance of guinea grass cv. Mackuenii under different levels of potassium. M.Sc. thesis, Kerala Agricultural University, Thrissur, 109 p.

Myhr, K. and Saibo, S. 1969. The effects of shade on growth, development and chemical composition in some grass species. *Forsk. Fors. Landhr.* 20: 297-315.

Nair G. S., Sudhadevi P. K., and Kurian A. 1989. Introduction of medicinal and aromatic plants as intercrops in coconut plantations. In: Raychauduri S.P. (ed.), Recent Advances in Medicinal, Aromatic and Spice Crops. Today and Tomorrow's Printers and Publishers, New Delhi, India, 1: 163-165.

Nair P. K. R. 1993. *An introduction to Agroforestry.* Kluwer Academic Publishers, Dordrecht.

Nair, M. A. and Sreedharan, C. 1986. Agroforestry Farming Systems in the Homesteads of Kerala, Southern India. *Agrofor. Syst.*4(4): 339-63.

Nair, P. K. R. 1983. *Soil Productivity of Aspects of Agroforestry.* International council for research on agroforestry. Nairobi, Kenya. Pp. 85

Nair, P. K. R. 1989. The role of trees in soil productivity and protection. In: Agroforestry systems in the Tropics. Ed. Nair, P. K. R., Kluwer Academic Publishers, Dordrecht, Netherlands, pp. 567-589.

Nair, P. K. R. and Dagar, J. C. 1991. An approach to developing methodologies for evaluating agroforestry systems in India. Agrofor Syst. 16: 55-81

Nair, P. K. R., Kumar, B. M., and Nair, V. D. 2009. Agroforestry as a strategy for carbon sequestration. *J. Plant Nutr. Soil Sci.* 172: 10-23.

Nair, R. V. 1964. Studies on the feasibility growing Japanese mint (*Mentha arvensis L. var. piperascens*) in Kerala and its response to nitrogenous phosphate and potasic fertilizers. M.Sc. (Agri.) thesis, Kerala Agricultural University, Thrissur 94 p.

Nayar, T. V. R. and Sadanandan, N. 1991. Effect of plant population and growth regulators on cassava intercropped in coconut gardens. *J. Root Crops* 17: 39-43.

Negi, A. S., Negi G. C. S. and Singh, S. P. 1996. Establishment of growth of *Quercus floribunda* seedlings after a mast year. *J. Veg. Sci.* 7: 559-564

Nelliat, E.V., Bavappa, K.V., Nair, P.V.R. 1974. Multi-storied cropping, a new dimension in multiple cropping for coconut plantations. *World Crops* 26(6), 262-266

Newman, S. M., Bennett, K., and Wu, Y. 1998. Performance of maize, beans and ginger as intercrops in Paulownia plantations in China. *Agroforest. Syst.* 39: 23-30.

Nissen, T. M., Midmore, D. J., and Cabera, M. L. 1999. Aboveground and belowground competition between intercropped cabbage and young *Eucalyptus torreliana. Agrofor. Syst.* 46: 83-93.

Noggle, G. R. and Fritz, G. J. 1979. *Introductory Plant Physiology.* Prentice Hall of India Pvt. Ltd, New Delhi, 688 p.

Norman, J. M. and Jarvis, P. G. 1974. Photosynthesis in stika spruce (Picea sitchensis) III. Measurement of canopy structure and interception of radiation. *J. appl. Ecol.* 11(1): 375-398.

Ohasi, H. 1962. The geographical variability of chemical substances in plants in relation to vernalization. *Agro. Biol.* 2: 268-273

Okali , D. U. U. and Owasu, J. K. 1975. Growth analysis and photosynthetic rate of cocoa seedlings in relation to varying shade and nutrient regimes. *Ghana J. of Agric. Sci.* 8: 50-57

Okoli, P. S. O. And Wilson, G. F. 1986. Response of cassava (*Manihot esculenta* Crantz) to shade under field conditions. *Fld. Crops Res.* 14: 349-359

Ong, C. K., Corlett, J. E, Singh, R. P. and Black, C. R. 1991. Above and below ground interactions in agroforestry systems. *For. Ecol. Manage.* 45: 45-47

Oswald, A., Alkarmper, J. and Midmore, D. J. 1995. Response of sweet potato (Ipomoea batatas L.) to shading at different growth stages. *J. Agron. and Crop Sci.*, 175: 29-107.

Palada M. C. and Williams M. E. (eds.) 2000. Utilizing Medicinal Plants to Add Value to Caribbean Agriculture. Proceedings of the Second International Workshop on Herbal Medicine in the Caribbean. University of the Virgin Islands, St. Croix, U.S. Virgin Islands, 217 p.

