PERFORMANCE OF SELECTED MEDICINAL HERBS UNDER RUBBER AND CASHEW PLANTATIONS

By

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(2013-17-113)

THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"PERFORMANCE OF SELECTED MEDICINAL HERBS UNDER RUBBER AND CASHEW PLANTATIONS"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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Introduction

1. INTRODUCTION

Humid tropical regions of India are characterized by intensive land use systems on account of congenial agroclimatic and edaphic conditions. Consequently, demographic pressure on land resources is extremely high in these regions. The state of Kerala is one among such regions in the country endowed with rich agro-biodiversity and cropping systems. Apart from being the home of paddy and innumerable spices, the green state is the land of plantation crops such as coconut, arecanut, rubber, cashew, tea and coffee. Abundant rainfall and fertile soil conditions in the state favoured the evolution of time-tested unique systems of tree-crop intensification such as homegardens. These traditional landuse systems were primarily focussed on the livelihood and nutritional security of the farm families. However, with the influx of cash crops such as rubber, cashew, coconut etc, these multi-tier systems started dwindling at an alarming rate. Paddy suffered major setback in this transformation; during 1970-2012, area under paddy had reduced to 24 percent (Suchitra, 2015).

Despite all favourable biophysical conditions, the agriculture prospects of the state are undergoing undesirable shifts primarily triggered by demographic pressure and adverse socioeconomic changes. With increasing emphasis on industrial models of agricultural development (*e.g.*, rubber), fragmentation of land holdings due to demographic pressure favouring land use intensification, the traditional agroforestry systems have declined and monocultures of commercial crops have become dominant (Kumar, 2011). Yet another reason for the large-scale expansion of the plantation crops in the state was to escape from the land ceiling limits under the Kerala land reforms Act, 1963 that exempted all commercial plantations from its purview, which prompted many to convert their land to plantations (Suchitra, 2015). This resulted in quantum leap in the area under perennial cash crops *viz.* rubber, cardamom, tea, coffee, pepper, coconut, arecanut and cashew which accounted for 65 percent of the state's cultivated area while food crops are confined to 20 percent or even less. The recent adverse socioeconomic changes prompted high opportunity cost of the land leading to 'real estate' boom and land conversion for non-agriculture practices. Probably the unique traditional multi-tier integrated farming systems, once the hallmark of the state's prosperity, were the most affected by these changes. Despite an array of commercially important agricultural crops suitable to the humid, high rainfall conditions of Kerala, drastic reduction in the land area has put serious limitation on their cultivation and the medicinal plants in particular.

Kerala being the land of Ayurveda, there is a heavy demand for medicinal plants, which is estimated to be growing at the rate of 10-12 per cent per annum (Ajithkumar, 2003). However, there exists wide gap in the demand and supply of these medicinal plants. At present 90 per cent of the supply is from forest and only 10 per cent is by way of cultivation. Rapid expansion of area under food crops and commercial crops, conversions of non-forest areas for other alternate land use, degradation of forest through fire, grazing etc. have reduced the availability of valuable medicinal plants. Such an over dependence on forests and natural woodlands for extraction of valuable medicinal plants is threatening the very existence of such ecologically fragile land resources. It is imperative therefore, that such medicinal and aromatic plants are cultivated outside their natural habitats to ensure their regular supply for human needs as well as to preserve the genetic diversity. In this context, the vast area under commercial plantations offers excellent opportunity for integrating compatible medicinal plants with these plantations. However, there is a lack of information on the strategies for the successful cultivation of medicinal plants under various land use systems where such crops can be integrated. Among the herbaceous medicinal crops, probably Zingiberaceae members such as ginger (*Zingiber officinale*), turmeric (*Curcuma longa*) and galangal (*Kaempferia galanga*) are potential species for integration with tree-based production systems primarily because of their shade tolerance and ability to thrive under polyculture systems. Rubber and cashew rubber (*Hevea brasiliensis* Muell. Arg,) and cashew (*Anacardium occidentale* L.) are the two dominant land use systems in Kerala that offer good opportunity for intercropping these medicinal herbs chiefly in view of the ample interspaces available under these plantations.

Intercropping in the tree-based system is primarily a function of light demand, tree root distribution and tree-crop interactions. Generally, intercropping is possible during the early growth phase of the trees when the system is at suboptimal levels of resource acquisition. However, at this young stage, vigorous growth of the tree stand may compete with the intercrop leading to poor crop performance. Nevertheless, towards maturity, tree growth and root development are usually stabilized; and may promote intercropping options. In India intercropping root and tuber crops with trees both at the immature and mature phases is a common practice, especially in small and medium sized land holdings, to augment the net income and employment opportunities (Nayar and Suja, 2004). However, there exists genuine lack of information on the understorey productivity of the medicinal herbs under mature rubber and cashew.

Hence the present study focuses on evaluating the compatibility of selected medicinal and aromatic herbs *viz* ginger (*Zingiber officinale* Roscoe), turmeric (*Curcuma longa* L.) and galangal (*Kaempferia galanga* L.) when grown under mature rubber (*Hevea brasiliensis* Muell. Arg,) and cashew (*Anacardium occidentale* L.) plantations. The study was undertaken with the following objectives:

1. To compare the productivity of two prominent land management systems in Kerala *viz* rubber and cashew through inter cropping with shade tolerant herbaceous medicinal crops *viz.* ginger, turmeric and galangal.
2. To analyse the biochemical changes affecting product quality of the medicinal crops from two tree based land use systems.
3. To study the biophysical attributes such as PAR availability, soil physico-chemical attributes and phytochemical characteristics that influence the productivity of both the systems.
4. To assess and compare soil carbon sequestration in these two land use systems.

Review of literature

2. REVIEW OF LITERATURE

The literature review in this chapter covers 190 publications of the last six decades.

2.1 FACTORS INFLUENCING UNDERSTOREY PRODUCTIVITY

2.1.1 Tree characteristics

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 (Toky and Bisht, 1992; 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.

2.1.2 Resource sharing

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 because of enhanced N fixation under the Acacia.

Root competition for nutrients is a complex combination of soil nutrient 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.

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 percent shade, below *Albizia odoratissima* trees providing 60 percent shade and underneath Mango trees having 50 percent shade and open field. They reported that ginger-mango intercropping having 50 percent shade recorded maximum rhizome yield of ginger (12.42 ton ha^{-1}) compared to ginger-guava system (5.07 ton ha^{-1}).

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 understory maize by 30 percent. The yield reduction was much greater than in the 25 percent shade. *Zea mays* shade was unaffected by 50 percent shade but decrease with increase in shade.

The fraction of above canopy light penetrating to the understory is inversely related to basal area of residual stand (Comeau *et al.*, 1998). 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 4x4 m in China. The result showed that soil moisture was the primary factor affecting the crop yield following the light. They concluded that apple-soyabean 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.

2.1.3 Light interception by overstorey crop

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. Shade loving species, requiring low light intensities are likely to perform better under high-density multi-storeyed cropping systems. In any intercropping system, light appears to be one of the most important limiting factors deciding the productivity of crops. Elasha *et al.* (2001) reported direct relationship between intercepted radiation and total dry matter production in sorghum. 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). Girish *et al.* (2003) reported that, incoming PAR was the highest (1.26 ly/ min.) during February and the lowest during July (0.62 ly/ min.) under Sirsi (Karnataka) conditions. The maximum mean PAR was recorded in monocropping of arecanut (0.76 ly/ min. i.e., 78.4 percent of open PAR) and minimum value (0.65 ly/min. i.e., 67.0 percent of open PAR) was observed in arecanut based mixed cropping system involving cardamom, banana and pepper as component crops. 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 (Kumar, 2005).

2.1.4 Photosynthetically active radiation

Understory 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 factors such as 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, interspecific variations 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 interspecific differences in understorey photosynthetic flux density (PPFD) data with *Acacia auriculiforrmis* interepting 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.

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*) were invariably highest in the treeless control followed by plants under least shade (75 percent crown removal). However, the positive crop response to reduced light availability has been reported earlier which include higher cocoa yield (415 g wet beans tree^{-1}) in combination with papaya (Tan *et al.*, 1991) increase banana and rubber yields 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; Gillepsie *et al.*, 2000). Jackson *et al.* (1989) studied the light requirements of trees and crops in agroforestry and identified four main tree-crop light responses which include, type A: yields as a linear function of light intensity, type B: yield increases linearly with light intensity upto a certain level and then plateaus, 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.

2.2 MEDICINAL AND AROMATIC PLANTS AS INTERCROPS

Many tropical MAPs 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*) (Chadhar and Sharma 1996; 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. 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*) and arecanut (*Areca catechu*) stands is an age-old practice in India and other parts of south- and southeast Asia. These palms allow 30 percent to 50 percent of incident light to the underneath, which is ideal for some MAPs, cardamom (*Elettaria cardamomum*). *Kacholam* or galangal (*Kaempferia galanga*) – a medicinal herb – is traditionally intercropped in mature coconut gardens in Kerala, India. Galangal intercropped in a 30 year-old coconut plantation produced 6.1 Mg ha^{-1} of rhizomes compared with 4.8 Mg ha^{-1} as a sole crop (Maheswarappa *et al.* 1998). Twelve year old coconut trees did not adversely affect the growth and yields of a number of medicinal plant species grown as intercrops compared to the yields in the open (Nair *et al.*, 1989). In Karnataka and Kerala states, 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 these 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*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 (Palada and Williams, 2000).

2.3 INTERCROPPING IN TREE PLANTATIONS

Tree plantation-based intercropping systems are being popularized on a large scale around the globe especially in the tropical countries (Nair, 1983). Smallholder farmers are inclined to intercrop young trees with intensively managed arable crops to confer nutrient and weeding benefits while gaining short-term returns. 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), Leucenia leucocephala-pearlmillet (Bhatia and Kanaujia, 2000), Hardwickia binata-based agrisilvicultural system involving sorgum-pearl millet, pigeon pea, soyabean and cotton (Khadse and Bharad, 1996), coconut-based crop combinations for humid tropics such as coffee-banana, banana with ginger, turmeric ,pineapple, papaya-pineaplle, coffee-MPT-pepper (Nair, 1983; Liyange *et al.*, 1985).

2.3.1 Rubber-based intercropping systems

Intercrops such as pineapple, banana and yam are cultivated during the immature phase of rubber whereas coffee, cocoa and medicinal plants are recommended for the mature phase (Siju, 2012; Rubber Board, 2015). In smallholder rubber plantations world-wide, food crops such as rainfed rice, groundnut, cassava and plantains are grown between the rows of rubber trees during the initial years of the plantations. These crops ensure a degree of food security for the smallholders and provide a source of income (CIRAD, 1997). The rationale for intercropping is that about 75 percent of the total area is not effectively occupied by the roots of the main crop when the rubber trees are under three years old (Ismail and Arshad, 1988).

The experiments conducted at the Rubber Research Institute of India have demonstrated the feasibility of growing intercrops during the initial three years of rubber planting. The reported intercrops in rubber smallholdings in India include cassava, rice, banana (*Musa* spp), ginger (*Zingiber officinale*), turmeric (*Curcuma longa*), elephant yam (*Amorphophallus paeniifolius*) and pineapple (*Ananas comosus*) (Sreenivasan *et al.*, 1987; Rajasekharan, 1989). In other rubber producing countries banana, cassava, upland rice, sugarcane, vegetables, maize and tobacco are reported as intercrops (Chandrasekara, 1984). Intercropping offers advantages of reduced risk, improved use of factors of production, greater total agricultural yield per unit of land and a more even use of family labour over the agricultural cycle (Vandermeer, 1989). Intercropping is used as a risk management and food security strategy in marginal environments and the practice reflects farmers' traditional wisdom for rationality as applied to their cropping decisions (Norman, 1974).

Apart from meeting food requirements and supplementing income of the farmers, the agronomic advantages of intercropping in rubber are also reported. Some of the studies indicate better growth of rubber in intercropped fields compared to monocropping (Chandrasekara, 1984). Apart from superior growth of rubber, depending on the frequency of cropping, dynamic changes in the soil nutrient status were observed due to the large amount of fertilisers applied for intercrops (Zainol *et al.*, 1993). In the intercropped fields, significant residual amounts of phosphorus, calcium and magnesium were observed.

An experiment conducted by the Rubber Research Institute of India on the intercropping of medicinal plants with rubber indicate the possibility of growing six plants which have good market potential. Based on the analysis, the two plant varieties worth considering for intercropping in mature rubber plantations on a limited scale appear to be *Plumbago rosea* and *Kaemferria galanga* in terms of the market potential (Joseph *et al.*, 1995).

Five species of medicinal plants were found to be best suited for intercropping in rubber plantations from the studies conducted by intercropping 48 species of medicinal plants in rubber plantations. The light requirements and physiology of shade adaptations of these five species of medicinal plants *viz. Plumbago rosea, Adhatoda beddomei Adhatoda vasica, Alpinia galanga and Strobilanthes heyneanus under* six shade treatments comprising 0 percent (open), 30 percent, 40 percent, 50 percent, 60 percent and 70 percent shade were suited. 70 percent shade was most favourable for growth of *A. vasica and P. rosea,* 60 percent for *A. beddomei* and 50 percent for *A. galanga* and *S.*

heyeneanus. All the five species tended to enhance the dry matter production under shade in spite of a clear reduction in the photosynthesis per unit area of the leaf. The main mechanisms of adaptations are increase in the total leaf area, photosynthesis per leaf and chlorophyll contents and a decrease in leaf thickness (Neerakkal *et al.*, 2005).

Rotan manau (*Calamus manan*) seedlings were planted between rows of rubber (*Hevea brasiliensis*) trees in a 1.4 ha plantation when the rubber was 13 years old. The relative light intensity (RLI) in the rubber plantation was 50 to 60 percent measured at midday. Survival of rotan manau at three years after planting was 80.6 percent (Aminuddin *et al.*, 1986). Atrope (1975) reported in individual studies that the soyabean and maize to be suitable intercrops in rubber. Azwar *et al* (1993) reported suitable intercrops such as rattan, banana, pineapple, salacca (*Salacca edulis),* and duku *Lansium domesticum*)for sustainable Rubber Based Forestry System Suitability of cacao, coffee, banana, pineapple, passion fruit for intercropping with rubber Chandrasekera (1977).

Growing species such as *Camellia sinensis* var.assamica, *Coffea arabica*, *Cinchona ledgeriana* and *Rauvolfia yunnanensis* under the shade of rubber trees improved the quality and quantity of their respective products and made better use of the available sunlight (Feng *et al.*, 1982). The different intecrops like banana, pineapple, ginger, turmeric, vegetables, tuber crops and medicinal plants etc. that can be planted in rubber plantations. Jessy (2001). Ginger was the most profitable intercrop, providing the largest net return per hectare (Krishnankutty, 1977).

Banana was found to be the best profitable intercrop under rubber followed by ginger (Kingsly, 1993). Among the intercrops, banana was recommended as the most suitable intercrop besides tapioca, paddy, ginger and green gram (Potty *et al.*, 1980). The most common crops grown during the immature phase of rubber are banana, pineapple, passion fruit, sugar cane and different kinds of vegetables (Rodrigo, 2001).

In a study conducted by Lisha (2005), it was revealed that coffee and cocoa could be grown as intercrops in mature rubber without adverse effect on growth and yield of rubber. Though competition existed between the component crops for above ground resources the soil fertility was improved under the intercropped situation compared to monoculture rubber.

Medicinal plants such as *Piper longum*, *Sorbilanthus haenianus*, *Boerhaavia diffusa*, *Desmodium gangeticum* and *Pseudarthria viscida* are recommended for cultivation in the interspace of rubber plantations in place of cover crops. Besides being ground cover their cultivation helps the farmer in generating subsidiary income. Being shade tolerant they can be cultivated even in mature rubber plantations. The introduction of medicinal plants in rubber plantations, as ground cover will enhance the biodiversity and sustain our herbal wealth (Mathewkutty, 2002). The probability of adoption of intercropping was highest for three intercrops, banana cassava and pineapple (Rajasekharan and Veeraputhran, 2002). Shade tolerant crops such as coffee and cocoa could be grown throughout the lifespan of rubber provided that temporary shades is given during the early stages (Rodrigo, 2002).

A field trial was conducted during Kharif season of 1999 to identify suitable annual crops to be grown as intercrop with immature rubber. Four crops *viz.* pigeon pea, groundnut, sesame and chilli were tried for this study. All the intercrops produced high yield except chilli (Roy *et al*, 1999). Among five intercrops tried in a rubber plantation in Tripura, net return was maximum for ginger (Roy *et al.*, 2004). Rubber growers are found raising different crops like banana, ginger, turmeric and elephant-foot yam (*Amorphophallus*) as intercrops, during the first three years after planting rubber (Sreenivasan *et al.*, 1987).

A study under intercropping systems on the growth of *Curcuma longa* planted in one and three year-old *Hevea brasiliensis*, and four year-old *Citrus reticulata* plantations was conducted by Khaunkuab *et al.* (2008) in Thailand. Monocropping of *Curcuma longa* was also established. The results showed that the greatest length of leaves and number of plants/clump of para rubber, 72 and 216 after planting, were 7.64 cm, 12.21 cm, 20.05 cm, 38.33 cm, 1.01 and 3.43 chief/grove, respectively, and the size of rhizome, weight of rhizome and the average yield of 1-year-old para rubber were significantly higher than the data of monocropping systems.

2.3.2 Cashew-based intercropping systems

Performance of intercrops varies with age of tree and also the extent of canopy coverage. Major area under cashew is on undulated lands of hill slope. And hence, the number of intercrops cultivated are also comparatively lesser. Information on cashew based intercropping systems is very less. Hence, some of the reviews on related tree based intercropping systems are also included. According to Directorate of Cashewnut and Cocoa Development, depending on soil and climatic conditions annual vegetables like tapioca, pulses, turmeric and ginger can be grown as inter crops under cashew (DCCD, 2015). Jindal *et al.* (1992) assessed the performance of cowpea, cluster bean, and dolichos bean in agro-forestry system formed with *Acacia tortills* Willd., *Prosopis cineraria* L. and *Tecomella undulata* Don. They also reported that, all the grain legume crops failed in association with *Acacia tortills*. Palad *et al.* (1992) carried out field experiments to investigate the effect of alley cropping of vegetables in *Leucaena* for two seasons in Nigeria. Four vegetable crops *Celosia argenta* L., amaranthus, okra and tomato were grown in control plot and in four meter wide alleys between established leucaena hedge rows. Better yield of vegetables under alley cropping was due to positive effects of the leucaena creating congenial microclimate for the growth of vegetable.

Adeyemi (1998) reported that weed suppression was better in intercropped than cashew alone. Weed suppression was best in plots carrying cashew + cassava and cashew + plantain + cassava mixtures with a 56 to 60 per cent reduction in the frequency of weeding per annum. Growth and yield of the annual food crops intercropped with newly planted cashew and two year old cashew were not significantly different to sole annual cropping as reported by Abeysinghe *et al.* (2003). Pawar and Sarwade (2006) reported soyabean sequenced with mustard intercropped in mango resulted the higher grain yield as compared to mango alone. Gill and Ajit (2006) recorded higher grain yield and straw yield in wheat intercropping with mango var. Amrapalli under Jhansi (Uttar Pradesh) conditions.

Rathna and Swain (2006) recorded the maximum average fruit number obtained in mango based intercropping with french bean (80 fruits/ plant) followed cowpea (75 fruits/ plant) compared to the minimum obtained from sole mango (47 fruits/ plant). Pawar *et al.* (2009) reported the higher growth and yield attributes in mango based intercropping systems with soya bean under Latur (Maharashtra) conditions.

2.3.3 Other tree-based intercropping system with rhizomatous spice crops

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 agro climatic conditions in coconut plantation. Jayachandran *et al.* (1992) observed significant differences in the performance of turmeric grown under different shaded (25, 50 and 75 percent) conditions. The turmeric crop 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 (32.50 cm). Performance of rhizomatous spice crops, *viz.*, ginger and turmeric was investigated under rainfed 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 popars based intercropping system under Solan (Himachal Pradesh) conditions due to shade loving nature of these crops. Both turmeric and ginger performed better as intercrop than as pure stands.

Sujatha *et al.* (1994) recorded the maximum number of leaves (27.75) in ginger cv. PGS-10 when it was grown as intercrop with coconut. 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. 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 (2004) reported higher plant height and number of tillers was produced by turmeric (69.33 cm and 6.69, 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).

Yield, morphology and specific leaf weight of the summer crops maize (*Zea mays*), beans (*Phaseolus* spp.) and ginger (*Zingiber officinale*) were studied in a 7-year-old plantation of *Paulownia elongata* grown. The yield of intercropped beans and maize was significantly reduced, compared with control monocrops, at all positions relative to the trees. Ginger gave high yields when intercropped and was reported to be an ideal shade crop for these systems (Newman, 1998).

2.4 RESPONSE OF UNDERSTOREY CROPS TO SHADE

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 in various crops including rhizomatous and tuberous crops.

2.4.1 Influence of shade on growth attributes

2.4.1.1 Plant height

Plant height has been reported as a character responsive to shading. 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 reports by George (1982); in vegetable cowpea by Krishnakutty (1983) and capsicum by Yinghua and Jianzhen (1988) and Sreelathakumary (2000).

Moss and Stinson (1961) reported increase in height of shade-grown corn. Under low light condition, the height of the rice plants was increased by 15 percent (Venkateshwarlu *et al.*, 1977). Ramanujam *et al.* (1984) reported that plant height continued to increase in all the cultivars of cassava grown under shade. Maheshwarappa *et al.* (2000) reported similar results in arrowroot. Minami *et al.* (1981) found that shaded tomato plants were taller than control. The response to shade on plant height showed a negative trend also as reported by Palis and Bustrillos (1976) in Sorghum; Tarila *et al.* (1977) in cowpea and George (1982) in red gram and grain cowpea.