Palis, R. K. and Bustrillos, A. R. 1976. The effect of limited light on the carbohydrate and protein content of grain sorghum. *Philippiine J. Crop Sci.* 1: 161-166.

Pandey, R. N., amd Pathak, A. M. 1975. The physical properties of normal ans salt affected soils of Uttar Pradesh. *Indian J. Agric. Res.* 9:63-70.

Patiram, Bhadauria, S. B. S. and Upadhyaya R. C. 1996. Agroforestry practices in hill farming of Sikkim. *Ind. For.* 122: 621-630.

Patterson, D. T. 1982. Effects of shading and temperature on showy crotalaria (*Crotalaria spectabilis*). *Weed Sci.* 30: 692-697.

Payne, W. J. A. 1985. A review of the possibilities of integrating cattle and tree crop production systems in the tropics. *For. Ecol. Manage.* 12: 101-157.

Pons, T. L. 1992. Seed responses to light. In: Ecology of Regeneration in Plant Communities. Fenner, M. (Ed), CAB International, Wallingford, UK, pp. 259-283

Post, W. and Kwon, K. 2000. Soil carbon sequestration and land use change: processes and potential. *Glob. Chang. Biol.* 6:317-328.

Potty, N. N., Radhakrishnan, T. C. and Asokan, P. K. 1979. A note on the early growth and performance of six varieties of pepper in the multi-storeyed cropping programme in coconut gardens. *Agric. Res. J. Kerala* 17(1): 151-152

Prajapati N.D., Purohit S.S., Sharma A.K. and Kumar T. 2003. *A Handbook of Medicinal Plants.* Agribios, India, 553 p.

Prameela, P. 1990. Screening different morphotypes of colocasia (*Colocasia esculenta*) for shade tolerance. M.Sc. (Ag.) thesis, Kerala Agricultural University, Thrissur, 62 p.

Puri, S., Bangarwa, K. S. and Singh, S. 1995. Influence of multipurpose trees on agricultural crops in arid regions of Haryana, India. *Ind. Arid Environ.* 30: 441-451.

Pushpakumari, R. and Sasidharan, V. K. 1992. Influence of shade on growth attributes of minor tuber crops. *J. Root Crops.* 18(1): 14-67

Radha, T. 1979. Effect of shade on growth fruiting in pineapple. M.Sc. (Hort.) Thesis, Kerala Agricultural University, Thrissur, 77 p.

Ramanujam, T., Nair, G. M. and Indira, P. 1984. Growth and development of cassava (*Manihot esculenta* crantz) genotypes under shade in a coconut garden. *Turrialba* 34: 367- 374.

Rao, M. R., Nair, P. K. R., and Ong, C. K. 1998. Biophysical interactions in tropical agroforestry systems. *Agrofor. Syst.* 38: 3-50

Ravisankar, C. and Muthuswami, S. 1988. Dry matter production and recovery of dry ginger in relation to light intensity. *Indian Cocoa, Arecanut and Spices J.* 10: 4-6.

Reynolds, P. E., Simpson , J. A., Thevathasan, N. V., and Gordon, A. M. 2007 Effects of tree competition on corn and soybean photosynthesis, growth, and yield in a temperate tree-based agroforestry intercropping system in southern Ontario, Canada. *Ecol. Eng.* 29(4): 362-371.

Reynolds, S.G. 1988. Pastures and cattle under coconuts. Plant Production and Protection Paper. Rome: FAO. 91 p

Rodrigo, V. H. L., Stirling, C M., Teklehaimanot, Z., and Nugawela, A. 2001. Intercropping with banana to improve fractional interception and radiation use efficiency of immature rubber plantations. *Field Crops Research* 69: 237-249.

Ross, S. 1976. *First Aid for House Plants*. McGraw Hill Book Co, New Delhi, 425 p.

Rowe, E. C., van Nordwijk, M., Suprayogo, D., Hairiah, K., Giler, K. E., and Cadisch, G. 2001. Root distribution s partially explain ^{15}N uptake patterns in Gliricidia and Peltophorum hedgerow intercropping systems. *Plant Soil* 235: 167-179.

Russell, A. E., Raich, J. W., Valver de-Barrantes, and Fisher, R. F. 2007. Tree species effect on soil properties in experimental plantations in tropical moist forests. *Soil Sci. Soc. Am. J.* 71: 1389-1397.