Some workers have noticed a decidedly positive influence of shade on plant height. Duggar (1903) and Ross (1976) studied the general effect of shading on plants and they reported that plants under shaded conditions exhibited increased growth of main axis. Allen (1975) observed that soyabean grown under 70 percent 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 percent sunlight and was least under 10 percent as compared to 30 and 100 percent. In *Mentha piperita*, plant height under 44 percent day light was significantly greater than under 100 or 14 % 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 percent shade and the minimum under full sunlight in guinea grass var. Mackuenii. According to Senanayake and Kirthisinghe (1983), longer shoot length in black pepper under 50 percent light compared to 75 and 25 percent light. Verghese (1989) reported that in ginger plant height increased with increase in shade intensity from zero to 75 percent at 60 DAP only, after which plants grown at 25 percent shade had the highest plant height, whereas in turmeric, with increase in shade, plant height increased upto medium shade of 50 percent 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 reappect to plant height in turmeric, taller plants were observed at 75 percent shade in the initial stages and 50 percent 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). Jung *et al.* (1994) observed that main stem length of pepper increased significantly under shaded conditions. In pepper, length of primary and secondary branches increased with decrease in light intensity from 100 to 50 percent (Devadas, 1997). In a field experiment to study response of blackgram to shade by Lakshmamma and Rao (1996) using 0, 33 and 66 percent shade, it was revealed that shading increased plant height. In onion, tallest pants were observed in 25 percent photosynthetically active radiation (PAR) treatment and smallest plants were observed under full sunlight (Miah *et al.*, 1998). Height increase in *Asparagus racemosus* grown as intercrop in coconut gardens has been reported from KAU (KAU, 1999).

2.4.1.2 Leaf production

Leaf production in pants also has been found to correspond to the light levels. Scientists have reported 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 where 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 percent shade. Asha (1986) reported that the number of leaves in pen condition would be less as compared to that shade under shade in begonia.

Number of leaves produced per day in betel vine was higher under 35 and 60 percent light compared to 10 percent (Shivashankara *et al.* 2000). The plants of *Centella asiatica* produced a greater number of leaves under high light than under low light (Wankher and Tripathi, 1990). According to Venkatakkraman and Govindappa (1987), in clove, seedlings kept under shade produced more number of leaves than those exposed to the sun. 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. Number of leaves was highest under 25 percent shade (Sarkar and Saha, 1997). In arrowroot, number of leaves was higher under intercrop compared to open crop (Maheshwarappa *et al.* 2000). In pepper, under shaded conditions, the production and retention of leaves was higher (Devadas and Chandini, 2000).

Contrary to these reports, a reduction of leaf production has been also noticed with provision of shade. A decrease in number of leaves was observed in ginger at all stages by increasing the intensity from zero to 75 percent (Verghese, 1989). According to Ancy (1992), maximum number of leaves per plant in ginger was recorded under 25 percent shade at all the growth stages and the lowest number of leaves were recorded at 75 percent shade. In ginger, Babu (1993) observed maximum leaf production under 25 percent shade and found it significantly superior to other shade levels at 120 and 180 DAO. Leaf production in ginger under open conditions was found to be significantly superior compared to other shade levels (Laura *et al.*, 1986).

2.4.2 Influence of shade on yield attributes

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 percent 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.

Prameela (1990) noticed that colocasia gave maximum tuber yield under 25 percent 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 percent light attenuation. Bai (1981) observed that in ginger and turmeric maximum yield were obtained under 25 percent and 50 percent 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 percent 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 per hectare 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 shade cambial activity and tuberisation were suppressed in sweet potato tubers. 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 thereby regulating light produce more number of laterals and spikes thereby 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 per ha.

2.4.3 Influence of shade on biochemical properties

2.4.3.1 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. According to Priestly (1929), the chloroplasts on leaves would undergo changes in position according to the differences in light intensity. It was pointed out that in leaves of plants grown under low light intensities the plastids were limited in number and they were arranged at right angles to the light rays and were larger in size, this increasing the area of light absorption.

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 that the sun plants (Copper and Qualls, 1967; Bjorkman, 1968). 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. Ravishankar 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 on content 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 days after planting (Sheela, 1992). Contrary to these reports, some scientists have noticed a negative effect of shading on chlorophyll content in some crops. Einert and Box (1968) observed that in *Lilium longiflorum,* leaf chlorophyll content was highest under full sunlight at the time of initiation observed that and directly proportional to light intensity.

2.4.3.2 Oleoresin

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). 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. Gupta (1964) carried out studies in this respect and reported that the shade dry herb contains 4 percent (w/w) of oil against 3 percent in the sun-dry hay in Japanese mint. An (1982) studied the effect of light intensity in groundnut and observed that shade increased the oil content of fruits. Ginger cultvar, 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 (Ravishankar and Muthuswamy, 1988). In ginger, George (1992) found an increase in volatile oil content with increase in shade intensity and the highest value recorded was under 75 percent shade. 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 percent shade, which was on par with treeless open.

Shading has also been reported to have an adverse effect with respect to oil contents in plants. Shade levels of 20, 47, 63, 80 and 93 percent were found to have little effect on quality parameters of soyabean *viz*. oil and protein content of seeds except at 93 percent 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 upto 50 percent level of shade (Verghese, 1989). Ancy (1992) recorded the highest volatile oil content under 25 percent shade followed by that under 50 percent shade.

2.5 NUTRIENT ACCUMULATION

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 percent 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 percent shade. In ginger uptake of N and K increased from zero to 20 percent 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 significance increase with increasing shade intensities (Geetha, 2004).

2.6 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).

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). The soil carbon stock estimated in the rhizosphere of five black pepper support trees *viz. Ailanthus triphysa, Erythrina variegate, Gliricidia sepium* and *Garuga pinnata* in the humid tropics of Kerala registered greater levels of soil organic C in the rhizosphere of *G. sepium* (26.5 g kg^{-1}), and the lowest level was registered under *A. triphysa* (21.6 g kg^{-1}; Dinesh *et al.*, 2010). Sreenivasan *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. Total SOC upto 1 m depth was found to be maximum in *Syzygium cumini* (77.72 Mg C ha^{-1}) followed by *Eucalyptus tereticornis* (74.69 Mg C ha^{-1}) and *Tectona grandis* (55.46 Mg C ha^{-1}; Arora and Chaudhry, 2014).

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 help in improving soil organic carbon through their decomposition (Brady and Weil, 2008) and supply C to soil through the process known as rhizo-deposition. 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 (Fontaine *et al.*, 2007).

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 percent 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 pruning 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

3. MATERIALS AND METHODS

3.1 STUDY SITE

3.1.1 Location

The two land use systems studied *viz.* rubber and cashew plantations and the control plot were located in the KAU main campus, Vellanikkara, Thrissur, Kerala (10° 13 N latitude and 76° 13' E longitude and at an elevation of 40 m above MSL). The rubber and cashew consisted of mature trees aged 28 and 20 years and planted at spacing of 4.5 m × 4.5 m and 8m × 8m respectively.

3.1.2 Climate and soil

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 in June to September. The mean monthly maximum temperature ranges from 29.10°C to 35.40°C in the months of July and March respectively. The mean monthly minimum temperature varies from 22.19°C (December) to 24.83°C (May). The soil of the experimental site is an Ultisol (Typic Plinthustult-Vellanikkara series midland laterite) (Thomas et al., 1998).

3.2 EXPERIMENT LAYOUT

3.2.1 Lay out and preparation of land

The experimental plots were cleared during April-May and the weeds, stubbles and roots were burnt *in situ.* Land was prepared by ploughing with a tractor thoroughly to bring the soil to fine tilth. Beds of size 5×1×0.3 m were prepared with an inter-space of 50 cm in between beds. In rubber and cashew plots, beds were established in such a way that two parallel row beds, each of size 5m × 1m were established in between the planted rows taking care to maintain a convenient crop free zone distance from the selected trees. In treeless open (control), single beds of size 10m × 1m each were established for every crop (Figures 1, 2 and 3).

3.2.2 Planting of intercrops

The three understorey crops selected for the study were ginger (*Zingiber officinale* R. var. Aswathi), turmeric (*Curcuma longa* var. Sona) and galangal

(*Kaempferia galanga* var. Thodupuzha local). The intercrops were grown in bed of size 5×1×0.3 m in the selected rubber and cashew-based land managemen systems. Randomized Block Design with three replications was followed for th intercropping experiment. There were two such beds for each intercrop such tha the total bed area per intercrop was 10 m^2. In addition to these treatments, a absolute treeless control was established where the crops were raised in ope contiguous plots. The intercrops were planted at 25 cm×25 cm spacing followin recommended package of practices (KAU, 2011).

3.2.3 Planting material and pre-treatment

Rhizomes were used for planting. For selection and preservation of seeds standard methods were adopted. Seed rhizomes were carefully handled to avoi damage to buds. The selected rhizomes were soaked for 30 minutes in a solutio of mancozeb and malathion to give terminal concentration of 0.3 per cent for th former and 0.1 per cent for the latter. The treated rhizomes were dried in shade b spreading on the floor. The treated rhizomes were stored in pits dug under shade the floor of which was lined with sand or saw dust. The pits were covered wit coconut fronds.

3.2.4 Season and method of planting

The intercrops were planted during the month of June. Rhizome bits of 1 g weight were planted in small pits at a spacing of 25 cm x 25 cm and at a dept of 4-5 cm with at least one viable healthy bud facing upwards.

3.2.5 Manuring

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

Plate 1. Experimental site of rubber

Plate 2. Experimental site of cashew

Plate 3. Experimental site of control (treeless open)

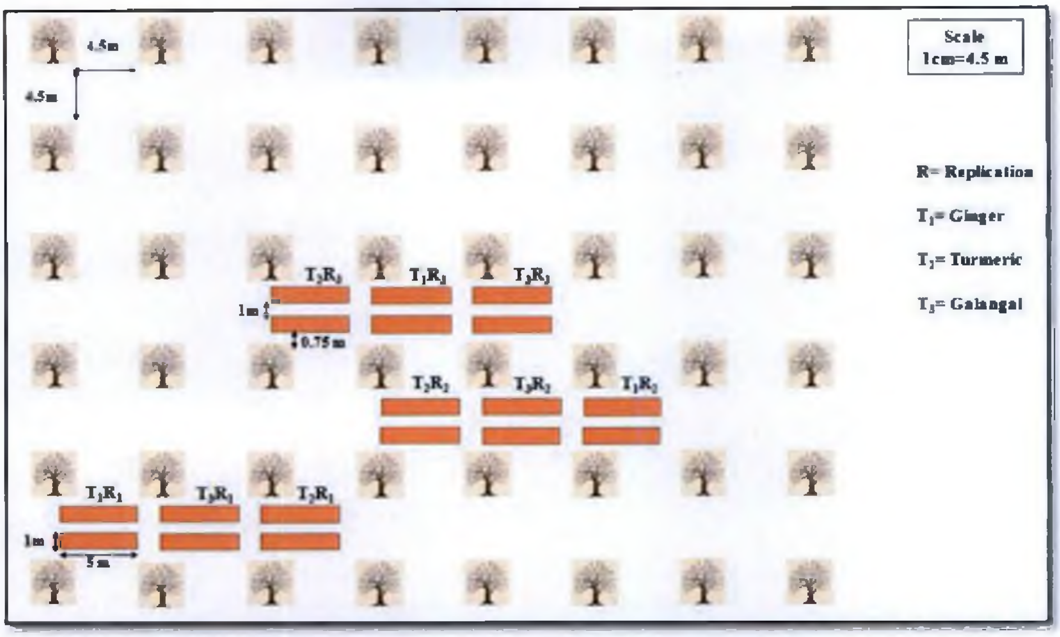

Fig. 1. Layout of rubber plot with understorey crops

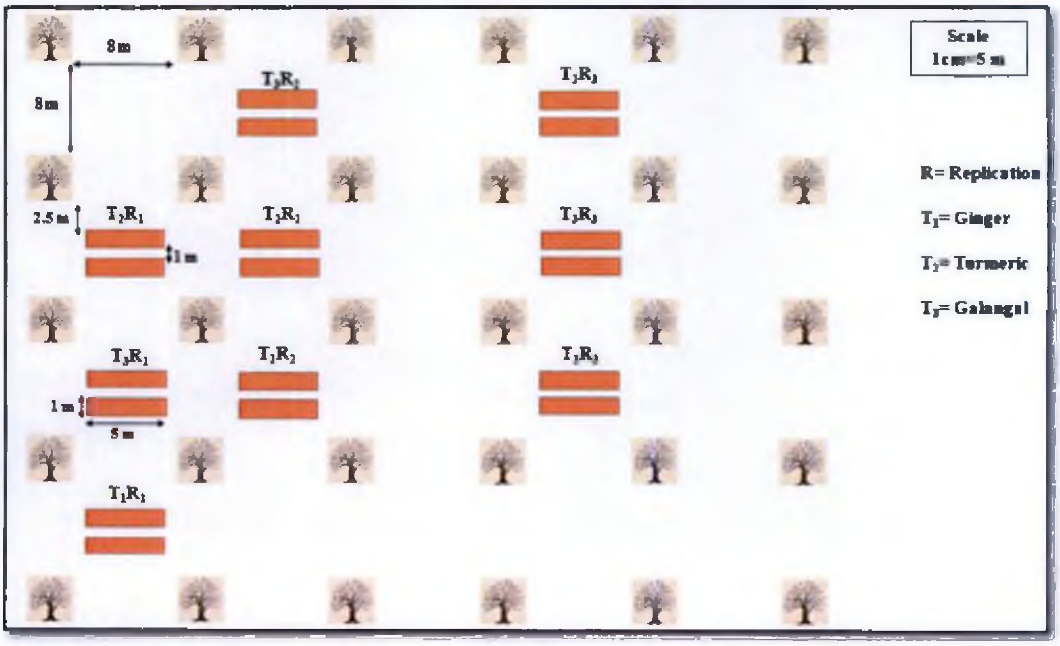

Fig. 2. Layout of cashew plot with understorey crops

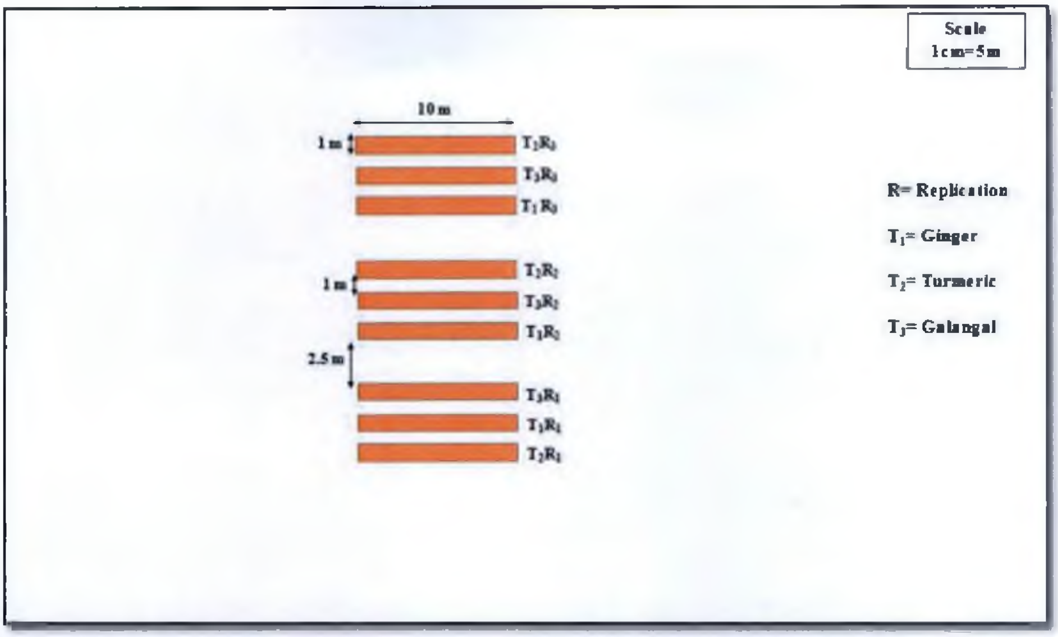

Fig.3. Layout of control (treeless open) with understorey crops

3.2.6 Mulching and weeding

Immediately after planting, the beds were mulched thickly with green leaves of *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 plucking-out with hand before each mulching and repeated according to weed growth.

3.2.7 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.

3.3 OBSERVATIONS AND DATA GATHERING

For biometric observations, eight plants were selected at random from each treatment by taking half-meter quadrats (0.5 ×0.5 m) at 90^{th}, 150^{th} and 230^{th} days after planting (DAP). Ginger, turmeric and galangal grown in all the experimental sites were destructively sampled. All the plants in the sampling units 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 component dry matter production and final rhizome yield (230 DAP) from ginger, turmeric and galangal was determined.

3.3.1 Growth and yield determination

3.3.1.1 Plant height

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

3.3.1.2 Pseudostem length

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

3.3.1.3 Leaf spread

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

3.3.1.4 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.

3.3.1.5 Number of tillers

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

3.3.1.6 Number of leaves per tiller

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

3.3.1.7 Specific leaf area

Specific leaf area is a function of leaf dry matter. It was determined by dividing leaf area by dry leaf weight and expressed as $cm^2\ g^{-1}$. The leaf area was measured by leaf area meter.

3.3.1.8 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^{th}, 150^{th} and 230^{th} DAP and expressed as g $plant^{-1}$

3.3.1.9 Belowground biomass

The below ground yield was assessed for all the three medicinal crops at 90^{th}, 150^{th} and 230^{th} DAP. The fresh rhizomes were washed, all roots from the rhizome were removed and rhizome weight determined. The weight was expressed in g $plant^{-1}$

3.3.1.10 Dry matter production (DMP)

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

3.3.1.11 Final rhizome yield

The understory ginger, turmeric and galangal were harvested (left out crop after sampling) from each experimental plot at 230 DAP. 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 per ha from each experimental site.

3.3.1.12 Net rhizome production

Net rhizome production was calculated by estimating the rhizome yield of plants from net-cropped area in rubber, cashew and treeless open.

3.3.2 Plant analysis

3.3.2.1 Chlorophyll content

Total chlorophyll content of the leaf samples was estimated using the method described by Arnon (1949). Leaf samples weighing 250 mg were macerated with 10 ml of 80 percent acetone using a pestle and mortar and the extract was centrifuged at 3000 rpm for 10 minutes. The supernatant solution was

Plate 4. Measurement of PAR with Light Quantum Sensor

Plate 5. Biometric measurements of plant samples

Plate 6. Measurement of the leaf spread of galangal

transferred into a 25 ml volumetric flask and made up to 25 ml using acetone. After reading the colour intensity of the green pigment at 645nm and 663nm for chlorophyll-a and chlorophyll-b content respectively, calculations were made using the following formula and expressed as mg g^{-1} of fresh leaf:

$$\text{Total Chlorophyll} = [(8.022 \times A_{663}) + (20.2 \times A_{645})] \times \frac{V.W}{1000} \text{ mg g}^{-1}$$

Where,

A_{663}: Absorbance at 663 nm

A_{645}: Absorbance at 645 nm

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

W: Weight of the tissue extracts (0.25g)

3.3.2.2 Oleoresin Content

Five grams of finely powdered sample was covered in a filter paper and made as thimble 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.

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

Where,

W_1 = weight of empty flask (g)

W_2 = weight of flask with extractives (g)

S = weight of sample (g)

3.3.2.3 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 reaction: after dialysis against a buffer solution of pH 5.2, the ammonia in the sample is chlorinated to monochloramine which reacts with salicylate to 5 aminosalicylate. After oxidation and oxidative coupling a green coloured complex was formed. The absorption of this complex formed is was measured at 660nm. The various reagents used include Potassium sodium tartarate solution, Sodium salicylate solution, Sodium nitroprusside solution, Sodium dichloroisocyanurate solution, Rinsing liquid sampler, Distilled water + Brij 35.

Sulphuric acid and Se powder mixture – 3.5g Se powder was weighed. 1 litre of conc. H_2SO_4 was carefully and slowly poured into a two litre beaker. Selenium 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.

Digestion mixture – 10.8g salicylic acid was weighed and added to mixture already prepared containing 150 ml of H_2SO_4 and Selenium.

Weighed 0.2 g of the plant sample (leaves, stem wood, branches and twigs) in the digestion tube. Poured 2.5 ml of the digestion mixture 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 percent 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 and the digestion was completed. The digest was made upto 75 ml in a standard flask. The nitrogen content of the plant sample was then analyzed using scalar

3.3.2.4 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 colourless. After that, the digest was made up to 50 ml. About 5 ml 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 pre dilution) 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.

3.3.2.5 Estimation of potassium

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

3.3.3 Soil analysis

3.3.3.1 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 by 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).

3.3.3.2 **Total nitrogen**

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

3.3.3.3 Available phosphorus

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

3.3.3.4 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).

3.3.4 Biophysical observations

3.3.4.1 Stand leaf area index (LAI)

LAI 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, primary photosynthetic production and evapotranspiration. 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 and below the canopy, based on theoretical relationship between leaf area and canopy transmittance (Stenberg *et al.*, 1994). The LAI outside the each plot was recorded as an above canopy reading of sky brightness and then understorey in each plot as below canopy reading as plot LAI. 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.

3.3.4.2 Understorey photosynthetically active radiation (PAR)

PAR measurement was carried out using Line Quantum Sensor (LQI 2404, K131). A battery powered data logger integrated the mean PAR at hourly intervals from 8 a.m. to 6 p.m. within each plot. PAR above the canopy of each plot was recorded from the nearby open area. PAR was then converted to canopy transmittance, which is the light below the canopy expressed as percentage of light incidence on the top of the canopy.

3.3.5 Soil carbon sequestration

Soil samples were collected by digging profile pits at random points in the interspaces between the rows of trees and from the contiguous and a treeless plot.

Plate 7. Digging pit for soil carbon sequestration assessment

Plate 8. Demarcation of soil profile into different depth classes

Plate 9. Taking a soil core for bulk density measurement

Three profile pits of one meter depth (1.5 m long and 60 cm wide) were dug in the selected plantations and three pits in the treeless open area. All profiles were demarcated into 0–20, 21–40, 41–60, 61–80, 81–100 cm horizons, and triplicate soil samples collected depth-wise. All samples were air dried, ground, sieved (2 mm sieve), bagged and stored for analysis. Prior to the estimation of SCS, soil bulk density was assessed for each of the soil depth separately for the soil profiles in the given land use systems. Soil bulk density (BD) was determined by taking cores of undisturbed soil by using a steel cylinder (7.5 cm length and 5.5 cm diameter) following standard procedures (Jackson, 1958). Soil cores were collected by inserting the cylinder horizontally on the wall of soil pits at the centre of each depth class without pressing the cylinder too hard on soil so that the natural bulk density of soil was not 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 (cm^{-3}) 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. Organic carbon of the soil was estimated by wet digestion method (Walkley and Black, 1934). Soil mass for each soil depth was computed from the corresponding bulk density and soil C-sequestration calculated for each soil depth by multiplying soil mass with soil organic C-concentration (percent). Also, representative triplicate soil samples were collected from contiguous treeless plots as control.

3.4 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

4. RESULTS

The study encompassed the assessment of the performance of selected medicinal herbs *viz.* ginger (*Zingiber officinale*), turmeric (*Curcuma longa*) and galangal (*Kaempferia galanga*) grown under rubber and cashew plantations. A comprehensive examination of important plant characteristics and other associated attributes was undertaken, with prominent results obtained as given below:

4.1 BIOMETRIC CHARACTERISTICS OF MEDICINAL CROPS GROWN UNDER CASHEW AND RUBBER

4.1.1 Plant height and Leaf Spread

The data on plant height of ginger and turmeric; and leaf spread of galangal at 90 and 150 Days after planting (DAP) as influenced by different landuse systems are presented in the Tables 1 & 2; and Fig. 4 & 5.

4.1.1.1. Plant height of ginger

Observations revealed appreciable changes in plant height during the growth period (Table 1). Rubber plot exhibited significantly maximum plant height (61 cm) at 90 DAP. This was followed by cashew (50.13 cm) and control plot (43.17 cm) which were on par. This translates to a percentage increase of 41.30 and 16.12 in rubber and cashew respectively. At 150 DAP, open grown ginger showed considerably lowest (59.33 cm) plant height whereas rubber grown plants showed maximum height (69.13 cm) and was on par with cashew (63.21 cm). This implies to 16.50 percent increase in plant height in rubber-grown plants and 6.54 percent increase in cashew compared to control plot. However, over the growth period from 90 to 150 DAP, ginger in control plot picked up the height growth resulting in 37.43 percent increase in plant height as against low performance of cashew (26.09 percent) and rubber (13.31 percent).

4.1.1.2 Plant height of turmeric

Observations revealed that turmeric grown under cashew recorded significantly highest (102.67 cm) plant height at 90 DAP followed by rubber

(81.38 cm) and control (76.13 cm). This amounts to a corresponding increase of 34.86 percent and 6.90 percent in plant height of turmeric grown in cashew and rubber as compared to control. At 150 DAP cashew plot again had notably tallest plants (118.75 cm) amounting to a percentage increase of 15.10 in comparison with control whereas rubber plot showed 7.04 percent increase. While comparing growth, over the period of two observations, maximum increment in plant height was noticed in rubber and open grown plants (35.64 and 35.40 percent respectively); followed by cashew grown plants which recorded an increase of 15.66 percent.

4.1.1.3 Leaf spread of galangal

A perusal of the data presented in the Table 2 reveals that no prominent variation existed in galangal leaf spread among the different landuse systems. However, maximum leaf spread at 90 DAP was recorded in rubber plot (26.5 cm) followed by cashew and treeless open plots. Rubber and cashew barely noticed 4.5 percent and 1.22 percent increase in leaf spread. At 150 DAP, it was again the rubber plot that maintained the widest (31.53 cm) leaf spread amounting to 18.05 percent increase from 90 to150 DAP in comparison with control plot. This was followed by cashew having leaf spread of 30.44 cm being 13.96 percent more than open. Over the growth period between two observational stages, rubber plot was found to have more (18.98 percent) increase in leaf spread.

4.1.2. Pseudostem length

The data on the pseudostem length of ginger and turmeric at different growth stages as influenced by different landuse systems are presented in the Table 3 and Fig.6.

4.1.2.1 Ginger

Observations revealed considerable changes in pseudostem length of ginger during initial sampling stage. Maximum pseudostem length (14.04 cm) was recorded in rubber followed by cashew (13.92 cm) and control plots (10.21 cm). This amounts to a respective percentage increase of 37.51 and 36.34 respectively in rubber and cashew as compared to the control. At 150 DAP also;

the same trend was maintained with rubber plot showing maximum (16.83 cm) pseudostem length followed by cashew (15.92 cm) and control (15.08 cm). Compared to control, rubber and cashew recorded 11.6 percent and 5.57 percent increase in pseudostem length. However, over different growth stages, notable increase in pseudostem length was recorded in control plot (47.70 percent). Rubber and cashew exhibited an increase of 19.87 percent and 14.37 percent during the same period (between 90 and 150 DAP).

4.1.2.2 Turmeric

A perusal of the data presented in the Table 3 revealed marginal changes at initial growth stage. At 90 DAP, maximum pseudostem length of turmeric was 20.25 cm (in cashew) closely followed by rubber (20.08 cm) and control plots (16.33 cm). In terms of percentage change, it translates to a 24 percent and 22.96 percent increase in pseudostem length of turmeric grown in cashew and rubber correspondingly compared to that of open grown plants. Perceptible changes were noticed during the subsequent sampling stag (150 DAP). Maximum pseudostem length was recorded in cashew (27.04 cm) which was on par with rubber (26.17 cm) and significantly different from treeless open plot (22.46 cm). There was an increase to the tune of 20.39 percent and 16.52 percent in cashew and rubber grown turmeric respectively. The percentage increase in pseudostem length between 90 and 150 DAP was found higher (37.54) in control plot followed by cashew (33.53 percent) and rubber (30.33 percent)

4.1.3 Root length

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 and Fig.7.

4.1.3.1 Ginger

An examination of data presented in the Table 4 demonstrated that root length at 90 DAP was recorded maximum (21.33 cm) in ginger grown in control plot, though changes were modest. It was followed by rubber (18.92 cm) and in cashew plot (17.46 cm). This implies to 18.14 percent decrease in root length in cashew and 11.30 percent in rubber compared to control plot. Observations revealed apparent changes during subsequent sampling stage (150 DAP). Control plot recorded highest (21.67 cm) root length considerably different from rubber (18.97 cm) but on par with cashew grown plants (19.83 cm). The values indicate relatively higher (12.46) percentage increase in root length of cashew grown ginger and 8.49 percent in case of rubber compared to open grown plants.

4.1.3.2 Turmeric

Observations revealed substantial differences during the initial sampling stage (Table 4). Turmeric grown in the open showed maximum (17.67 cm) root length at 90 DAP followed by cashew (16.08 cm) which were on par. A distinctively lowest root length was recorded in rubber (15.42 cm). In comparison with control, reduction of 12.73 percent and 9.0 percent in root length was observed in rubber and cashew plots respectively. Modest changes were noticed during the subsequent sampling stage (150 DAP). The open plot registered a maximum root length of 19.33 cm followed by rubber (17.75 cm) and cashew (16.79 cm). Over the growth period between 90 and 150 DAP; rubber recorded a maximum increase of 15.11 percent. This was followed by open and cashew recording an increase of 9.39 percent and 4.42 percent respectively.

4.1.3.3 Galangal

A perusal of data presented in the Table 4 displays perceptible variation in galangal root length during the first sampling stage (at 90 DAP). Open grown galangal had maximum (18.75 cm) root length significantly different from cashew (15.46 cm). Rubber showed the least (13.08 cm) length on par with cashew and open grown plants. Compared to control there was a decrease of 30.24 percent root length in rubber-grown galangal and 17.55 percent in cashew plot. At 150 DAP open plot again recorded the longest (20.38 cm) root length followed by cashew (17.38 cm) and rubber (15.21 cm). It amounts to a reduction of 14.72 percent and 25.37 percent in root length in rubber and cashew respectively in comparison with open. During the growth stages form 90 DAP to 150 DAP there was an increase of 16.28, 5.65 and 8.69 percent in root length in rubber, open and cashew grown galangal respectively.

4.1.4 Number of tillers per plant

The data on number of tillers in ginger, turmeric and galangal during different growth stages as influenced by different landuse systems are given in the Table 5 and Fig 8.

4.1.4.1 Ginger

An examination of the data presented in the Table 5 demonstrates that during the first observation at 90 DAP, rubber and cashew grown ginger were significantly different from each other. Cashew plot exhibited more number of tillers (8.04) followed by control (6.5). The least was produced in rubber (5.79). Yet both rubber and cashew grown plants were on par with treeless open plot. Compared to the control plot, an increment of 23.69 percent was observed in cashew plot while a reduction of 10.92 percent in number of tillers was in rubber-grown ginger. During the second observation (150 DAP), the significant variation was noticed. Control plot recorded increased (14.0) number of tillers followed by cashew (11.88) while rubber again produced the least (10.58). Besides, reduction of 24.43 and 15.14 percent was noticed in rubber and cashew plots correspondingly compared to control. Over the growth period, control plot exhibited the highest (115.38) percentage increase in number of tillers between 90 and 150 DAP. Rubber plot was noticed to have 82.73 percent increase in number of tillers while cashew had the least percentage increase (47.76) between the two growth stages.

4.1.4.2 Turmeric

Marginal differences were noticed in tiller production among the land use systems during the first stage of observation (Table 5). Number of tillers per plant at 90 DAP was recorded more in cashew grown turmeric with a mean number of 2.1 followed by control plot (2.04). Minimum tiller production was noticed in rubber plot (1.63). Thus, rubber grown turmeric showed 20 percent reduction in tiller production compared with control. Appreciable variation was noticed during subsequent sampling stage (150 DAP). Control produced more (2.33) number of tillers which was significantly different from the rubber producing the lowest (1.67). However, the values obtained from open and rubber (1.67) plots were on par with cashew (2.12). In comparison with control, reduction of 28.32 percent and 9 percent in tiller production was noticed in rubber and cashew plots respectively. Over the growth period between 90 and 150 DAP Open grown turmeric showed an overall percentage increase of 14.22 in tiller production.

4.1.4.3 Galangal

Notable changes were noticed in tiller production in galangal during the first observation stage (Table 5). Galangal exhibited maximum tiller production in rubber plot (6.08) at 90 DAP followed by cashew (3.42) and control (2.58) plots. This translates to a percentage increase of 135.66 and 32.56 in rubber and cashew grown galangal correspondingly in comparison with control. Observations revealed modest changes during second sampling stage (150 DAP). Rubber grown galangal again produced higher number of tillers and was followed by cashew and open producing 8.71 and 7.83 tillers respectively. Compared with control, rubber-grown galangal showed a percentage increase of 31.42 in tiller production while an increment of 11.24 percent was noticed in cashew plot. However in terms of percentage change, overall better performance in tiller production between 90 and 150 DAP was observed in control plot recording 203.49 percent increase. Cashew and rubber plots recorded increase of 154.68 and 69.24 percent respectively during the same period.

4.1.5. Number of leaves per tiller

The data on number of leaves per tiller of ginger, turmeric and galangal during different growth stages as influenced by different landuse systems are given in the Table 6 and Fig.9.

4.1.5.1 Ginger

Modest changes were found in the number of leaves per tiller at 90 DAP. Cashew grown ginger (13.96) produced highest number of leaves per tiller followed by open (13.08) whereas lowest number was noticed in rubber plot

(11.08). Noticeable variation in leaf production was observed during successive sampling stage (150 DAP). Open grown ginger exhibited maximum (14.58) number of leaves, which was on par with cashew (13.25). These were however significantly different from rubber grown (12.54) ginger which showed the lowest number of leaves. This further implies that there was a reduction in number to the tune of 13.99 percent and 9.12 percent in rubber and cashew-grown ginger respectively as compared to open.

4.1.5.2 Turmeric

Marginal variation was observed during the first observational stage at 90 DAP (Table 6). Highest number of leaves was found in open (7.00) grown turmeric whereas followed by rubber (6.71) and cashew (6.37). However perceptible changes were observed at 150 DAP. Open grown turmeric recorded highest (8.29) number of leaves which was on par with cashew (7.58) whereas rubber plot produced significantly lowest (7.16) number of leaves per tiller, which amounts to a reduction of 30.16 percent in comparison to open. Over the growth period between two observational stages, an increment of 18.43, 15.96 and 6.71 was noticed in open, cashew and rubber respectively.

4.1.5.3 Galangal

Open grown galangal exhibited significantly highest number of leaves at 90 DAP (Table 6). This was succeeded by rubber and cashew plots, which were on par with each other. This corresponds to a decrease of 41.19 and 37.67 percent of leaf production per tiller in rubber and cashew respectively compared to open. Further at 150 DAP, small difference was found. Almost similar leaf production was noticed in rubber and cashew grown galangal while least in the open plot. During the growth period, open plot recorded a 50.44 percent reduction in leaf production whereas rubber and cashew recorded 15.90 and 10.86 percent decrease between the two observational stages.

Table 1. Plant height (cm) of ginger & turmeric at 90 and 150 days after planting (DAP) grown in different landuse systems

Landuse System	Plant height (cm)			
	Ginger		Turmeric	
	90 DAP	150 DAP	90 DAP	150 DAP
Rubber	61.00^{a} (4.93)	69.13^{a} (1.02)	81.38^{b} (10.49)	110.38^{b} (0.90)
Cashew	50.13^{b} (1.26)	63.21^{a} (1.02)	102.67^{a} (7.53)	118.75^{a} (7.26)
Open	43.17^{b} (1.19)	59.33^{b} (1.19)	76.13^{b} (8.54)	103.08^{c} (6.43)
F	8.881	6.505	11.626	6.879
p	0.016	0.031	0.028	0.009

Values in parenthesis indicate Standard Error
Values with same superscript in a column do not differ significantly
DAP- Days after planting

Table 2. Leaf spread (cm) in galangal at 90 and 150 DAP grown in different landuse systems

Landuse System	Leaf spread (cm) in galangal	
	90 DAP	150 DAP
Rubber	26.5 (0.63)	31.53 (1.67)
Cashew	25.67 (3.04)	30.44 (1.22)
Open	25.36 (0.26)	26.71 (4.14)
F	0.108	0.894
p	0.899	0.457

Values in parenthesis indicate Standard Error
DAP- Days after planting

Table 3. Pseudostem length (cm) of ginger & turmeric at 90 & 150 DAP grown in different landuse systems

Landuse System	Pseudostem length (cm)			
	Ginger		Turmeric	
	90 DAP	150 DAP	90 DAP	150 DAP
Rubber	14.04[a] (0.56)	16.83 (3.48)	20.08 (3.65)	26.17[a] (2.67)
Cashew	13.92[a] (2.11)	15.92 (0.89)	20.25 (1.83)	27.04[a] (2.50)
Open	10.21[b] (0.15)	15.08 (0.40)	16.33 (1.45)	22.46[b] (1.69)
F	12.963	0.176	0.783	5.170
p	0.027	0.843	0.499	0.050

Values in parenthesis indicate Standard Error
Values with same superscript in a column do not differ significantly
DAP- Days after planting

Table 4. Root length (cm)of ginger, turmeric and galangal grown in different landuse systems

Landuse System	Root length (cm)					
	Ginger		Turmeric		Galangal	
	90 DAP	150 DAP	90 DAP	150 DAP	90 DAP	150 DAP
Rubber	18.92 (1.12)	18.97[b] (0.54)	15.42[b] (0.47)	16.79 (2.33)	13.08[ab] (0.79)	15.21 (1.12)
Cashew	17.46 (1.94)	19.83[ab] (3.73)	16.08[ab] (0.44)	17.75 (0.27)	15.46[b] (1.67)	17.38 (1.60)
Open	21.33 (1.49)	21.67[a] (1.34)	17.67[a] (0.67)	19.33 (0.40)	18.75[a] (0.95)	20.38 (2.95)
F	1.592	13.702	14.635	0.781	5.595	1.617
p	0.279	0.021	0.019	0.499	0.043	0.274

Values in parenthesis indicate Standard Error
Values with same superscript in a column do not differ significantly
DAP- Days after planting

Table 5. Number of tillers per plant in ginger, turmeric and galangal at 90 and 150 DAP grown in different landuse systems

Landuse System	Number of tillers per plant					
	Ginger		Turmeric		Galangal	
	90 DAP	150 DAP	90 DAP	150 DAP	90 DAP	150 DAP
Rubber	5.79[b] (0.44)	10.58[b] (3.87)	1.63 (0.22)	1.67[b] (0.72)	6.08[a] (0.96)	10.29 (0.83)
Cashew	8.04[a] (0.60)	11.88[b] (0.40)	2.10 (0.22)	2.12[ab] (0.22)	3.42[ab] (1.19)	8.71 (0.34)
Open	6.50[ab] (0.38)	14.00[a] (0.50)	2.04 (0.85)	2.33[a] (0.44)	2.58[b] (0.11)	7.83 (2.61)
F	5.703	13.580	0.191	5.506	14.288	0.669
p	0.031	0.009	0.831	0.044	0.013	0.546

Values in parenthesis indicate Standard Error
Values with same superscript in a column do not differ significantly
DAP- Days after planting

Table 6. Number of leaves per tiller in ginger, turmeric and galangal grown in different land use systems

Landuse System	Number of leaves per tiller					
	Ginger		Turmeric		Galangal	
	90 DAP	150 DAP	90 DAP	150 DAP	90 DAP	150 DAP
Rubber	11.08 (0.37)	12.54[b] (2.19)	6.71 (0.07)	7.16[b] (0.83)	2.83[b] (0.22)	2.38 (0.13)
Cashew	13.96 (2.02)	13.25[a] (4.00)	6.37 (0.26)	7.58[a] (0.37)	2.67[b] (0.18)	2.38 (0.72)
Open	13.08 (0.61)	14.58[a] (0.30)	7.00 (0.38)	8.29[a] (0.37)	4.54[a] (0.29)	2.25 (0.13)
F	1.418	8.250	1.171	17.710	19.385	0.429
p	0.313	0.019	0.372	0.003	0.002	0.670

Values in parenthesis indicate Standard Error
Values with same superscript in a column do not differ significantly
DAP- Days after planting

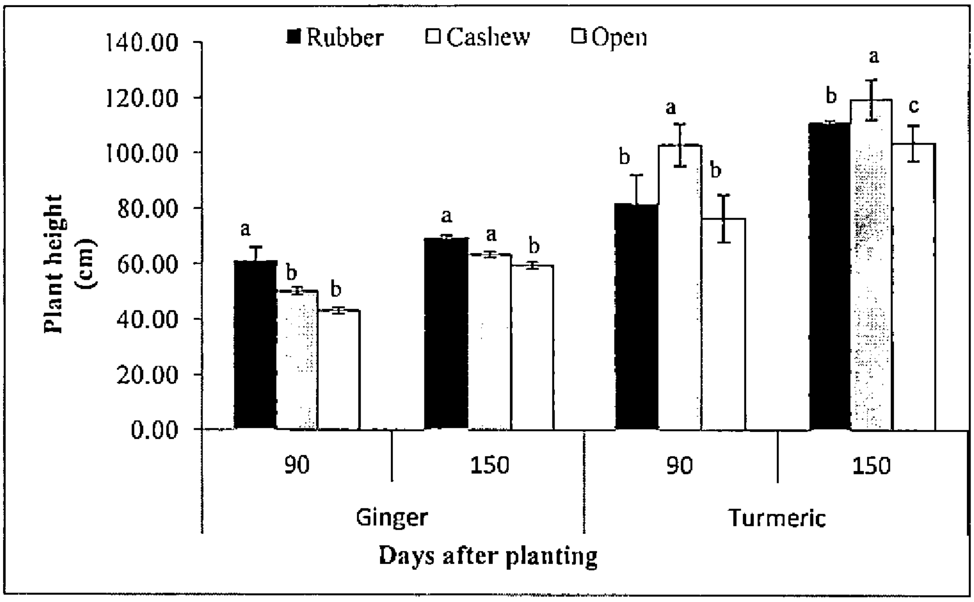

Fig. 4. Plant height (cm) of ginger & turmeric at 90 and 150 DAP grown in different landuse systems