Saha, S., Nair, P. K. R., Nair, V. D., and Kumar, B. M. 2010. Carbon storage in relation to soil size fractions under some tropical tree based land use systems. *Plant Soil* 328: 433-446.

Samad, A. 1953. Ginger cultivation in Malabar. *Indian Farming* 3(3): 22-25

Sampson, D. A. and Smith, F. W. 1993. Influence of canopy architecture on light penetration in lodge pole pine (*Pinus contorta*) forests. Agric. For. Mateorol. 64(1-2): 63-79

Samritika, T. 2013. Belowground architecture and carbon stocks of silver oak (Grevillea robusta A. Cunn.) trees. M.Sc. (For.) thesis, Kerala Agricultural University, Vellanikkara, Thrissur, 150 p.

Sankar, C. R. and Muthuswamy, S. 1986. Dry matter production and recovery of dry ginger in relation to light intensity. *Indian Cocoa and Arecanut and Spices J.* 10: 4-6

Senanayake, Y. D. A. and Kirthisunghe, J. P. 1983. Effect of shade and irrigation on black pepper cuttings. *J. Plantn. Crops.* 11: 105-108

Sharma, S. K. and Peshin, S. N. 1994. Influence of nitrogen nutrition and spacing on plant growth, fruit and seed yield of sweet pepper. *Indian J. Hort.* 51(1): 100-105

Sheela, P. 1992. Evaluation of turmeric (*Curcuma longa* L.) cultivars for shade tolerance. M.Sc. (Hort.) thesis, Kerala Agricultural University, Thrissur, 114 p.

Singh R. S., Bhattacharya T. K., Dutta A. K., Das P. K. and Nag D. 1998. Production potential in the intercropping sequence of medicinal yam

(*Dioscorea floribunda*) with pigeonpea (*Cajanus cajan*) and rubber (*Hevea brasiliensis*). *Indian J Agric Sci.*68: 231-232.

Singh, I. S., Awasthi, O. P., and Meena, S. R. 2010. Influence of tree plantation on soil physic-chemical properties in arid regions. *Indian J. Agroforest.* 12(2): 42-47.

Singh, S. 1994. Physiological response of different crop species to low light stress. *Indian J. Pl. Physiol.* 36: 147-151

Singh, U. B., Kothari, S. K. and Verma, B. S. 2002. Growth, yield and quality of mint species as intercrop in sugarcane under subtropical climate of north Indian plains. *J. Med. Arom. Pl. Sci.* 24: 60-64

Sprtova, M. and Marek, M. V. 1999. Response of photosynthesis to radiation and intercellular CO_2 concentration in sun and shade shoots of Norway Spruce. *Photosynthetica* 37: 433-445

Sreekala, G. S. 1999. Biomass production and partitioning of photosynthesis in ginger under different shade levels. M.Sc. (Hort.) thesis, Kerala Agricultural University, Thrissur p. 116

Sreekala, G. S. and Jayachandran, B. K. 2001. Photosynthetic rate and related parameters of ginger under different shade levels. *J. Plantation Crops* 29: 50-52.

Sreelathakumary, I. 2000. Genetic analysis of shade tolerance in chilli (Capsicum spp.) Ph. D thesis, Kerala Agricultural University, Thrissur, pp. 1-153

Srinivasan, K., Ashokan, P. K., Kunhamu, T. K., Navas, I. E., and Eldho, V. 2010. Influence of multipurpose tree species on physicochemical properties of soil in coconut based agroforestry systems. *Indian J. Agroforest.* 12 (2): 6-13

Srinivasan. K. 2006. Performance of multipurpose trees in coconut based agroforestry systems and their influences on soil physic-chemical and biological properties. M.Sc. (For.) thesis, Kerala Agricultural University, Thrissur, 68 p.

Stenberg, P., Lindeer, S., Smolander, H. and Ellis, J. F. 1994. Performance of the LAI-2000 plant canopy analyser in estimating leaf area index of some scats pine stands, Tree Physiology 14: 981-995.

Sujatha, K., Latha, P.,and Nair, N. K., 1994. Evaluation of ginger varieties as an intercrop in coconut gardens. *South Indian Hort*. 42 (5) : 339.

Suma, A. Pushkaran, K. Babylatha, A. K. and Nybe, E. V. 1989. Comparative evaluation of banana cultivars in coconut garden. *Indian J. Coconut* 20: 6-7

Sureshkumar, S. 1997. Functional dynamics of an agrisilvicultural system involving coconut palms, multipurpose trees and kacholam. M.Sc. (For.) thesis, Kerala Agricultural University, Thrissur. 106 p.