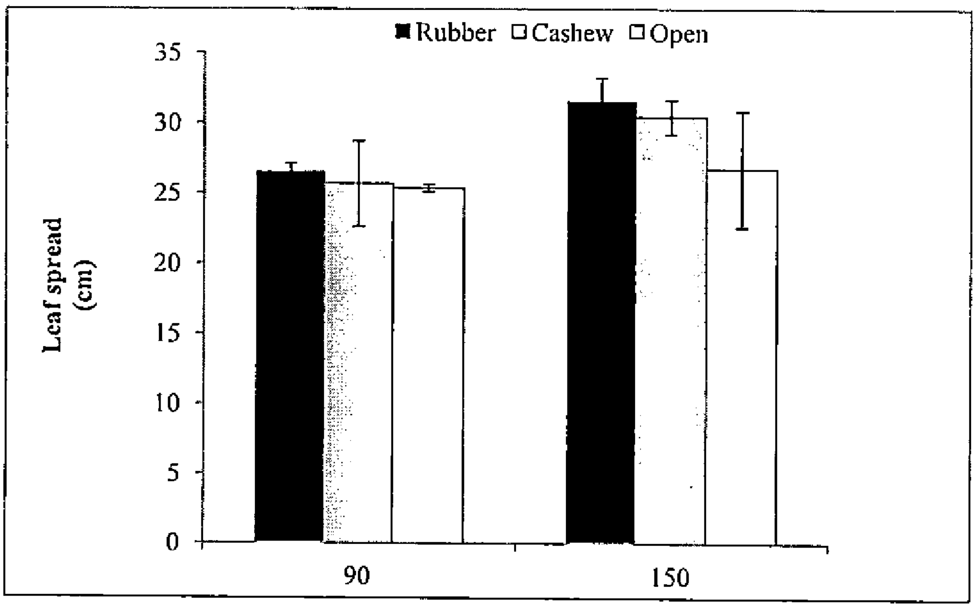

Fig. 5. Leaf spread (cm) of galangal at 90 and 150 DAP growing in different land use systems

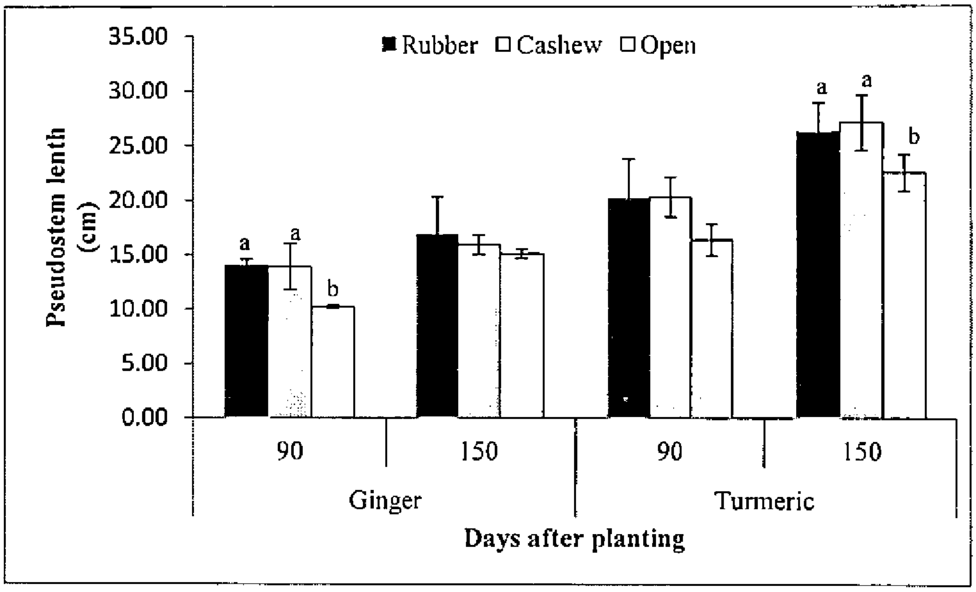

Fig. 6. Pseudostem length (cm) of ginger & turmeric at 90 & 150 DAP as influenced by land use systems

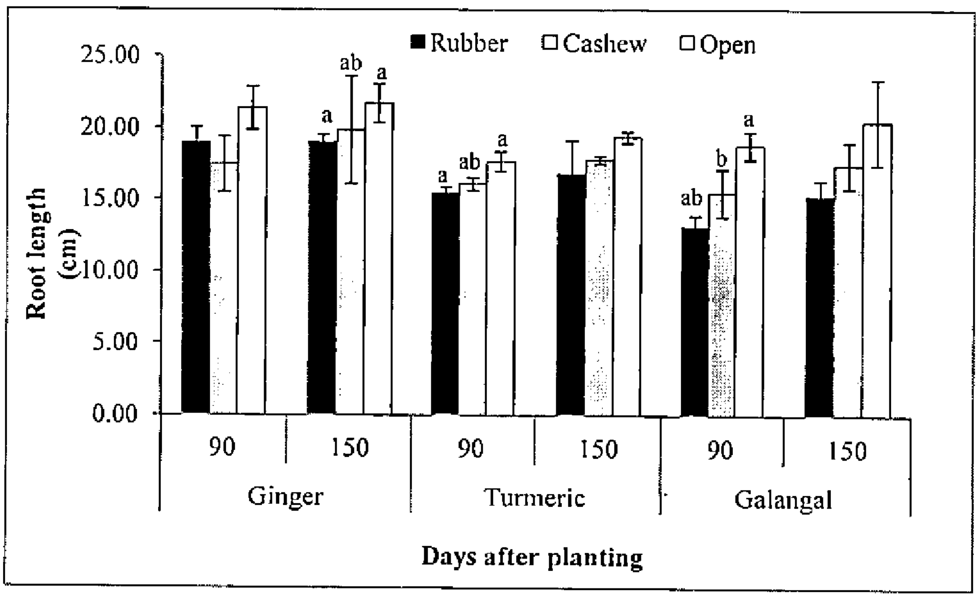

Fig.7. Root length (cm) of ginger, turmeric and galangal grown in different landuse systems

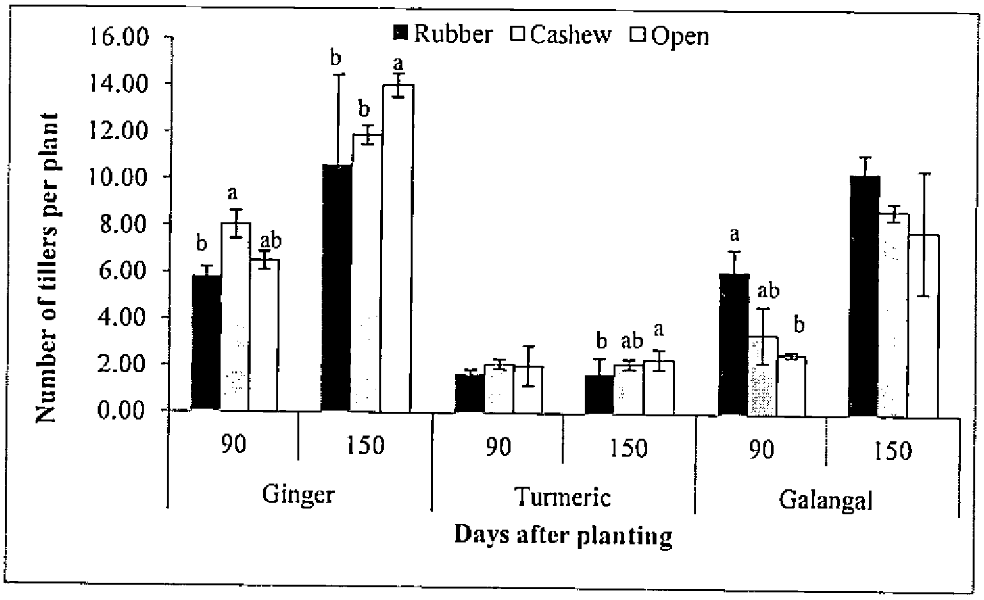

Fig. 8. Number of tillers per plant in ginger, turmeric and galangal at 90 and 150 DAP grown in different landuse systems

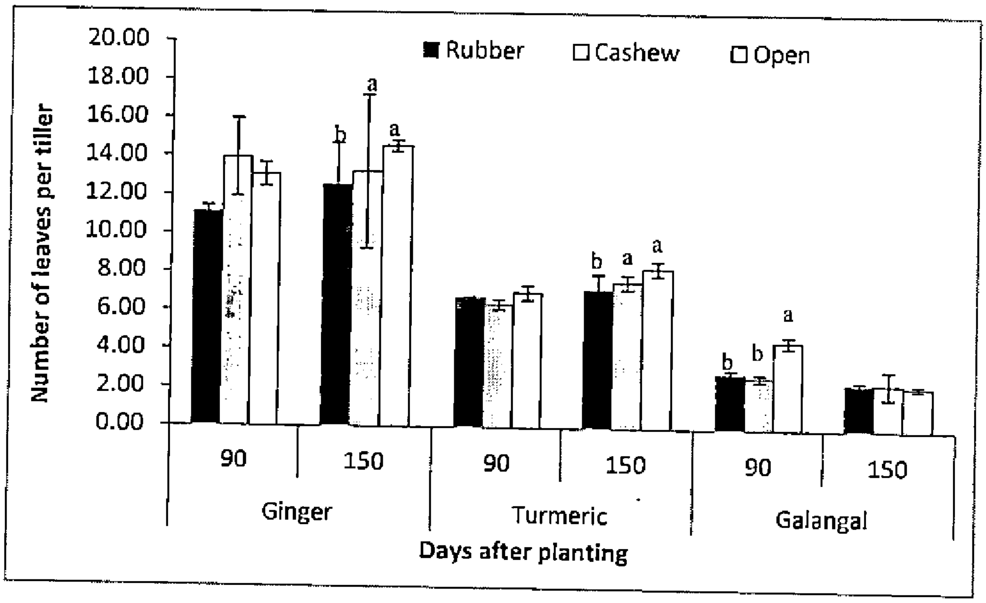

Fig. 9. Number of leaves per tiller in ginger, turmeric and galangal at 90 and 150 DAP grown in different land use systems

Table 7. Specific leaf area ($cm^2\ g^{-1}$) of ginger, turmeric and galangal grown in different land use systems at 150 DAP

Landuse system	Ginger	Turmeric	Galangal
Rubber	130.90 (11.36)	182.66 (15.56)	138.11 (18.27)
Cashew	170.30 (21.06)	218.12 (17.98)	165.52 (29.89)
Open	91.05 (13.05)	139.66 (19.24)	151.16 (24.71)
F	0.216	2.256	1.168
p	0.341	0.134	0.426

Values in parenthesis indicate Standard Error

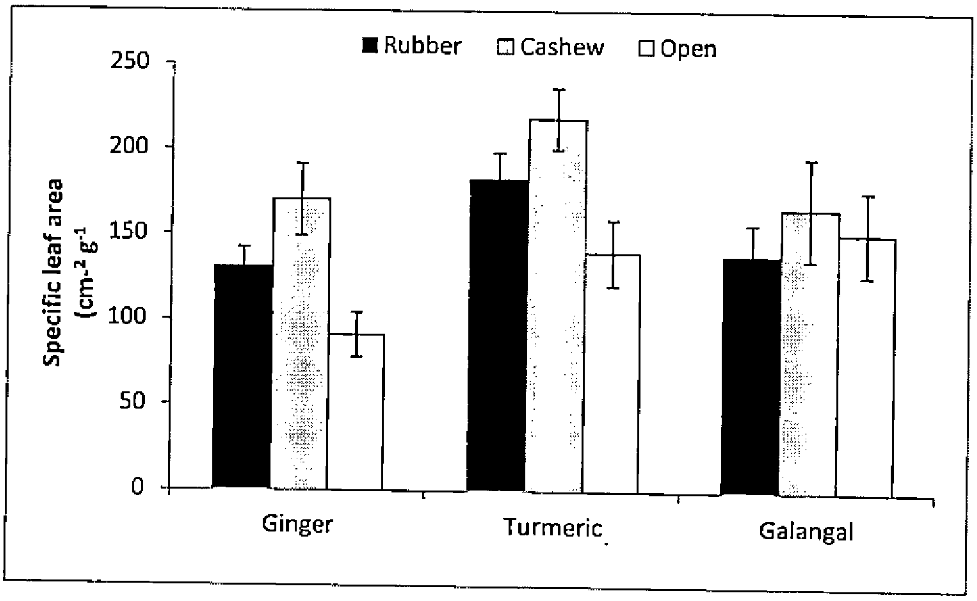

Fig. 10. Specific leaf area ($cm^2\ g^{-1}$) of ginger, turmeric and galangal grown in different land use systems at 150 DAP

4.1.6 Specific leaf area

Specific leaf area provides information about the net leaf area available for photosynthesis. In the present study specific leaf area varied significantly among the intercrops. The observations pertaining to specific leaf area of ginger, turmeric and galangal at 150 DAP as influenced by various land use systems are presented in Table 7 and Fig. 10

In ginger maximum specific leaf area was found in cashew plot (170.30 $cm^2 g^{-1}$) followed by rubber (130.9 $cm^2 g^{-1}$) and treeless open plot (91.05 $cm^2 g^{-1}$). Turmeric showed maximum leaf area in cashew (218.12 $cm^2 g^{-1}$) followed by rubber (182.66 $cm^2 g^{-1}$) and open (139.66 $cm^2 g^{-1}$), on the lines similar to ginger. Cashew recorded modestly maximum (165.52 $cm^2 g^{-1}$) values followed by open (151.16 $cm^2 g^{-1}$) and rubber (138.11 $cm^2 g^{-1}$) in case of galangal.

4.1.7 Aboveground biomass production

The data on aboveground production including the fresh and dry aboveground weights of ginger, turmeric and galangal during different growth stages as influenced by different landuse systems are given in the Tables 8 & 9 and Fig.11 & 12.

4.1.7.1 Ginger

A perusal of the data presented in the Table 8 reveals that perceptible differences in fresh aboveground weight per plant were found over the growth period. At 90 DAP, rubber grown ginger showed highest (62.62 g) fresh weight per plant followed by cashew (40.85 g) and control plots. At 150 DAP a different trend was noticed with control grown ginger recording highest fresh weight of 163.93 g $plant^{-1}$ which was followed by cashew (112.51 g) and rubber (75.38 g). Observations revealed modest changes during initial sampling stage (90 DAP) of aboveground dry weight (Table 9). At this stage, dry aboveground weight per ginger plant was found highest in control (8.62 g) succeeded by rubber (6.58 g) while the least was recorded in cashew (5.07 g). During subsequent sampling stage (150 DAP) differences were considerable, though it followed a trend similar to samples investigated at initial stage. Sole ginger again exhibited significantly maximum (21.25) dry weight per plant than cashew (14.02 g) and rubber-grown (11.40 g) plants, which were on par.

4.1.7.2 Turmeric

Inconsequential variation was noticed during the initial sampling stage (90 DAP). Observations demonstrate that cashew-grown turmeric showed highest (132.16 g $plant^{-1}$) fresh aboveground weight at 90 DAP followed by control (109.52 g). The lowest weight was recorded in rubber-grown turmeric. At 150 DAP open grown plants had significantly highest (146.88 g) weight compared to cashew (108.57 g) and rubber (74.61 g).

Observations revealed considerable variation in aboveground dry weight (Table 9). Dry weight per plant exhibited a trend similar to fresh weight at both the observations. Although showing marginal variation highest dry weight was noticed in cashew (16.30 g) followed by control (15.91g) and rubber (8.70 g) plots at 90 DAP. During the subsequent stage at 150 DAP, variation in dry weight was highly perceptible. Open control plot recorded significantly maximum dry weight of 21.57 g $plant^{-1}$ followed by cashew (20.62 g) and rubber (14.90 g) grown plants.

4.1.7.3 Galangal

An examination of data presented in the Table 8 demonstrated the modest variation exhibited during the initial stage (90 DAP). Open grown galangal recorded highest (62.28 g) fresh weight per plant followed by rubber (48.87 g) and cashew (46.73 g) at 90 DAP. Appreciable variation was noticed at subsequent sampling stage (150 DAP), a trend similar to samples examined at 90 DAP was noticed. Open plot recorded highest fresh above ground weight per plant (83.70 g) followed by rubber (75.04 g) and cashew (51.98 g).

A perusal of data given in the Table 9 demonstrated modest differences in aboveground dry weight per plant over the growth period. Open grown galangal recorded highest (5.23 g) dry weight per plant followed by rubber (3.51g) and cashew (3.38) at 90 DAP. However at 150 DAP; there was a shift in normal trend of weights so far. While cashew recorded highest (12.45 g) followed by rubber (6.28 g), control registered least (5.95 g) dry above ground weight per plant.

4.1.8 Belowground biomass production

The data on belowground production including the fresh and dry belowground weights of ginger, turmeric and galangal during different growth stages as influenced by different landuse systems are presented in the Tables 10 & 11; and Fig. 13 & 14.

4.1.8.1 Ginger

An examination of data presented in the Table 10 demonstrates appreciable changes in belowground fresh weight of ginger over the growth period, however modest changes were noticed second sampling stage. At 90 DAP fresh rhizome weight per plant was found maximum (104.81 g) in open conditions, considerably different from rubber (61.70 g) and cashew (59.28 g). At 150 DAP, dry weight per plant was again recorded highest (198.03 g) in open and followed first by cashew (122.46 g) and rubber (108.78 g). At 230 DAP open grown ginger recorded considerably highest value of 216.33 g plant^{-1} succeeded by rubber and cashew having fresh weight per plant of 119.61 and 118.12 g respectively.

It is evident from the data presented in the Table 11 that variation in belowground dry weight per plant was perceptible over the growth period during all sampling stages. In general belowground dry weight showed decreasing trend with reduction in PAR levels during the growth period. At 90 DAP significantly highest rhizome dry weight per plant was observed in control plot (8.95) compared to rubber and cashew plots which recorded 4.89 and 4.73 g per plant respectively.

At 150 DAP control again showed higher (18.86 g) rhizome dry weight per plant followed by cashew (16.13 g) and rubber (12.67 g). At 230 DAP also, the same trend was noticed. At 230 DAP, open grown ginger exhibited highest (21.62 g) rhizome dry weight per plant while cashew and rubber recorded 18.20 and 16.30 g per plant respectively. On comparison to open grown ginger at 230 DAP, the values translate to percentage decrease of 15.81 and 24.62 rhizome dry weight per plant in rubber and cashew plots correspondingly. Over the growth period from 90 to 230 DAP rhizome dry weight per plant showed highest increment of 247.78 percent in cashew grown ginger while an increase of 233.33 and 141.56 percent was noticed in rubber and open respectively.

4.1.8.2 Turmeric

A perusal of data presented in the Table 10 illustrates the considerable variation in belowground dry weight over the growth period, samples at second observational stage varied marginally. The rhizome fresh weight per plant was found to be highest (96.82 g) in open grown turmeric at 90 DAP. This was followed by cashew and rubber plots recording 64.00 and 41.51 g respectively. At 150 and 230 DAP, there was the same trend of open grown turmeric maximum fresh weights where as cashew and rubber following the lines of 90 DAP. Open grown turmeric recorded weight of 233.16 and 238.33 g at 150 and 230 DAP correspondingly. While rhizome fresh weight per plant in cashew plot at 150 DAP was 202.25 g, it registered 214.37g at 230 DAP. Rubber grown turmeric showed fresh weight of 149.16 and 173.48 g during 150 and 230 DAP respectively.

Observations revealed modest changes in rhizome dry weight during initial sampling stages (90 & 150 DAP). However at the harvesting stage (230 DAP) quite considerable changes were noticed (Table 11). Rhizome dry weight at 90 DAP followed the same trend of fresh weight with open plot recording considerably highest value of 15.02 g, compared to cashew (5.50 g) and rubber grown plants (4.13 g). However during 150 and 230 DAP, cashew plot recorded highest rhizome dry weight amongst the treatments. At 150 DAP, cashew grown turmeric was found to have per plant rhizome dry weight of 42.47 g followed by open (40.95) and rubber (24.48 g). At 230 DAP cashew again recorded the highest value per plant of 47.69 g, open 43.86 g and rubber 29.77 g. This implies to an increase of 8.73 percent of rhizome dry weight of cashew grown plants whereas a decrease of 32.12 percent in rubber plot in comparison with open. Overall during the growth period between 90 and 230 DAP, highest percentage increase in rhizome dry weight was noticed in cashew (767.09) plot followed by rubber (620.82) and least in open (192.01).

4.1.8.3 Galangal

An examination of data presented in the Table 10 demonstrates that there were modest changes in rhizome fresh weight during initial sampling stage. However, during subsequent sampling stages (150 and 230 DAP), considerable changes were observed. Rhizome fresh weight of galangal rhizome per plant was found invariably highest in control during all the stages of observation. At 90 DAP control grown galangal recorded as much as 70.32 g per plant weight of fresh rhizome whereas cashew and rubber plots showed 43.27 and 36.43 g correspondingly. At 150 DAP control plot exhibited 115.29 g per plant of rhizome fresh weight followed by rubber (86.72) and cashew (86.23 g). During the final observation at 230 DAP, open grown galangal showed yet again increased (116.15 g per plant) weight to that of cashew and rubber grown which recorded 92.68 and 92.21 g per plant of rhizome fresh weight respectively.

Observations revealed appreciable changes in dry rhizome weight per plant in galangal over the growth period (Table 11). Similar on the lines of fresh rhizome weight open grown galangal consistently showed the highest rhizome dry weight per plant as well during all the stages of observation. At 90 DAP, open recorded maximum of 8.71 g, cashew 4.32 g and rubber 3.50 g per plant. During the next growth stage at 150 DAP, rhizome dry weight per plant was noticed again highest (18.15 g) in control plot followed by rubber (14.75 g) and cashew (14.19 g). Yet again during the final observation at 230 DAP, open grown galangal exhibited the highest dry rhizome weight per plant of 19.12 g whereas cashew and rubber plots showed 18.44 and 15.13 g respectively.

4.1.9 Rhizome yield

The data on rhizome yield of ginger, turmeric and galangal as influenced by different land use systems at different growth stages are presented in the Table 12 and Fig.15.

4.1.9.1 Ginger

A perusal of data presented in the Table 12 demonstrates the considerable variation in rhizome yield over the growth period. Observations revealed that a quantity of 1.43 Mg ha^{-1} of rhizome yield in open plot while 0.78 and 0.76 Mg ha^{-1} in rubber and cashew respectively during first sampling stage. At 150 DAP significant differences in yield were noticed with open recording 3.02 Mg ha^{-1} followed by cashew (2.58 Mg ha^{-1}) and rubber (2.03 Mg ha^{-1}). During the final sampling stage, maximum rhizome yield of 3.46 in Mg ha^{-1} in open while in cashew and rubber the yields were 2.91 and 2.61 Mg ha^{-1} respectively. This implies to a percentage decrease of 24.56 percent and 15.89 percent in rubber and cashew-grown ginger respectively.

4.1.9.2 Turmeric

An examination of data given in the Table 12 illustrates the appreciable variation in turmeric rhizome yield over the growth period, though middle stage samples showed modest variation. The highest amount of turmeric rhizome yield (2.40 Mg ha^{-1}) was recorded in open plot followed by cashew (0.88 Mg ha^{-1}) and rubber (0.66 Mg ha^{-1}) respectively at 90 DAP. During second observation, cashew plot recorded the maximum yield of 6.80 Mg ha^{-1} whereas open and rubber recorded 6.55 and 3.92 Mg ha^{-1} respectively. At 230 DAP also, the highest yield was recorded by cashew (7.63 Mg ha^{-1}) followed by open (7.02 Mg ha^{-1}) and rubber (4.76 Mg ha^{-1}) respectively. This amounts to a reduction of 32.19 percent turmeric rhizome yield in rubber whereas enhancement of 8.09 percent in cashew.

4.1.9.3 Galangal

During the first observation (90 DAP), significantly highest rhizome yield of 1.39 Mg ha^{-1} was exhibited by open plot followed by rubber and cashew (Table 12). At 150 DAP open plot again showed a maximum rhizome yield of 2.90 (Mg ha^{-1}) This was followed by rubber and cashew recording 2.62 and 2.27 Mg ha^{-1} respectively. During final sampling stage open was noticed to produce a yield of 3.06 Mg ha^{-1} whereas rubber and cashew recorded 2.42 and 2.91 Mg ha^{-1}

respectively. This implies to a rhizome yield reduction of 20.9 and 3.59 percent in rubber and cashew-grown galangal.

Table 8. Aboveground fresh weight per plant (g) of ginger, turmeric and galangal grown in different land use systems

Landuse System	Aboveground fresh weight per plant (g)					
	Ginger		Turmeric		Galangal	
	90 DAP	150 DAP	90 DAP	150 DAP	90 DAP	150 DAP
Rubber	62.62[a] (3.64)	75.38[b] (9.14)	79.79 (25.05)	74.61[b] (3.67)	48.87 (10.27)	75.04[b] (6.76)
Cashew	40.85[b] (7.92)	112.51[ab] (55.72)	132.16 (27.99)	108.57[b] (16.67)	46.73 (14.43)	51.98[b] (5.11)
Open	45.01[ab] (4.53)	163.93[a] (11.56)	109.52 (10.44)	146.88[a] (7.99)	62.28 (6.23)	83.70[a] (32.04)
F	5.158	7.239	1.361	11.037	0.604	5.837
p	0.034	0.025	0.326	0.010	0.577	0.039

Values in parenthesis indicate Standard Error
Values with same superscript in a column do not differ significantly
DAP- Days after planting

Table 9. Aboveground dry weight per plant (g) of ginger, turmeric & galangal at 90 &150 DAP as influenced by land use systems

Landuse System	Aboveground dry weight per plant (g)					
	Ginger		Turmeric		Galangal	
	90 DAP	150 DAP	90 DAP	150 DAP	90 DAP	150 DAP
Rubber	6.58 (0.54)	11.40[b] (0.96)	8.70 (2.13)	14.90[c] (0.36)	3.51 (0.75)	6.28 (0.38)
Cashew	5.07 (0.91)	14.02[b] (3.75)	16.30 (4.95)	20.62[b] (4.21)	3.38 (0.76)	12.45 (5.60)
Open	8.62 (2.16)	21.25[a] (1.18)	15.91 (1.93)	21.57[a] (1.55)	5.23 (0.65)	5.95 (2.53)
F	1.646	5.626	1.676	6.655	2.040	1.061
p	0.269	0.042	0.264	0.030	0.211	0.403

Values in parenthesis indicate Standard Error
Values with same superscript in a column do not differ significantly
DAP- Days after planting

Table 10. Belowground fresh weight per plant (g) in ginger, turmeric and galangal at 90,150 and 230 DAP grown in different land use systems

Landuse System	Belowground fresh weight per plant (g)								
	Ginger			Turmeric			Galangal		
	90 DAP	150 DAP	230 DAP	90 DAP	150 DAP	230 DAP	90 DAP	150 DAP	230 DAP
Rubber	61.70^{b} (6.09)	108.78 (12.54)	119.61^{b} (23.98)	41.51^{b} (13.97)	149.16 (16.48)	173.48^{b} (20.29)	36.43 (8.84)	86.72^{b} (4.77)	92.21^{b} (6.61)
Cashew	59.28^{b} (14.53)	122.46 (51.41)	118.12^{b} (47.49)	64.00^{ab} (13.53)	202.25 (46.12)	214.37^{ab} (40.45)	43.27 (14.99)	86.23^{b} (0.62)	92.68^{b} (0.84)
Open	104.81^{a} (1.28)	198.03 (6.71)	216.33^{a} (7.55)	96.82^{a} (2.36)	233.16 (15.91)	238.33^{a} (19.59)	70.32 (9.51)	115.29^{a} (23.87)	116.15^{a} (22.03)
F	7.882	2.436	9.424	6.047	2.041	8.036	2.450	7.061	5.586
p	0.021	0.168	0.014	0.036	0.211	0.020	0.167	0.027	0.043

Values in parenthesis indicate Standard Error; Values with same superscript in a column do not differ significantly; DAP- Days after planting

Table 11. Belowground dry weight per plant (g) in ginger, turmeric and galangal at 90,150 and 230 DAP grown in different land use systems

Landuse System	Belowground dry weight per plant (g)								
	Ginger			Turmeric			Galangal		
	90 DAP	150 DAP	230 DAP	90 DAP	150 DAP	230 DAP	90 DAP	150 DAP	230 DAP
Rubber	4.89^{b} (0.67)	12.67^{c} (0.65)	16.30^{b} (1.19)	4.13^{b} (1.07)	24.48 (2.35)	29.77^{b} (3.16)	3.50^{b} (0.92)	14.75^{b} (1.01)	15.13^{b} (1.36)
Cashew	4.73^{b} (1.12)	16.13^{b} (6.46)	18.20^{b} (6.44)	5.50^{b} (1.14)	42.47 (14.87)	47.69^{a} (6.44)	4.32^{b} (0.72)	14.19^{c} (4.35)	18.44^{b} (0.19)
Open	8.95^{a} (1.20)	18.86^{a} (0.69)	21.62^{a} (0.63)	15.02^{a} (2.23)	40.95 (2.49)	43.86^{ab} (2.69)	8.71^{a} (1.38)	18.15^{a} (3.60)	19.12^{a} (3.35)
F	5.467	9.378	8.881	14.207	1.282	5.555	7.228	6.505	5.612
p	0.044	0.014	0.016	0.005	0.344	0.04	0.025	0.031	0.042

Values in parenthesis indicate Standard Error; Values with same superscript in a column do not differ significantly; DAP- Days after planting

Table 12. Rhizome yield (Mg ha^{-1}) of ginger, turmeric and galangal at 90, 150 and 230 DAP grown in different land use systems

Land use system	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
Rubber	0.78^b (0.04)	2.03^c (0.13)	2.61^b (0.42)	0.66^b (0.04)	3.92 (0.33)	4.76^b (0.09)	0.56^b (0.04)	2.36^b (0.18)	2.42^b (0.34)
Cashew	0.76^b (0.09)	2.58^b (0.19)	2.91^b (0.08)	0.88^b (0.06)	6.80 (0.16)	7.63^a (0.28)	0.69^b (0.08)	2.27^c (0.24)	2.95^b (0.49)
Open	1.43^a (0.12)	3.02^a (0.23)	3.46^a (0.35)	2.40^a (0.12)	6.55 (0.52)	7.02^a (0.61)	1.39^a (0.24)	2.90^a (0.76)	3.06^a (0.44)
F	5.467	9.378	8.881	14.207	1.282	5.555	7.228	6.505	5.612
p	0.044	0.014	0.016	0.005	0.344	0.041	0.025	0.031	0.042

Values in parenthesis indicate Standard Error; Values with same in a column superscript do not differ significantly; DAP- Days after planting

Table 13. Net rhizome production (Mg ha^{-1}) of ginger, turmeric & galangal at 230 DAP grown in different land use systems

Land use system	Net rhizome production (Mg ha^{-1})		
	Ginger	Turmeric	Galangal
Rubber	1.29^a (0.11)	2.35^b (0.17)	1.44^a (0.18)
Cashew	0.41^b (0.06)	1.19^c (0.31)	0.46^b (0.09)
Open	2.2^a (0.12)	4.60^a (0.97)	1.94^a (0.27)
F	9.374	16.710	11.377
p	0.036	0.006	0.006

Values in parenthesis indicate Standard Error; Values with same superscript in a column do not differ significantly

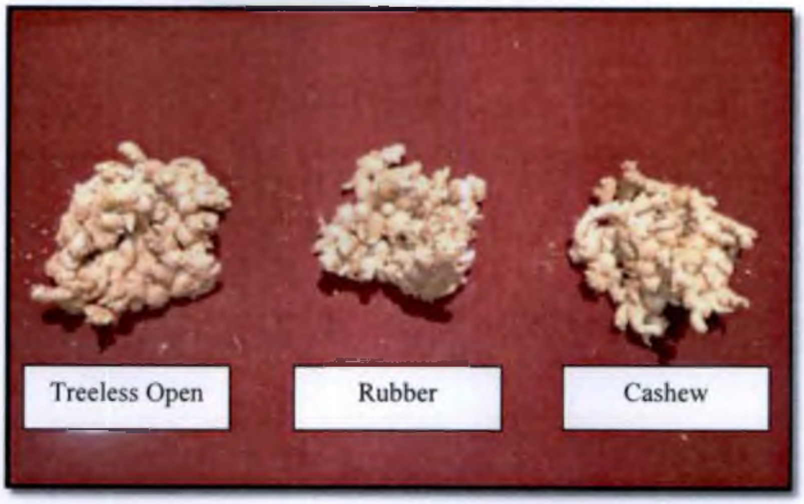

Plate 10. Per plant ginger rhizome yield in different land use systems

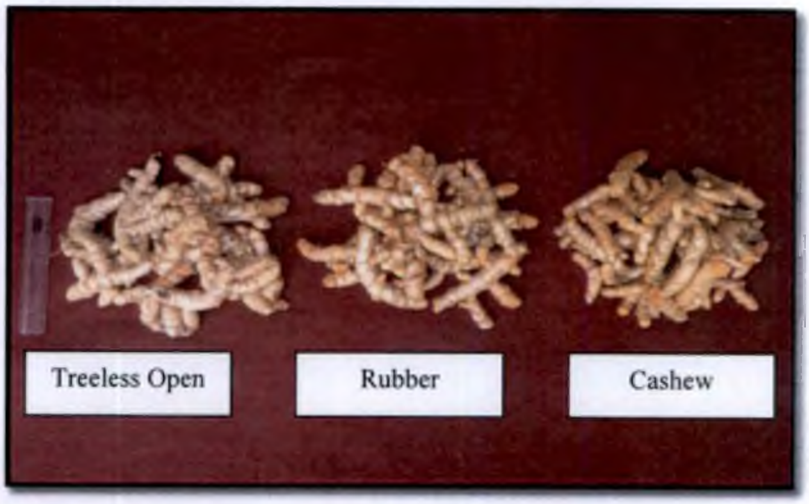

Plate 11. Per plant turmeric rhizome yield in different land use systems

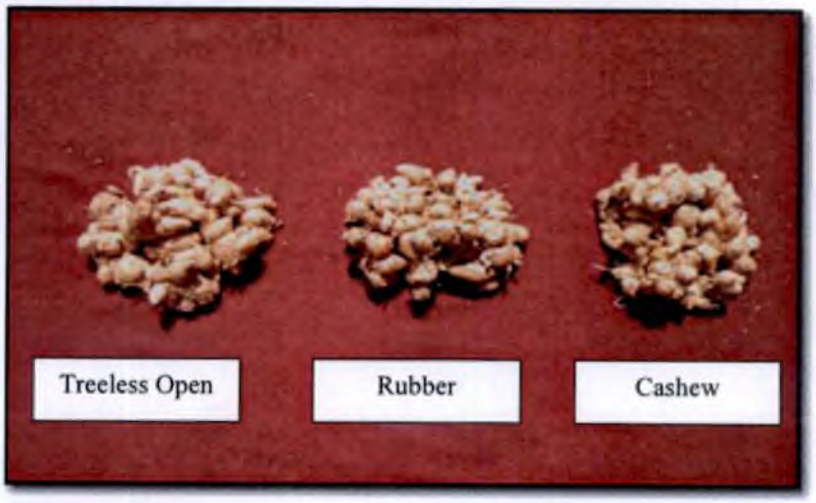

Plate 12. Per plant galangal rhizome yield in different land use systems

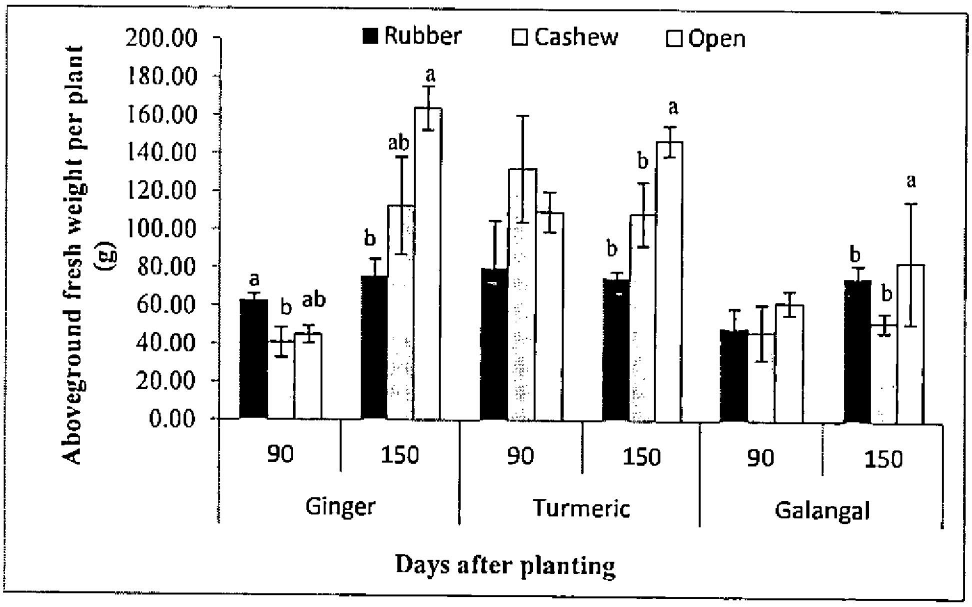

Fig.11. Aboveground fresh weight per plant (g) of ginger, turmeric and galangal at 90 and 150 DAP grown in different landuse systems

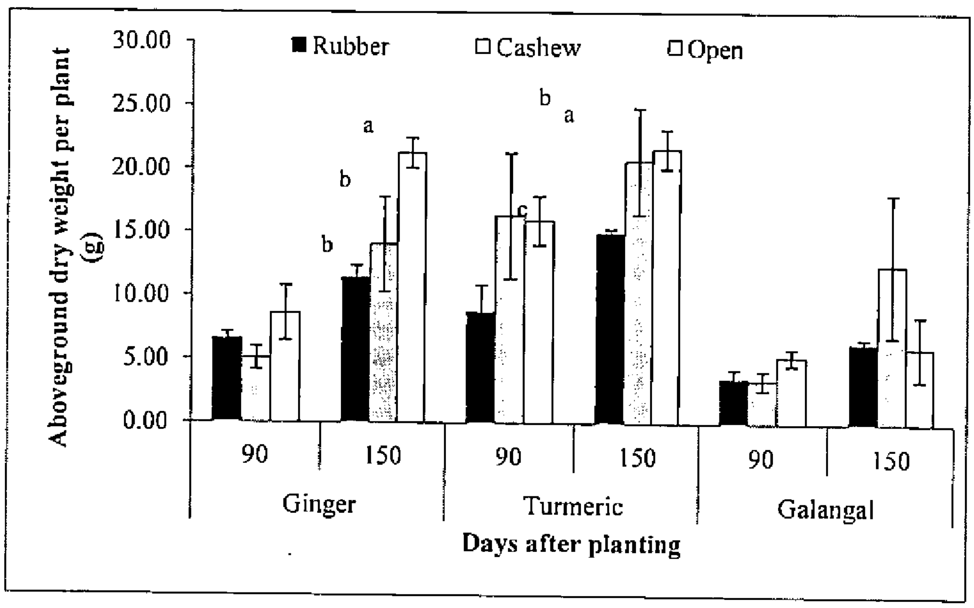

Fig.12. Aboveground dry weight per plant (g) of ginger, turmeric and galangal at 90 &150 DAP grown in different landuse systems

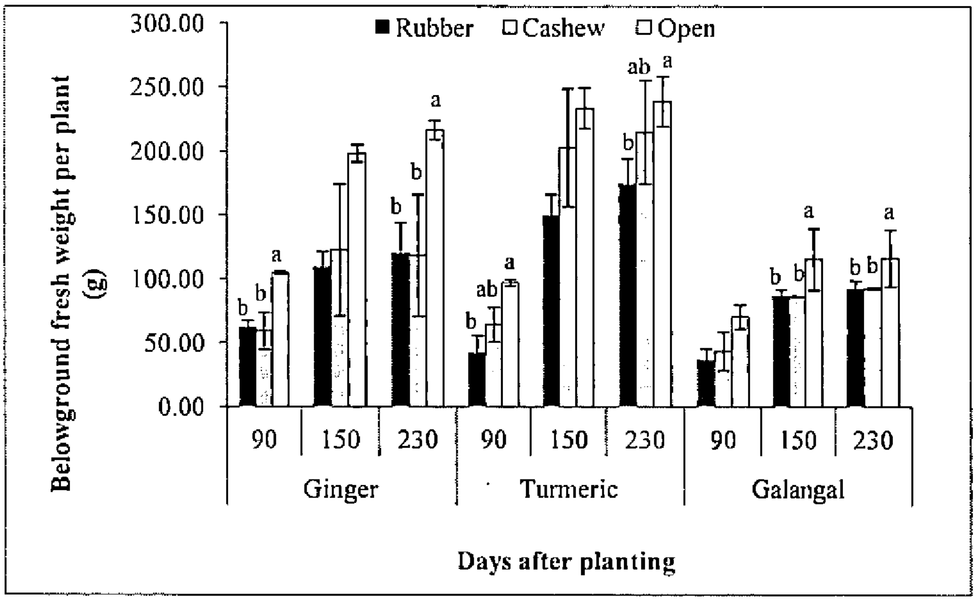

Fig.13. Belowground fresh weight per plant (g) in ginger, turmeric and galangal at 90,150 and 230 DAP grown in different landuse systems

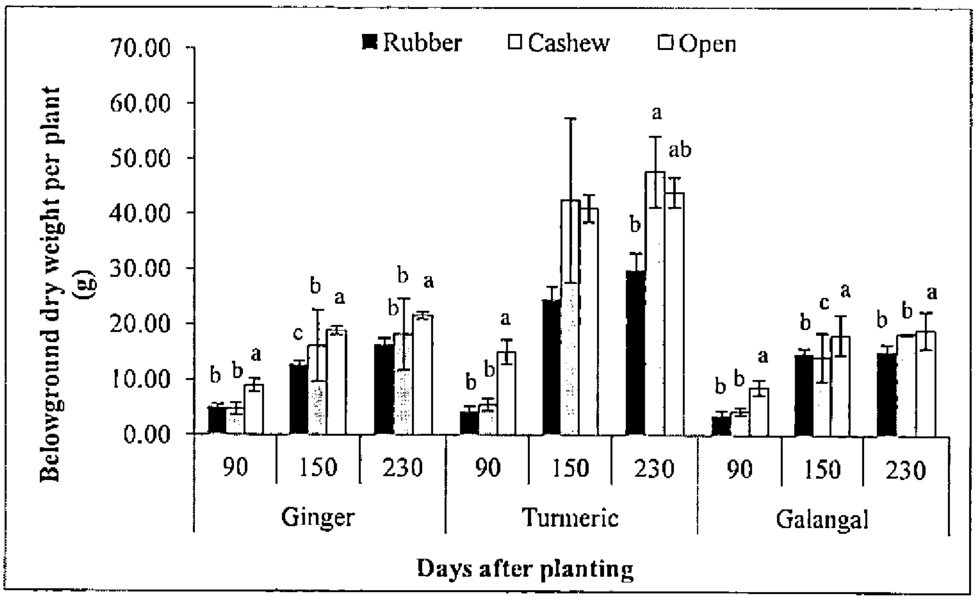

Fig.14. Belowground dry weight per plant (g) of ginger, turmeric & galangal at 90, 150 & 230 DAP grown in different landuse systems

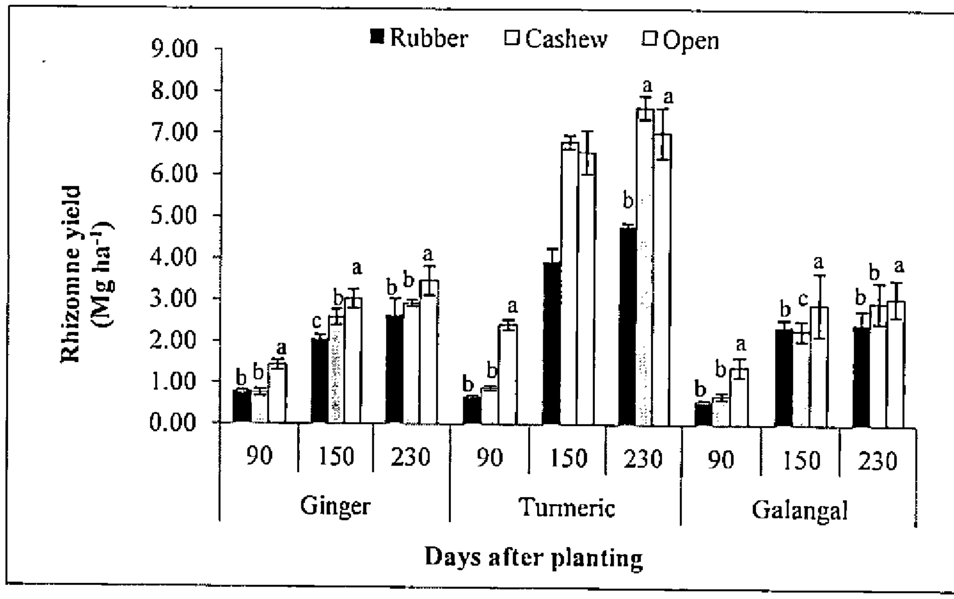

Fig.15. Rhizome yield (Mg ha^{-1}) of ginger, turmeric and galangal at 90, 150 and 230 DAP rubber, cashew and treeless open plots grown in different landuse systems

4.1.10 Net rhizome production

The observations on net rhizome yield in ginger, turmeric and galangal in various land use systems during final harvesting (230 DAP) are presented in Table 13 and Fig.16.