Tan, C. H., Chan, C. L. and Tay, S. P. 1991. Commercial establishment of papaya intercropping with cocoa. *Asiatic Experience. Plnater*. 67: 301-313

Tarila, A. G. I., Ormrode, D. P. and Adedipe, N. O. 1977. Effects of phosphorus nutrition and light, intensity on growth and development of cowpea (*Vigna unguiculata* L.) *Ann, Bot*. 41: 75-83.

Terjeing, W. H. And Louise, S. S. F. 1972. Potential solar radiation on plant shapes. *Int. J. Biometereol*. 16(1):25-43.

Thakur, P. S. and Singh, S. 2002. Effect of Morus alba canopy management on root parameters in agroforestry tree species of temperate regions *Indian. J. Aagrofor*. 2: 75-78

Thomas, J., Kumar, B. M., Wahid, P. A., Kamalam, N. V. and Fisher, R. F. 1998. Root competition for phosphorus between ginger and *Ailanthus triphysa* in Kerala, India. *Agrofor. Syst*. 41(3): 293-305

Togari, Y. 1950. A study in tuberous root formation in sweet potatoes. *Bull. Agric. Extenstion Studies* 3: 1-96

Trenbath, B. 1976. Plant interactions in mixed crop communities. Multiple cropping, ASA Special Pub. No. 27, American Society of Agronomy, Madison, Wisconsin, p. 129-170

Tumwebaze, S. B. Bevilacqua, E., Briggs, R., and Volk, T. 2012. Soil organic carbon under a linear simultaneous agroforestry system in Uganda. *Agroforest. Syst*. 84(1): 11-23.

Vandenbeldt, R. J., Brenner, A. J. and Sinclair, F. L. 1990. Tree / crop interactions in agroforestry systems. Paper presented to the 19th IUFRO World Congress, Montreal, Aug. 5-11. pp 124-127

Venkatakkraman, D. and Govindappa, D. A. 1987. Shade requirement and productivity of coffee. *J. Coffee. Res.*17(2): 16-39.

Venkateshwarlu, B., Prasad, V. V. S. S. and Rao, A. V. 1977. Effect of low light intensity at different growth phases in rice (*Oryza sativa*). *Indian J. Pl. Physiol.* 23:300-308.

Verghese, S. 1989.Screening of varieties of ginger and turmeric for shade tolerance. M.Sc.(Ag.) thesis, Kerala Agricultural University, Thrissur,126 p.

Vijayakumar, K. R., Unni, P. N. and Vamadevan, V. K. 1985. Prevention of photo induced chlorophyll content by the use of light reflectant on the leaves of black pepper (*Piper nigrum* L.). *Agric. Forest. Meteor.* 34: 17-20

Vikram, H. C., and Hegde, N. K. 2014. Performance of turmeric in cashew plantation as intercrop compared to sole cropping. *Asian J. Hort.* 9(2): 496-499.

Virzo De, S. A. and Alfani, A. 1980. Adaptability of *Mentha piperita* to irradiance growth, specific leaf area and levels of chlorophyll, protein and mineral nutrients as affected by shading. *Biologia Pl.* 22(2): 117-123

Vyas, S. and Nein, S. 1999. Effect of shade on the growth of *Cassia ungustifolia*. *Ind. For.* 125: 407-410.

Wahua, T. A. T. and Miller, D. A. 1978. Effects of shading on the nitrogen fixation, yield and plant composition of field grown soyabean. *Agron. J.* 70(3): 387-392

Wankher, B. and Tripathi, R. S. 1990. Growth and reproductive allocation pattern of *Centella asiatica* raised from stem cuttings of different sizes in relation to light regimes, soil texture and soil moisture. *Acta Oecologica* 11: 683-692

Watanabe, F. S. and Olsen, S. R. 1965. Test of an ascorbic acid method for determining phosphorus in water and $NaHCO_3$extracts from soil. Soil Science society of America Proceedings, 29: 677-678

Whitmore, T. C. 1998. Introduction to Tropical Rain Forest, 2nd ed. Oxford University Press, New York, 282 p.

Wilson, H and Ovid, A. 1992. Growth and yield responses of ginger (*Zingiber officinale* Rosc) as affected by shade and fertilizer applications. *J. Plant Nutr*. 16:1539-1546.