Net rhizome yield of ginger, turmeric and galangal at harvesting time (230) DAP varied substantially, among the three land use system. Highest net rhizome production in ginger was noted in treeless open plot (2.2 Mg ha^{-1}) which was on par at rubber (1.29 Mg ha^{-1}) and considerably different from cashew (0.41 Mg ha^{-1}). The same trend followed in turmeric also, though variation was highly considerable compared to that found in ginger. The net rhizome production in was significantly highest in sole turmeric plot (4.60 Mg ha^{-1}) followed by rubber (2.35 Mg ha^{-1}) and cashew (1.19 Mg ha^{-1}). Exactly similar trend was noticed in galangal even if variation was relatively less considerable. Sole galangal plot (1.94 Mg ha^{-1}) recorded highest net rhizome production followed by rubber (1.44) and cashew (0.46 Mg ha^{-1}). The observations illustrate net yield reduction of 41.36 and 81.36 percent in rubber and cashew-grown ginger respectively. While there was reduction of 48.91 and 74.13 percent in turmeric in rubber and cashew correspondingly, there was decrease of 25.77 and 76.29 percent in net rhizome production of galangal.

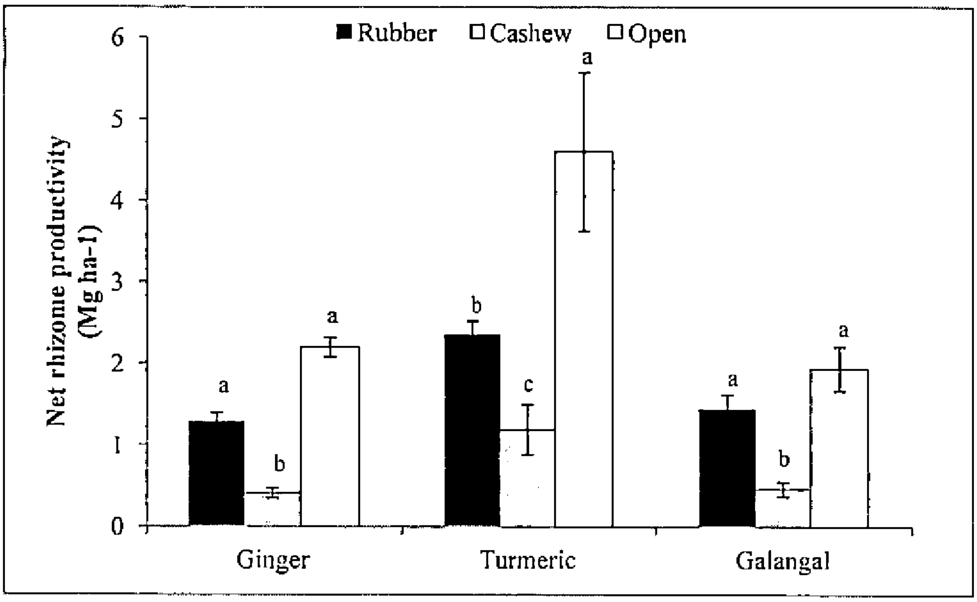

Fig.16. Net rhizome production (Mg ha^{-1}) of ginger, turmeric & galangal at 230 DAP in grown in different landuse systems

4.2. PLANT BIOCHEMICAL ATTRIBUTES

4.2.1. Chlorophyll content

Total chlorophyll content (mg g^{-1}) in ginger, turmeric and galangal at 150 DAP as influenced by different landuse systems presented in Table 14 and Fig. 17 is detailed below.

4.2.1.1 Ginger

Table 14 illustrates modest changes in chlorophyll content. The highest chlorophyll content in ginger was in rubber plot (2.25 mg g^{-1}, 15.38 percent increase over control) succeeded by cashew (2.08 mg g^{-1}, 6.67 percent over control) having and the lowest (1.95 mg g^{-1}) was in control.

4.2.1.2 Turmeric

There was substantial increase in chlorophyll contents in turmeric under rubber (2.02 mg g^{-1}, 45.32 percent over control) and cashew (1.39 mg g^{-1}, 33.09 percent over control). However, the difference between crops under rubber and cashew was marginal.

4.2.1.3 Galangal

Similar to ginger and turmeric, highest (1.17 mg g^{-1}, 67.14 percent increase over control) chlorophyll content in galangal was in rubber plot followed by cashew (1.02 mg g^{-1}, 45.71 percent increase over control) and the lowest (0.70 mg g^{-1}) was in control.

4.2.2. Oleoresin Content

The oleoresin content (percent) increased marginally in ginger, turmeric and galangal under rubber and cashew (Table 15 and Fig. 18). However, the difference was negligible between rubber and cashew.

4.2.2.1 Ginger

Ginger recorded maximum oleoresin content in rubber (4.49 percent, 11.69 percent increase over control) closely followed by cashew (4.43 percent, 10.2 percent increase over control) and the least (4.02 percent) content was in control-grown ginger.

4.2.2.2 Turmeric

Highest percentage of oleoresin content was noticed in rubber grown turmeric (10.68) closely followed by cashew plot (10.6 percent) while least (9.92 percent) was in control grown crop. Thus turmeric grown under rubber and cashew contained more oleoresin (increase of 7.66 and 6.85 percent respectively) as compared to control.

4.2.2.3 Galangal

The oleoresin content in galangal exhibited a trend similar to ginger and turmeric. The highest (2.60) percentage was found in rubber-grown galangal followed by cashew (2.57) plot. The control plot again recorded least (2.26

percent) oleoresin content. On comparison with control, the result translates to a percentage increase of 15.04 and 13.72 in oleoresin content in rubber and cashew respectively.

Table 14. Total Chlorophyll content (mg g^{-1}) in ginger, turmeric and galangal grown in different land use systems at 150 DAP

Landuse System	Ginger	Turmeric	Galangal
Rubber	2.25 (0.05)	2.02^{a} (0.05)	1.17^{a} (0.15)
Cashew	2.08 (0.19)	1.85^{ab} (0.16)	1.02^{ab} (0.06)
Open	1.95 (0.25)	1.39^{b} (0.19)	0.70^{b} (0.05)
F	0.662	4.773	7.796
p	0.550	0.048	0.039

Values in parenthesis indicate Standard Error
Values with same superscript in a column do not differ significantly

Table 15. Oleoresin content (percent) in ginger, turmeric and galangal grown in different land use systems at 150 DAP

Landuse System	Ginger	Turmeric	Galangal
Rubber	4.49 (0.31)	10.68 (0.74)	2.60 (0.18)
Cashew	4.43 (0.36)	10.60 (0.75)	2.57 (0.27)
Open	4.02 (0.07)	9.92 (0.32)	2.26 (0.17)
F	0.867	0.432	0.796
p	0.467	0.668	0.493

Values in parenthesis indicate Standard Error
Values with same superscript in a column do not differ significantly
DAP- Days after planting

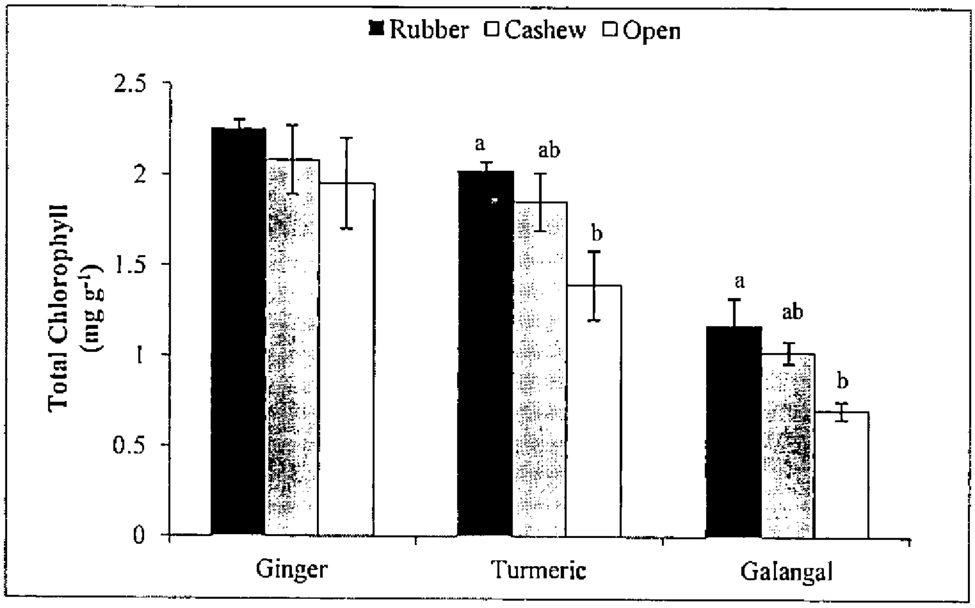

Fig. 17. Total Chlorophyll content (mg g^{-1}) in ginger, turmeric and galangal as influenced by landuse systems at 150 DAP

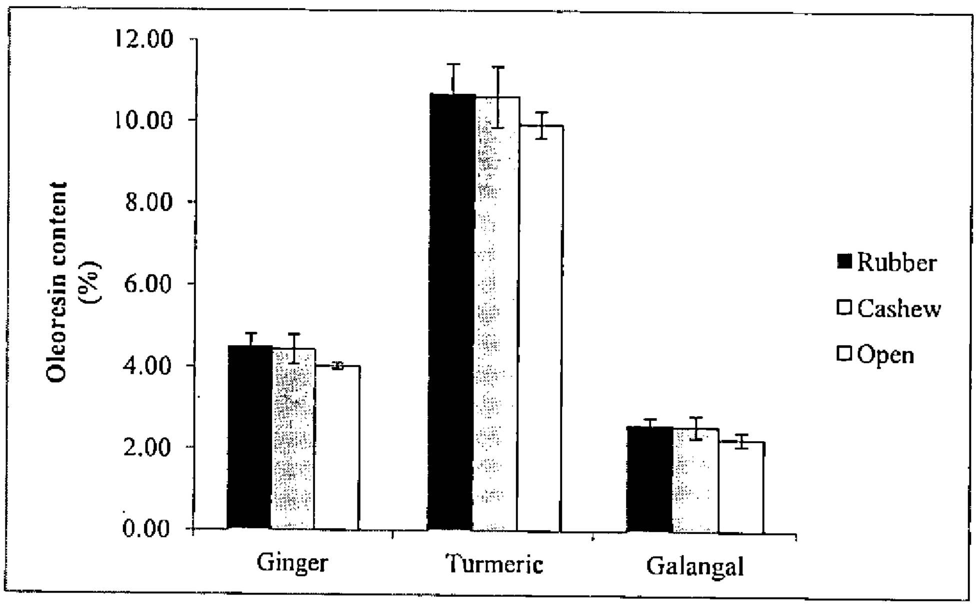

Fig. 18. Oleoresin content (percent) in ginger, turmeric and galangal as influenced by landuse systems at 150 DAP

4.3 BIOPHYSICAL ATTRIBUTES INFLUENCING THE UNDERSTOREY PRODUCTIVITY

4.3.1 Stand Leaf Area Index

Stand leaf area index is an important determinant of understorey productivity in agroforestry systems. Fig. 19 shows Stand Leaf Area Index (LAI) in rubber and cashew plots. Observations revealed that rubber recorded maximum (1.98) LAI compared to cashew (1.43).

4.3.2 Understorey Photosynthetically Active Radiation

Diurnal variations in understorey Photosynthetically Active Radiation (PAR) in rubber, cashew and treeless open plots were distinct (Table 16 and Figures 20 & 21). Understorey transmittance ranged from 44.1 to 56.62 percent in rubber and cashew respectively to that of treeless open plot. In rubber plot, Mean photosynthetic photon flux density (PPFD) above the canopy ranged from 191 μ moles $m^{-2}sec^{-1}$ (8 a.m) to 1469.5 μ moles $m^{-2}sec^{-1}$ (1-2 p.m) while corresponding below canopy PPFDs were 79 μ moles $m^{-2}sec^{-1}$ to 885.5 μ moles $m^{-2}sec^{-1}$. In case of cashew plot, mean above canopy PPFD values ranged from 311 μ moles $m^{-2}sec^{-1}$ (8 a.m) and 1494 μ moles $m^{-2}sec^{-1}$ (1-2 p.m) whereas respective below canopy PPFDs were 129 μ moles $m^{-2}sec^{-1}$ (8 a.m) and 1105 μ moles $m^{-2}sec^{-1}$ (1-2 p.m). Mean mid day (12 –1p.m) understorey photosynthetic Photon Flux Density (PPFD) levels were 1072.5 moles μ $m^{-2}sec^{-1}$ in rubber and 1275 μ moles $m^{-2}sec^{-1}$ in cashew. Mean daily interception by rubber and cashew trees canopies, which are residual to transmittance, ranged from 55.90 to 43.38 percent respectively.

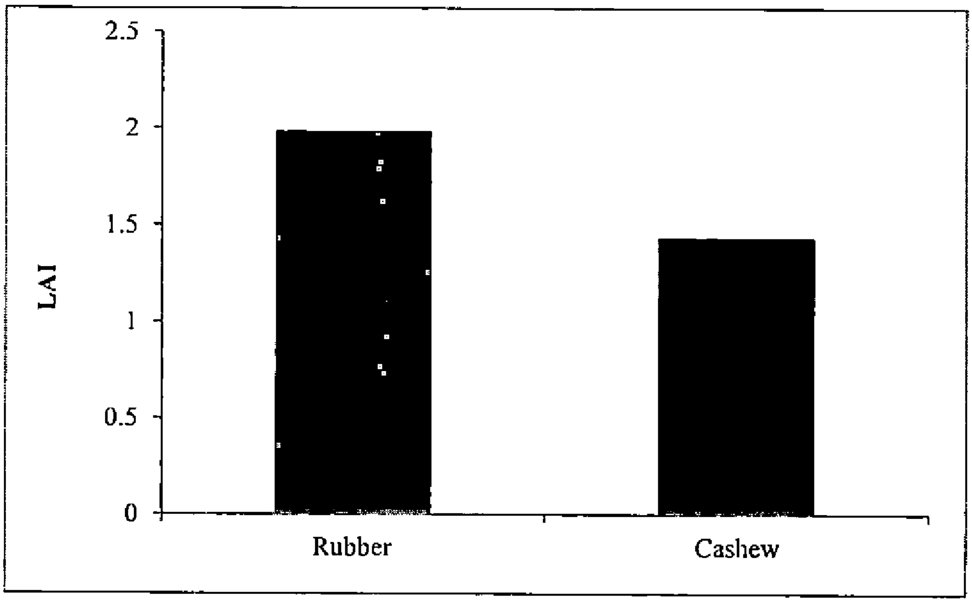

Fig.19. Stand leaf area index (LAI) of rubber and cashew.

Table 16 Mean hourly-integrated values of photosynthetically active radiation (PAR) above and below the canopies of rubber and cashew

Time (hours)	Rubber			Cashew		
	I_1	I_2	PAR Transmittance (percent)	I_1	I_2	PAR Transmittance (percent)
08:00:00	191	79	41.36	311	129	41.48
09:00:00	695	298	42.88	738	298	40.38
10:00:00	1154	485	42.03	1217	685	56.29
11:00:00	1366	612	44.80	1416	812	57.34
12:00:00	1645	1019	61.95	1623	1126	69.38
13:00:00	1725	1126	65.28	1664	1425	85.64
14:00:00	1214	645	53.13	1324	785	59.29
15:00:00	1032	355	34.40	1032	548	53.10
16:00:00	1085	372	34.29	1085	572	52.72
17:00:00	856	316	36.92	924	406	43.94
18:00:00	246	69	28.05	239	88	36.82

I_1: above canopy PAR value , I_2: below canopy PAR values

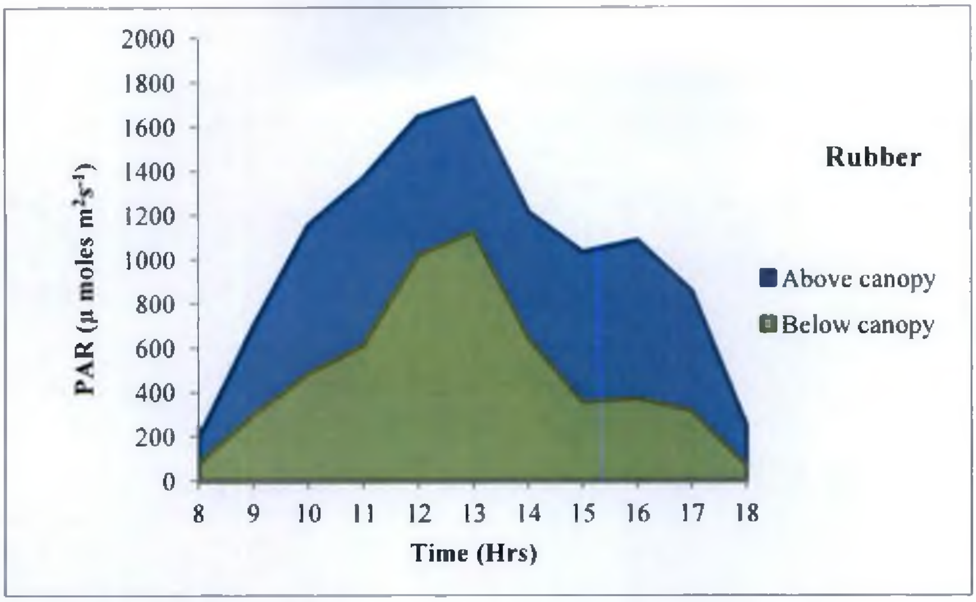

Fig. 20. Mean hourly-integrated values of photosynthetically active radiation (PAR) above and below canopies of rubber

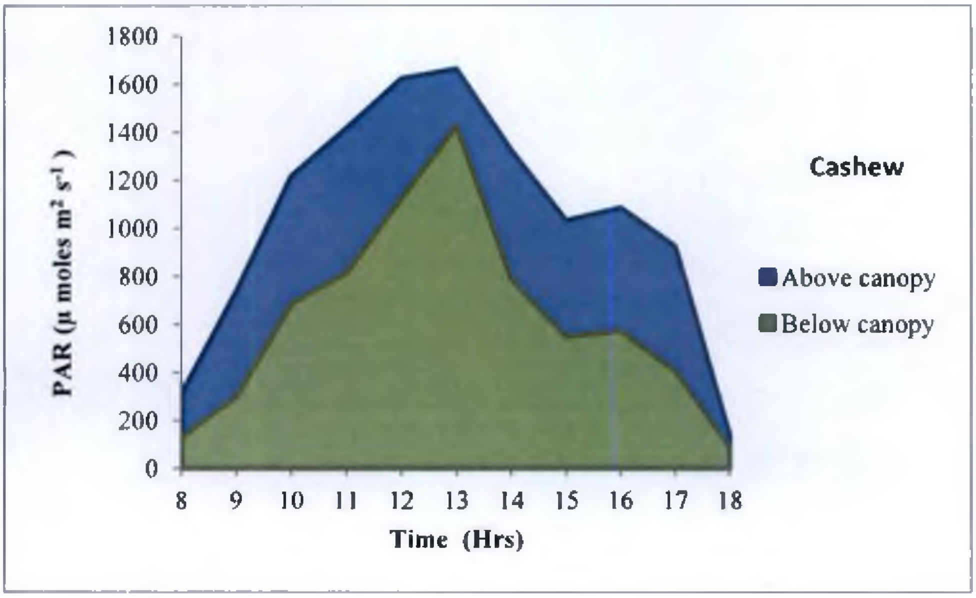

Fig. 21. Mean hourly-integrated values of photosynthetically active radiation (PAR) above and below canopies of cashew

4.4 PLANT NUTRIENT CONCENTRATION

4.4.1 Aboveground plant nutrients

A perusal of data presented in the Tables 17, 18 and 19 demonstrates a regular increase in aboveground nutrient concentration over the growth period (90, 150 and 230 DAP) for all the intercrops.

4.4.1.1 Ginger

The data on the plant nutrients recorded in the aboveground portions of ginger are presented in Table 17.

Although there was not any considerable difference in the foliar N content of ginger among the land use systems, open grown plants recorded highest N concentration (2.0 percent) followed by cashew (1.99 percent) and rubber (1.92 percent). Further at 150 DAP, a similar trend was noticed, yet differences were comparatively considerable. Rubber grown ginger exhibited significantly lowest (2.01 percent) N content compared to cashew (2.13 percent) and open (2.19 percent) grown plants. Over the growth period, N concentration increased subsequently during second observational stage.

Phosphorus content of aboveground portions of ginger varied marginally during initial sampling. Observations revealed maximum P concentration in open (0.35 percent) grown ginger followed by cashew (0.31 percent) and rubber (0.26 kg ha^{-1}) at 90 DAP. During the subsequent sampling stage (150 DAP), highly significant variation was observed. Open plot showed highest (0.73 percent) P content followed by cashew (0.63 percent) and rubber (0.41 percent).

Highest potassium content was noted in open grown plants (3.27 percent) at 90 DAP which was on par with cashew (3.18 percent) and significantly different from rubber (2.91 percent). The content increased with growing season recording maximum percentage yet again in open (5.11 percent) grown plants at 150 DAP. On lines similar to previous observation perceptible variation was observed with open recording significantly highest (5.11 percent) K content compared to cashew (5.04 percent) and rubber (4.81 percent).

4.4.1.2 Turmeric

The data on the plant nutrients recorded in the aboveground portions of turmeric are presented in Table 18.

Nitrogen content present in the aboveground portions of turmeric varied inappreciably at 90 DAP. Nonetheless, maximum concentration was recorded in cashew grown plants (2.23 percent) followed by rubber (2.10 percent) and open (2.08 percent). However during second sampling stage at 150 DAP, cashew (2.41 percent) grown turmeric recorded significantly highest N content compared to open (2.32 percent) and rubber (2.16 percent). The content increased with the growing season and peak concentration was recorded at 150 DAP.

Inconsiderably highest foliar concentration of phosphorus was noted in cashew (0.53 percent) grown turmeric during the first observational stage. This was followed by open (0.51 percent) and rubber (0.43 percent). During the second observation stage, comparatively appreciable changes were noticed. While significantly lowest P content was found in rubber plot (0.51 percent), cashew (0.67 percent) grown plants exhibited yet again the highest concentration followed by rubber (0.51 percent).

No considerable changes were noticed in foliar potassium content of turmeric during both the observational stages. Yet cashew grown plants recorded the highest followed by open and rubber plots during both the sampling stages. Furthermore, concentration increased over the growth period.

4.4.1.3 Galangal

The data on the plant nutrients recorded in the aboveground portions of ginger are presented in Table 19.

Open grown galangal recorded highest (2.01 percent) foliar nitrogen content during both the first sampling stage, though differences were inconsiderable. This was followed by rubber (1.97 percent) and cashew (1.94 percent). During second sampling stage at 150 DAP, nitrogen concentration in open (2.18 percent) and cashew (2.12 percent) grown galangal was on par with each other and significantly different from cashew (2.06 percent).

Highest concentration of phosphorus in the aboveground portions of galangal was recorded in treeless open plot (0.44 percent) at 90 DAP followed by cashew (0.38 percent) and rubber (0.31 percent), though changes were inconsiderable. There was increment in P content with growing season peaking at 150 DAP registering high content in open (0.73 percent) grown plants followed by cashew (0.66 percent) and rubber (0.62 percent).

Potassium content followed a trend similar to nitrogen and phosphorus. At 90 DAP inconsiderably highest K content was noticed in open plot (3.48 percent) followed by cashew (3.30 percent) and rubber (3.24 percent). The concentration enhanced over the growth period with 150 DAP samples recording maximum. Significantly maximum K content was observed in open (5.12 percent) grown galangal. This was followed by cashew (4.92 percent) and rubber (4.83 percent) which were also on par with each other.

4.4.2 Belowground plant nutrients

4.4.2.1 Ginger

The data on the plant nutrients recorded in the belowground portions of ginger are presented in Table 23.

Nitrogen content in the belowground portions of ginger increased with each growing season having peak levels at 230 DAP. Open grown plants invariably showed highest N content during all the observational stages recording 0.87, 1.18 and 1.55 percent at 90, 150 and 230 DAP respectively. This was consistently followed by cashew grown plants recording 0.75, 1.01 and 1.46 percent of N in the same order. Further rubber grown plants exhibited the least concentration of 0.71, 0.93 and 1.11 percent at 90, 150 and 230 DAP respectively. Although differences were inconsiderable during the first two sampling stages, comparably appreciable changes were noticed at the third stage. At 230 DAP open grown plants recorded significantly different N content (1.55 percent) from that of rubber (1.46 percent) grown plants, though both were on par with cashew-grown ginger (1.11 percent).

Although phosphorus content in belowground portions exhibited an increase from 90 to 230 DAP, differences were inconsequential. At 90 DAP open recorded highest (0.24 percent) followed by cashew (0.21 percent) and rubber (0.18 percent). During the second sampling stage, open grown ginger again showed highest (0.31 percent) P concentration followed by cashew (0.25 percent) and rubber (0.22 percent). On the similar lines the plants at harvesting stage resembled in the P content trend with open (0.43 percent) showing highest followed by cashew (0.28 percent) and rubber (0.27 percent).

Again, similar changes were noticed in potassium content as well. Potassium content was registered maximum in open grown plants during all the observational stages. The variation is inconsequential during first and last stages of sampling, however showed relatively considerable differences at second sampling stage. Nevertheless, at 90 DAP a maximum of 0.56 percent of K concentration was noticed in open plot followed by cashew (0.44 percent) and rubber (0.38 percent). At 150 DAP, open grown plants recorded 1.01 percent which was considerably different from cashew (0.97 percent) and rubber (0.64 percent).

4.4.2.2 Turmeric

The data on the plant nutrients recorded in the belowground portions of turmeric are presented in Table 24.

Cashew grown turmeric recorded considerably highest (0.88 percent) nitrogen content compared to open (0.69 percent) and rubber (0.63 percent) at 90 DAP. The content increased in all the landuse systems with growing season. At 150 DAP again cashew grown plants had highest N content (0.99 percent) followed by rubber (0.82 percent) and open (0.78 percent). During the final sampling stage at 230 DAP, yet again cashew plot exhibited highest (1.37 percent) N content. This was however significantly different from open (1.29 percent) and rubber (1.24 percent) plots which were on par with each other.

Phosphorus content varied appreciably during the first observational stage with cashew grown turmeric showing significantly highest (0.18 percent) P content followed by rubber (0.17 percent) and open (0.13 percent) plots. During second sampling stage cashew grown plots recorded 0.30 percent P content followed by open (0.26 percent) and rubber (0.22 percent). At the harvesting stage, cashew recorded a maximum of 0.37 percent of P content which was succeeded by open (0.31 percent) and rubber (0.28 percent) grown plants

Potassium content also showed a similar trend of nitrogen and phosphorus of cashew plot exhibiting the maximum nutrient levels at all observational stages However, appreciable differences were only at second sampling stage. Furthermore, as cashew grown plants consistently recorded highest values, lowest levels were in rubber plot at all the observational stages.

4.4.2.3 Galangal

The data on the plant nutrients recorded in the belowground portions of galangal are presented in Table 25. During the first observational stage, inconsiderably highest nitrogen concentration was recorded in open (0.73 percent) grown galangal and lowest in rubber (0.73 percent). At 150 DAP cashew grown plants recorded highest (1.12 percent) N levels and lowest again in rubber (1.18 percent). However at 230 DAP, significantly highest N concentration was observed in open plot (1.42 percent) followed by cashew (1.32 percent) and rubber (1.18 percent) plots.

Phosphorus content was consistently highest in open grown galangal during all the stages of observation. At 90 DAP open grown plants recorded 0.21 percent followed by cashew (0.19 percent) and rubber (0.15 percent). Significant variation was noticed at 150 DAP. Open grown plants showed considerably highest (0.27 percent) phosphorus content followed by cashew (0.25 percent) and rubber (0.21 percent). During the harvesting stage, although variation was inconsequential, open plot again exhibited highest (0.32 percent) P content followed by cashew (0.29 percent) and rubber (0.27 percent).

Potassium content continually followed a trend similar to phosphorus in all the landuse systems. Despite modest differences at 90 DAP highest potassium content was recorded in open (0.21 percent) grown plants followed by cashew (0.19 percent) and rubber (0.15 percent). At 150 DAP significantly highest K content was noticed in open (0.27 percent) followed by cashew (0.25 percent) and rubber (0.21 percent) grown plants. During the final sampling stage, open plot again exhibited highest K levels followed by cashew and rubber, though differences were inconsequential.

4.5 PLANT NUTRIENTS ACCUMULATION

4.5.1 Aboveground Plant nutrient accumulation (kg ha^{-1})

4.5.1.1 Ginger

The data on the aboveground plant nutrient (N, P and K) accumulation in ginger are presented in Table 20.

The nitrogen accumulation by ginger plants revealed no discernible changes during the sampling stages at 90 and 150 DAP. However highest content of nitrogen was shown by open grown plants at both these stages. i. e. at 90 DAP (16.55) and 150 DAP (44.68 kg ha^{-1}).

Phosphorus accumulation was also observed more in open grown ginger plants at both the stages of observation. No considerable changes noticed at 90 DAP, highly significant differences were noticed at 150 DAP. At second stage of sampling the highest phosphorus content was found in open plot (14.89 kg ha^{-1}) followed by rubber (6.89 kg ha^{-1}) and cashew (5.52 kg ha^{-1}).

Potassium accumulation did not vary considerably over the growth period in any of the land use systems. During both the stages, highest content was found in open grown ginger.

4.5.1.2 Turmeric

The data on the aboveground plant nutrient (N, P and K) accumulation in turmeric are presented in Table 21.

At 90 DAP, the highest nitrogen accumulation was recorded in cashew grown plants (34.90 kg ha^{-1}); at 150 DAP in open grown plants (48.04 kg ha^{-1}). Lowest content was found in rubber grown plants (17.54 and 30.90 kg ha^{-1} at 90 and 150 DAP respectively)

Phosphorus accumulation at 90 DAP varied considerably showing highest value in cashew grown plants which was on par with open grown plants and significantly different from rubber grown turmeric. The observations at second stage of sampling however did not reveal any significant changes, nevertheless.

Difference in Potassium accumulation was negligible at 90 DAP. However, at 150 DAP, significant changes were noticed. Open grown plants recorded highest (101.88 kg ha^{-1}) Potassium content followed by cashew (99.17 kg ha^{-1}) and rubber (67.37 kg ha^{-1}).

4.5.1.3 Galangal

The data on the aboveground plant nutrient (N, P and K) accumulation in galangal are presented in Table 22.

Nitrogen accumulation varied considerably at both the sampling stages. At 90 DAP nitrogen content was recorded maximum in open plot followed by rubber and cashew. However at 150 DAP highest (25.34 kg ha^{-1}) N content was found in cashew grown plants which was significantly different from rubber (12.42 kg ha^{-1}) and on par with open (10.27 kg ha^{-1}).

No appreciable changes were found in phosphorus accumulation over the growth period. Nevertheless observations revealed that the highest P content at 90 DAP in open grown plants whereas the highest at 150 DAP was in cashew plot. Over the growth period the nutrient content increased from 90 to 150 DAP.

Potassium accumulation recorded relatively significant changes during first observational stage. The highest content was registered in open grown galangal followed by rubber and cashew. However at 150 DAP no appreciable differences were noticed. The highest content of 38.80 kg ha^{-1} was recorded in cashew grown plants followed by rubber and open.

4.5.2 Belowground nutrient accumulation (kg ha^{-1})

4.5.2.1 Ginger

The data on the belowground plant nutrient accumulation recorded in ginger are presented in Table 26.

Nitrogen accumulation during first two sampling stages varied marginally. The highest nitrogen contents of 7.48 and 21.36 kg ha^{-1} were recorded in open grown ginger rhizome. During the final sampling stage (230 DAP) differences in

N content existed but were moderate. Highest content recorded in open plot and varied significantly from cashew and rubber plots. The content increased with the advancement of growth.

Phosphorus accumulation in ginger rhizomes varied slightly at first sampling stage with open recording maximum and cashew the lowest. The observations during other two stages revealed relatively significant changes in P content. At 150 DAP highest P content of 5.61 kg ha^{-1} was recorded in open grown ginger which was significantly different from cashew but on par with rubber. Further at 230 DAP a trend similar to 150 DAP observations was noticed. A significantly maximum content was recorded in open plot, which was different from rubber and cashew.

Observations revealed moderately significant changes in rhizome K content at 90 DAP. open grown ginger rhizomes recorded significantly highest (2.07 kg ha^{-1}) K content compared to rubber and on par with cashew. at next sampling stage of 150 DAP highly significant differences were noticed. Open plot recorded significantly highest (18.29 kg ha^{-1}) K content in rhizome followed by rubber (11.80 kg ha^{-1}) and cashew (9.91 kg ha^{-1}). However at 230 DAP no appreciable changes were found, though the nutrient content followed a similar trend as observed during previous two sampling stages.

4.5.2.2 Turmeric

The data on the belowground plant nutrient accumulation recorded in turmeric are presented in Table 27.

During the first sampling stage nitrogen accumulation varied modestly showing highest (9.95 kg ha^{-1}) value in open plot followed by cashew and rubber. However relatively significant variation was noticed during the other two sampling stages. At 150 DAP cashew grown turmeric rhizomes recorded significantly highest (40.36 kg ha^{-1}). N content compared to open (30.66 kg ha^{-1}) and on par with rubber (19.27 kg ha^{-1}). During the final observational stage, highest (62.72 kg ha^{-1}) K content was exhibited again by cashew which was significantly different from open (54.32 kg ha^{-1}) and rubber (35.44 kg ha^{-1}).

Phosphorus accumulation in turmeric rhizomes showed relatively significant differences during first two sampling stages. At 90 DAP highest (1.87 kg ha^{-1}) P content was recorded in open grown turmeric rhizomes which was significantly different from cashew (0.95kg ha^{-1}) and rubber (0.67kg ha^{-1}) plots. Further at 150 DAP highest nutrient content was shown by cashew grown turmeric which was on par with open but significantly different from rubber. During the final stage of sampling, changes were inconsiderable in nutrient content, nevertheless it followed a trend similar to that observed at 150 DAP.

Potassium accumulation showed inappreciable changes during first two sampling stages. Notwithstanding this, highest K content was found in open and cashew grown turmeric rhizomes at 90 and 250 DAP respectively. However during the final stage of sampling appreciable changes were observed in K content. Cashew grown turmeric exhibited significantly highest (67.30kg ha^{-1}) nutrient content followed by open (51.37 kg ha^{-1}) and rubber (32.29 kg ha^{-1}) plots.

4.5.2.3 Galangal

The data on the belowground plant nutrient accumulation recorded in galangal are presented in Table 28.

A perusal of data presented in the Table 33 Illustrates appreciable changes in accumulation of nitrogen in land use systems during all the stages of observation. At 90 DAP, highest nitrogen accumulation was found in open (7.69 Mg ha^{-1}) grown galangal rhizomes followed by cashew (3.44 Mg ha^{-1}) and rubber (7.69 Mg ha^{-1}). During subsequent sampling stage (150 DAP), crops growing in open, cashew and rubber accumulated 18.22, 15.26 and 14.75 Mg ha^{-1} nitrogen. The same trend was noted during harvesting time with open recording highest (26.06 Mg ha^{-1}) followed by cashew (23.37 Mg ha^{-1}) and rubber (20.63 Mg ha^{-1}).

Observations revealed open grown galangal recorded highest rhizomatous phosphorus accumulation during various stages of growth. At the initial sampling stage variations were considerable with open registering 1.76 Mg ha^{-1} of phosphorus followed by cashew (0.79 Mg ha^{-1}) and rubber (0.52 Mg ha^{-1}). Along the similar lines, appreciable variation was also noticed at 150 DAP. Open, cashew and rubber grown crops accumulated 7.70, 3.41 and 3.40 Mg ha^{-1} of phosphorus. However, towards the end of growth period at 230 DAP, variation in phosphorus accumulation among the systems was modest, while following the same trend as that of previous sampling stages. Galangal growing in open, cashew and rubber accumulated 5.87, 5.13 and 4.72 Mg ha^{-1} respectively, thus exhibiting an enhancement over the growth period.

Observations over the growth revealed considerable variation in K accumulation in rhizome at all sampling stages. At 90 DAP, galangal growing in open (5.52 Mg ha^{-1}) showed significant difference compared to that of cashew (2.16 Mg ha^{-1}) and rubber (1.51Mg ha^{-1}). Rhizomes at 150 DAP showed highest potassium accumulation in open followed by cashew (18.99 Mg ha^{-1}) and rubber (13.76 Mg ha^{-1}). Over the growth period, potassium accumulation increased showing peak values at the harvesting time with open, cashew and rubber registering accumulation of 25.15, 23.37 and Mg ha^{-1} 22.03.

Table 17. Aboveground plant nutrient concentration (percent) in ginger under different land use systems

Landuse System	N (%)		P (%)		K (%)	
	90 DAP	150 DAP	90 DAP	150 DAP	90 DAP	150 DAP
Rubber	1.92 (0.05)	2.01^{b} (0.17)	0.26 (0.04)	0.41^{c} (0.05)	2.91^{b} (0.08)	4.81^{b} (0.16)
Cashew	1.99 (0.05)	2.13^{a} (0.17)	0.31 (0.01)	0.63^{b} (0.12)	3.18^{a} (0.04)	5.04^{b} (0.14)
Open	2.0 (0.11)	2.19^{a} (0.12)	0.35 (0.02)	0.73^{a} (0.08)	3.27^{a} (0.05)	5.11^{a} (0.13)
F	0.313	5.414	3.110	4.209	5.181	7.811
p	0.743	0.041	0.118	0.049	0.049	0.021

Values in parenthesis indicate Standard Error
Values with same superscript in a column do not differ significantly
DAP- Days after planting

Table 18.Aboveground plant nutrients concentration in turmeric under different land use systems

Landuse System	N (%)		P (%)		K (%)	
	90 DAP	150 DAP	90 DAP	150 DAP	90 DAP	150 DAP
Rubber	2.10 (0.14)	2.16[b] (0.15)	0.43 (0.04)	0.51[c] (0.03)	3.36 (0.05)	4.71 (0.13)
Cashew	2.23 (0.04)	2.41[a] (0.22)	0.53 (0.04)	0.67[a] (0.07)	3.83 (0.04)	5.01 (0.10)
Open	2.08 (0.08)	2.32[b] (0.09)	0.51 (0.02)	0.66[a] (0.15)	3.59 (0.02)	4.92 (0.16)
F	0.410	5.233	3.553	10.018	1.312	4.596
p	0.681	0.048	0.096	0.012	0.337	0.062

Values in parenthesis indicate Standard Error; Values with same superscript in a column do not differ significantly; DAP- Days after planting

Table 19. Aboveground plant nutrients concentration in galangal under different land use systems

Landuse System	N (%)		P (%)		K (%)	
	90 DAP	150 DAP	90 DAP	150 DAP	90 DAP	150 DAP
Rubber	1.97 (0.09)	2.06[b] (0.10)	0.31 (0.06)	0.62 (0.16)	3.24 (0.03)	4.83[b] (0.18)
Cashew	1.94 (0.07)	2.12[a] (0.24)	0.38 (0.01)	0.66 (0.04)	3.30 (0.07)	4.92[b] (0.28)
Open	2.01 (0.09)	2.18[a] (0.07)	0.44 (0.03)	0.73 (0.08)	3.48 (0.0)	5.12[a] (0.29)
F	0.482	9.742	3.551	2.480	0.429	5.263
p	0.639	0.013	0.096	0.164	0.669	0.048

Values in parenthesis indicate Standard Error; Values with same superscript in a column do not differ significantly; DAP- Days after planting

Table 20. Aboveground plant nutrients accumulation in ginger under different landuse systems

Land use system	N ($kg\ ha^{-1}$)		P ($kg\ ha^{-1}$)		K ($kg\ ha^{-1}$)	
	90 DAP	150 DAP	90 DAP	150 DAP	90 DAP	150 DAP
Rubber	12.57 (0.15)	23.31 (0.04)	1.96 (0.11)	6.89[b] (0.16)	20.09 (0.61)	55.16 (1.93)
Cashew	9.35 (0.26)	27.05 (0.77)	1.27 (0.38)	5.52[c] (0.09)	14.16 (0.72)	64.74 (1.01)
Open	16.55 (2.67)	44.68 (0.15)	2.90 (0.54)	14.89[a] (0.21)	27.06 (0.15)	104.24 (3.74)
F	0.736	0.523	1.005	29.23	0.134	0.059
p	0.566	0.572	0.420	0.001	0.870	0.941

Values in parenthesis indicate Standard Error; Values with same superscript in a column do not differ significantly; DAP- Days after planting

Table 21. Aboveground plant nutrients accumulation in turmeric under different landuse systems

Land use system	N (kg ha^{-1})		P (kg ha^{-1})		K (kg ha^{-1})	
	90 DAP	150 DAP	90 DAP	150 DAP	90 DAP	150 DAP
Rubber	17.54 (0.64)	30.90 (0.26)	3.59^{b} (0.52)	7.30 (0.27)	28.06 (1.13)	67.37^{c} (0.19)
Cashew	34.90 (0.78)	47.71 (0.54)	8.29^{a} (0.23)	13.26 (0.19)	59.93 (0.75)	99.17^{b} (2.16)
Open	31.77 (0.42)	48.04 (0.24)	7.79^{a} (0.29)	13.67 (0.52)	54.83 (1.87)	101.88^{a} (0.26)
F	0.315	0.056	18.268	0.728	0.129	12.135
p	0.815	0.954	0.003	0.722	0.892	0.04