Yinghua, C. and Jianzhen, J. 1998. The effects of light intensity on photosynthetic characteristics, growth and development in pepper. *Acta Agri*. 14: 46-50

Yirdaw, E. and Luukkanen, O. 2004. Photosynthetically active radiation transmittance of forest plantation canopies in the Ethiopian highlands. *For. Ecol. Manag*. 188: 17-24

Young, A. 1987. The potential of agroforestry for soil conservation and sustainable landuse. IRAF Reprint No. 39, Nairobi, Kenya

Young, A. 1989. Ten hypothesis fro soil agroforestry research. *Agrorforest. Today* 1(1): 13-16.

Zachariah T J & Gopalam A 1987 Nature, production and quality of essential oil of pepper, turmeric, cardamom and tree spices. *Indian Perfumer* 31(3): 188-205.

Zhou, S. Q. 1993. Cultivation of *Amomum villosum* in tropical forests. *Forest Ecol Manag*. 60: 157-162.

Zou, X. and Sanford, R. L. 1990. Agroforestry systems in China: a survey and classification. *Agroforest. Syst*. 11: 85-94.

PERFORMANCE OF SELECTED MEDICINAL HERBS UNDER TYPICAL HOMEGARDEN AND PURE COCONUT PLANTATION

By
NIYAS P
(2013-17-106)

ABSTRACT

Submitted in partial fulfillment of the requirement for the degree of

Master of Science in Forestry

Faculty of Forestry
Kerala Agricultural University

Department of Silviculture and Agroforestry
COLLEGE OF FORESTRY
VELLANIKKARA, THRISSUR-680656
KERALA, INDIA

2015

ABSTRACT

A field research was undertaken at Vellanikkara, Kerala to assess the understorey productivity of coconut and homegarden through intercropping with three selected herbaceous medicinal crops viz. *Zingiber officinale* (ginger), *Curcuma longa* L. (turmeric) and *Kaempferia galangal* L. (galangal). These landuse systems by virtue of spatial and temporal advantages offer good scope for integrating shade tolerant crops and thereby offer supplementary returns to the farmer. The biochemical changes in the understorey crops and the biophysical attributes influencing the productivity of the land management systems were studied. Additionally soil carbon sequestration in both the given land use systems and a treeless open plot was estimated.

The intercrop growth considerably varied among the land use systems both in vegetative growth and rhizome yields. Growth observations at various sampling period revealed considerably higher plant heights of ginger and turmeric in shaded condition than treeless open. As regards leaf spread galangal performed well in the coconut garden followed by homegarden and treeless open. All the intercrops exhibited higher root length in treeless open plots, except galangal for which coconut was the best. Invariably root production was lowest in homegarden. Tiller production at final stages showed highest in treeless open. Contrary to the plant height growth trends, homegarden recorded lowest tiller production at final stages of sampling.

Understorey productivity for ginger in terms of rhizome yield at final harvest followed the order treeless open (3.45 Mg ha^{-1}), coconut (2.86 Mg ha^{-1}), and homegarden (1.49 Mg ha^{-1}). Turmeric rhizome production showed considerable variation with intercropping system with highest yield from open area (7.01 Mg ha^{-1}) and the lowest from homegarden (1.77 Mg ha^{-1}). Highest Galangal yields were reported in the treeless open (3.05) while homegarden represented lowest production (2.04 Mg ha^{-1}). Understorey photosynthetically active radiation (PAR) transmittance presumed to have a cardinal influence on intercrop growth which was highest for coconut (37%) and lowest under

homegarden (17%). Turmeric and galangal showed strong positive correlation with understorey PAR. Regression equation relating PAR with rhizome yields showed statistical soundness with high value of coefficient of determination (r^2).

Leaf Area Index varied between the homegarden and coconut considerably with higher value for homegarden (3.84) while the same for pure coconut plantation was considerably low (2.21). The oleoresin concentration in all the intercrops was found to be greatest in homegarden followed by coconut and treeless open. Soil physico-chemical attributes were assessed at periodic intervals in all the landuse system and results indicate overall better condition prevailed in the homegarden in terms of organic carbon content, soil bulk density, total N, available P and exchangeable K which however registered lowest values in the treeless open. Similar was the trend in soil carbon sequestration with homegarden giving higher values (67.45 Mg ha^{-1}) followed by coconut (59.65 Mg ha^{-1}) lowest by treeless open soil (55.1 Mg ha^{-1}).

Result converges to the generalisation that despite better soil physico-chemical attributes, understory productivity in the homegarden is by and large decided by the PAR availability. Hence there is need to develop stand structure that optimize the productivity in homegarden through judicious stand density regulation and tree management practices.

Appendices

Appendix I. Weather parameters during the experimental period (Jan 2014 to Dec 2014)