Values in parenthesis indicate Standard Error
Values with same superscript in a column do not differ significantly
DAP- Days after planting

Table 22. Aboveground plant nutrients accumulation in galangal under different landuse systems

Location	N (kg ha^{-1})		P (kg ha^{-1})		K (kg ha^{-1})	
	90	150	90	150	90	150
Rubber	6.64^{b} (0.28)	12.42^{b} (0.22)	1.04 (0.09)	3.74 (0.05)	10.92^{b} (0.36)	29.12 (0.29)
Cashew	6.29^{b} (0.14)	25.34^{a} (0.49)	1.23 (0.41)	7.89 (0.64)	10.71^{ab} (0.79)	38.80 (1.02)
Open	10.09^{a} (0.54)	10.27^{ab} (0.74)	2.21 (0.19)	2.77 (0.51)	17.47^{a} (0.94)	19.42 (0.54)
F	5.391	11.621	1.280	0.491	9.228	0.325
p	0.052	0.031	0.344	0.699	0.026	0.797

Values in parenthesis indicate Standard Error
Values with same superscript in a column do not differ significantly
DAP- Days after planting

Table 23. Belowground plant nutrients concentration in ginger under different landuse systems

Landuse System	N (kg ha^{-1})			P (kg ha^{-1})			K (kg ha^{-1})		
	90 DAP	150 DAP	230 DAP	90 DAP	150 DAP	230 DAP	90 DAP	150 DAP	230 DAP
Rubber	0.71 (0.25)	0.93 (0.06)	1.11^{b} (0.07)	0.18 (0.01)	0.22 (0.05)	0.27 (0.05)	0.38 (0.04)	0.64^{b} (0.06)	1.00 (0.08)
Cashew	0.75 (0.22)	1.01 (0.44)	1.46^{ab} (0.08)	0.21 (0.01)	0.25 (0.03)	0.28 (0.03)	0.44 (0.08)	0.97^{b} (0.15)	1.21 (0.24)
Open	0.87 (0.11)	1.18 (0.08)	1.55^{a} (0.29)	0.24 (0.01)	0.31 (0.01)	0.43 (0.11)	0.56 (0.18)	1.01^{a} (0.17)	1.41 (0.20)
F	0.164	2.438	5.975	3.212	1.728	1.767	0.693	5.211	1.180
p	0.852	0.168	0.037	0.113	0.255	0.249	0.536	0.049	0.370

Values in parenthesis indicate Standard Error; Values with same superscript in a column do not differ significantly; DAP- Days after planting

Table 24. Belowground plant nutrients concentration in turmeric under different landuse systems

Landuse System	N (kg ha^{-1})			P (kg ha^{-1})			K (kg ha^{-1})		
	90 DAP	150 DAP	230 DAP	90 DAP	150 DAP	230 DAP	90 DAP	150 DAP	230 DAP
Rubber	0.63^{b} (0.10)	0.82 (0.05)	1.24^{b} (0.06)	0.17^{a} (0.01)	0.22 (0.03)	0.28 (0.07)	0.36 (0.15)	0.64^{b} (0.05)	1.13 (0.21)
Cashew	0.88^{a} (0.13)	0.99 (0.16)	1.37^{a} (0.04)	0.18^{a} (0.01)	0.30 (0.05)	0.37 (0.03)	0.52 (0.09)	0.97^{a} (0.21)	1.47 (0.10)
Open	0.69^{b} (0.08)	0.78 (0.12)	1.29^{b} (0.26)	0.13^{b} (0.01)	0.26 (0.04)	0.31 (0.02)	0.41 (0.1)	0.78^{b} (0.12)	1.22 (0.13)
F	7.923	0.528	5.810	14.971	0.845	1.934	0.836	6.042	2.257
p	0.021	0.615	0.039	0.005	0.475	0.225	0.478	0.037	0.186

Values in parenthesis indicate Standard Error; Values with same superscript in a column do not differ significantly; DAP- Days after planting

Table 25. Belowground plant nutrients concentration in galangal under different landuse systems

Landuse System	N (kg ha^{-1})			P (kg ha^{-1})			K (kg ha^{-1})		
	90 DAP	150 DAP	230 DAP	90 DAP	150 DAP	230 DAP	90 DAP	150 DAP	230 DAP
Rubber	0.73 (0.11)	0.94 (0.11)	1.18^{b} (0.35)	0.15 (0.01)	0.21^{c} (0.02)	0.27 (0.01)	0.45 (0.09)	0.94^{b} (0.11)	1.26 (0.23)
Cashew	0.83 (0.05)	1.12 (0.09)	1.32^{b} (0.06)	0.19 (0.01)	0.25^{b} (0.01)	0.29 (0.05)	0.52 (0.08)	1.01^{a} (0.11)	1.32 (0.26)
Open	0.92 (0.19)	1.04 (0.13)	1.42^{a} (0.18)	0.21 (0.03)	0.27^{a} (0.02)	0.32 (0.01)	0.66 (0.22)	1.09^{a} (0.12)	1.37 (0.04)
F	0.518	0.655	9.186	0.095	10.240	1.862	1.394	10.410	0.101
p	0.620	0.553	0.015	0.911	0.012	0.235	0.318	0.011	0.905

Values in parenthesis indicate Standard Error; Values with same superscript in a column do not differ significantly: DAP- Days after planting

Table 26. Belowground plant nutrient accumulation in ginger under different landuse systems

Land use system	N			P			K		
	90 DAP	150 DAP	230 DAP	90 DAP	150 DAP	230 DAP	90 DAP	150 DAP	230 DAP
Rubber	3.52 (0.65)	12.28 (0.83)	22.85^{b} (1.28)	0.99 (0.04)	3.04^{ab} (0.51)	4.38^{b} (0.46)	2.07^{b} (0.11)	11.80^{b} (0.14)	18.93 (0.55)
Cashew	3.22 (0.52)	14.40 (0.1)	17.53^{b} (0.23)	0.82 (0.09)	3.41^{b} (0.14)	4.26^{b} (0.79)	1.73^{ab} (0.12)	9.91^{c} (1.08)	15.79 (0.65)
Open	7.48 (0.44)	21.36 (0.28)	32.17^{a} (0.68)	2.06 (0.16)	5.61^{a} (0.27)	8.92^{a} (0.19)	4.81^{a} (0.08)	18.29^{a} (0.11)	29.26 (0.78)
F	0.168	4.081	7.185	2.916	5.835	15.368	4.457	15.163	0.152
p	0.857	0.076	0.035	0.136	0.052	0.021	0.065	0.005	0.869

Values in parenthesis indicate Standard Error; Values with same superscript in a column do not differ significantly: DAP- Days after planting

Table 27. Belowground plant nutrients accumulation in turmeric under different landuse systems

Land use system	N ($kg\ ha^{-1}$)			P ($kg\ ha^{-1}$)			K ($kg\ ha^{-1}$)		
	90 DAP	150 DAP	230 DAP	90 DAP	150 DAP	230 DAP	90 DAP	150 DAP	230 DAP
Rubber	2.50 (0.14)	19.27^{ab} (0.64)	35.44^{b} (0.67)	0.67^{b} (0.06)	5.17^{b} (0.49)	8.00 (0.09)	1.43 (0.07)	15.04 (1.24)	32.29^{c} (1.45)
Cashew	4.65 (0.19)	40.36^{a} (1.13)	62.72^{a} (1.09)	0.95^{b} (0.08)	12.23^{a} (0.19)	16.94 (0.21)	2.75 (0.4)	39.55 (0.77)	67.30^{a} (0.98)
Open	9.95 (0.04)	30.66^{b} (0.32)	54.32^{b} (0.19)	1.87^{a} (0.1)	10.22^{a} (0.87)	13.05 (0.54)	5.91 (0.64)	30.66 (1.02)	51.37^{b} (1.83)
F	4.113	9.256	11.168	4.932	5.612	0.802	2.113	0.189	4.816
p	0.118	0.031	0.039	0.043	0.042	0.514	0.360	0.833	0.057

Values in parenthesis indicate Standard Error; Values with same superscript in a column do not differ significantly; DAP- Days after planting

Table 28. Belowground plant nutrients accumulation in galangal under different landuse systems

Land use system	N ($kg\ ha^{-1}$)			P ($kg\ ha^{-1}$)			K ($kg\ ha^{-1}$)		
	90 DAP	150 DAP	230 DAP	90 DAP	150 DAP	230 DAP	90 DAP	150 DAP	230 DAP
Rubber	2.45^{ab} (0.41)	14.75^{b} (0.84)	20.63^{ab} (1.21)	0.50^{b} (0.04)	3.30^{c} (0.24)	4.72 (0.42)	1.51^{c} (0.74)	14.75^{b} (0.87)	22.03^{b} (1.04)
Cashew	3.44^{b} (0.72)	15.26^{b} (0.09)	23.37^{b} (0.74)	0.79^{b} (0.06)	3.41^{b} (0.41)	5.13 (0.26)	2.16^{b} (0.32)	13.76^{b} (0.46)	23.37^{a} (1.03)
Open	7.69^{a} (0.61)	18.12^{a} (0.19)	26.06^{a} (0.64)	1.76^{a} (0.14)	4.70^{a} (0.41)	5.87 (0.07)	5.52^{a} (0.45)	18.99^{a} (1.01)	25.15^{a} (0.78)
F	15.435	4.105	19.985	7.453	23.103	0.595	10.235	27.506	9.906
p	0.047	0.052	0.038	0.033	0.002	0.581	0.054	0.006	0.043

Values in parenthesis indicate Standard Error; Values with same superscript in a column do not differ significantly; DAP- Days after planting

4.6 SOIL ANALYSIS

4.6.1 Soil nutrients and pH before intercropping

Soil nutrients and pH before intercropping are presented in Table 29. Highest pH was in cashew (5.43) followed by rubber (5.13) and open (4.88). Carbon content also followed the same order (cashew 0.80 percent, rubber 0.76 percent and open 0.63 percent). Soil nitrogen content varied appreciably in all the landuse systems. Significantly highest nitrogen content was recorded in cashew (233.63 kg ha^{-1}) followed by rubber (174.83 kg ha^{-1}) and open (146.43 kg ha^{-1}). Phosphorus content also showed the same trend. Although variation was not significant, highest phosphorus content was noticed in cashew (64.36 kg ha^{-1}) followed by rubber (52.58 kg ha^{-1}) and open (31.62 kg ha^{-1}). Marginal variation was in potassium content with cashew registering highest (146.83 kg ha^{-1}) values followed by rubber (136.48 kg ha^{-1}) and open (125.21 kg ha^{-1}).

4.6.2. Soil nutrients at 150 and 230 DAP

Tables 30, 31, 32 and 33 suggest that intercropping improved N, P and K content in the soil at final crop harvest compared to initial soil samples.

4.6.2.1 Soil nutrients under ginger

The data on soil nutrients in ginger grown beds under rubber and cashew at 150 and 230 DAP are given in the Table 30.

Nitrogen content in ginger beds varied inconsiderably at 150 DAP varying from minimum of 191.81 kg ha^{-1} in treeless open condition to 305.22 kg ha^{-1}. However, at 230 DAP, difference was quite considerable. Significantly highest (295 kg ha^{-1}) nitrogen content in ginger beds was recorded in cashew plot followed by rubber plot (233.98 kg ha^{-1}) and lowest was exhibited by open plot (178.67 kg ha^{-1}). There was also a decrease in nitrogen content with the growing season.

Relatively appreciable changes were found in soil phosphorus content in the ginger beds in different landuse systems. Highest P content at 150 DAP was found in cashew plot (142.34 kg ha^{-1}) which was on par with rubber plot (106.59 kg ha^{-1}) and open (61.87 kg ha^{-1}) plots. The content showed reduction over the growth period with lowest values at 230 DAP. At this sampling stage, highest P content was again exhibited by cashew (129.67 kg ha^{-1}), which was on par with rubber (101.28 kg ha^{-1}), yet different than open (55.43 kg ha^{-1}).

Soil potassium content in ginger beds showed inconsequential changes during both the stages of observation. At 150 DAP highest K content was recorded in cashew plot (192.74 kg ha^{-1}) followed by open (173.09 kg ha^{-1}) and rubber (161.52 kg ha^{-1}). However at 230 DAP rubber plot exhibited maximum (146.30 kg ha^{-1}) K content in ginger beds followed by open (146.02 kg ha^{-1})and cashew (142.33 kg ha^{-1})

4.6.2.2 Soil nutrients under turmeric

Data on soil nutrients in turmeric grown beds as influenced by different landuse systems at 150 and 230 DAP are given in the Table 31.

Appreciable changes were observed in nitrogen content during both the stages of sampling in the turmeric beds. At 150 DAP nitrogen content in all landuse systems was significantly different from each other. Highest content was recorded in cashew plot (375.9 kg ha^{-1}) followed by rubber (275.83 kg ha^{-1}) and lowest in open plot (180.30 kg ha^{-1}). At 230 DAP nitrogen content again varied significantly. A trend similar to 150 DAP was noticed as cashew recorded significantly highest (368.25 kg ha^{-1}) amount of nitrogen followed by rubber (266.38 kg ha^{-1}) and treeless open plot (169.19 kg ha^{-1}). The nutrient content over the time decreased with advancement of growth.

Phosphorus content at 150 DAP did not vary appreciably in turmeric beds. Yet cashew exhibited highest (117.71 kg ha^{-1}) phosphorus content succeeded by rubber (104.09 kg ha^{-1}) and open (59.75 kg ha^{-1}) plots. However, at 230 DAP, changes were relatively considerable. Cashew plot again exhibited highest (91.35 kg ha^{-1}) phosphorus content on par with rubber (89.42 kg ha^{-1}). Significantly, lowest content was recorded in open (44.06 kg ha^{-1}) plot.

Potassium content in turmeric beds did not show any considerable variation during both the sampling stages. Yet observations revealed highest potassium content in cashew plot (181.53 kg ha^{-1}) at 150 DAP followed by open (161.96 kg ha^{-1}) and rubber (151.3 kg ha^{-1}). At 230 DAP cashew recorded highest

(153.11 kg ha^{-1}) K values followed by rubber (124.48 kg ha^{-1}) and open (118.85 kg ha^{-1}) plots. Moreover, over the growth period potassium content decreased as samples at 230 DAP showed lowest K values.

4.6.2.3 Soil nutrients under galangal

The data on soil nutrients in galangal grown beds as influenced by different landuse systems at 150 & 230 DAP are given in the Table 32.

Highly significant differences were observed in nitrogen content in galangal beds at 150 DAP. While cashew recorded considerably maximum (371.81 kg ha^{-1}) nitrogen content followed by rubber (273.92 kg ha^{-1}), lowest (192.85 kg ha^{-1}) value was exhibited by open plot. At 230 DAP cashew plot exhibited yet again highest (373.19 kg ha^{-1}) nitrogen content significantly different from rubber (270.56 kg ha^{-1}) and open (177.6 kg ha^{-1}).

Phosphorus content in galangal beds showed highly appreciable differences at 150 DAP in different landuse systems. Cashew plot exhibited significantly highest (157.95 kg ha^{-1}) values of phosphorus content followed by rubber (105.63 kg ha^{-1}) and lowest in open (61.63 kg ha^{-1}) plot. At 230 DAP, changes were relatively less appreciable. Highest P content was observed again in cashew plot (118.63 kg ha^{-1}) which was on par with rubber (82.07 kg ha^{-1}). Comparably lowest value was recorded in open (47.93 kg ha^{-1}) plot.

Potassium content did not vary considerably over the growth period. Yet at 150 DAP highest K content was recorded in open plot (188.66 kg ha^{-1}) and lowest in rubber (153.22 kg ha^{-1}). However at 230 DAP highest content was exhibited by cashew plot (142.83 kg ha^{-1}) and lowest by open (134.32 kg ha^{-1}). Over the growth period potassium content decreased from 150 to 230 DAP.

4.6.2.4 Intercrop less-soil nutrients

The data on the soil nutrients in rubber, cashew and tree-less open plots without intercrops are given in the Table 33.

Nitrogen content in intercrop-less beds recorded maximum value in cashew (246.79 kg ha^{-1}) which was significantly different from open (153.93 kg ha^{-1}). Rubber recorded the content amounting to 184.61 kg ha^{-1}. However at 230

DAP appreciable changes was noticed in nitrogen content. Cashew recorded significantly highest (237.33 kg ha^{-1}) content followed by rubber (169.76 kg ha^{-1}) and lowest in open plot (156.13 kg ha^{-1}).

At 150 DAP highest potassium content was registered in cashew (76.38 kg ha^{-1}) significantly different from rubber (56.78 kg ha^{-1}) and (36.67 kg ha^{-1}). Cashew plot again recorded maximum P content (77.95 kg ha^{-1}) on par with rubber (55.52 kg ha^{-1}) and considerably different from tree-less open (37.21 kg ha^{1}) at 230 DAP.

Potassium content showed inconsequential changes throughout the growth period. Yet at 150 DAP highest content of potassium was recorded in open (139.13 kg ha^{-1}) followed by rubber (126.78 kg ha^{-1}) and cashew (122.72 kg ha^{-1}). The same trend prevailed during final sampling stage in the order of open (140.85 kg ha^{-1}), rubber (131.95 kg ha^{-1}) and cashew (129.47 kg ha^{-1}).

Table 29. Soil nutrients and pH before intercropping under different land use systems

Land use system	pH	C (%)	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
Rubber	5.13 (0.21)	0.76^{b} (0.02)	174.83^{b} (3.69)	52.58 (13.57)	136.48^{b} (5.49)
Cashew	5.43 (0.33)	0.80^{a} (0.03)	233.63^{a} (4.44)	64.36 (7.92)	146.83^{a} (8.62)
Open	4.88 (0.08)	0.63^{c} (0.05)	146.43^{c} (10.94)	31.62 (7.82)	125.21^{b} (13.28)
F	4.145	5.720	6.648	3.117	6.940
p	0.074	0.041	0.030	0.118	0.027

Values in parenthesis indicate Standard Error;
Values with same superscript in a column do not differ significantly

Table 30. Soil nutrient content in ginger beds under different landuse systems

Landuse Systems	Nitrogen (%)		Phosphorus (%)		Potassium (%)	
	150 DAP	230 DAP	150 DAP	230 DAP	150 DAP	230 DAP
Rubber	246.97 (31.44)	233.98^{b} (42.91)	106.59^{b} (14.2)	101.28^{a} (12.76)	161.52 (16.35)	146.30 (16.04)
Cashew	305.22 (63.14)	295.12^{a} (56.44)	142.34^{a} (16.73)	129.67^{a} (7.58)	192.74 (43.55)	142.33 (35.69)
Open	191.81 (6.74)	178.67^{c} (9.94)	61.87^{ab} (7.76)	55.43^{c} (3.0)	173.09 (16.15)	146.02 (19.49)
F	2.535	5.609	9.004	18.374	0.308	0.008
P	0.159	0.042	0.016	0.003	0.746	0.992

Values in parenthesis indicate Standard Error
Values with same superscript in a column do not differ significantly
DAP- Days after planting

Table 31.Soil nutrient content in turmeric beds under different landuse systems

Landuse Systems	N (%)		P (%)		K (%)	
	150 DAP	230 DAP	150 DAP	230 DAP	150 DAP	230 DAP
Rubber	275.83^{b} (10.2)	266.38^{b} (18.89)	104.09 (13.6)	89.42^{a} (7.28)	151.3 (24.16)	124.48 (1.36)
Cashew	375.9^{a} (13.13)	368.25^{a} (15.29)	117.71 (19.23)	91.35^{a} (8.02)	181.53 (4.94)	153.11 (19.69)
Open	180.39^{c} (11.62)	169.19^{c} (11.63)	59.75 (4.33)	44.06^{b} (3.15)	161.96 (18.84)	118.85 (6.99)
F	69.677	66.386	4.804	16.877	0.732	2.310
p	.000	.000	0.057	0.003	0.519	0.180

Values in parenthesis indicate Standard Error
Values with same superscript in a column do not differ significantly
DAP- Days after planting

Table 32. Soil nutrient content in galangal beds under different landuse systems

Landuse Systems	N (%)		P (%)		K (%)	
	150 DAP	230 DAP	150 DAP	230 DAP	150 DAP	230 DAP
Rubber	273.92[b] (12.48)	270.56[b] (6.65)	105.63[b] (9.44)	82.07[a] (8)	153.32 (16.18)	142.39 (19.19)
Cashew	371.81[a] (5.32)	373.19[a] (9.43)	157.95[a] (4.46)	118.63[a] (11.57)	168.58 (39.58)	142.83 (7.97)
Open	192.85[c] (7.76)	177.6[b] (5.48)	61.63[c] (6.3)	47.93[b] (8.62)	188.66 (10.32)	134.32 (3.61)
F	106.812	175.922	46.897	13.775	0.487	0.155
p	0.002	0.001	0.002	0.006	0.637	0.860

Values in parenthesis indicate Standard Error
Values with same superscript in a column do not differ significantly
DAP- Days after planting

Table 33. Soil nutrient content in different land use systems without intercrops

Landuse Systems	N (%)		P (%)		K (%)	
	150 DAP	230 DAP	150 DAP	230 DAP	150 DAP	230 DAP
Rubber	184.61[ab] (9.33)	169.76[b] (3.69)	56.78[b] (3.72)	55.22[a] (5.15)	126.78 (7.43)	131.95 (10.64)
Cashew	246.79[a] (17.07)	237.33[a] (4.61)	76.38[a] (7.5)	77.95[a] (6.92)	122.72 (13.73)	129.47 (17.5)
Open	153.93[b] (7.0)	156.13[b] (3.91)	36.67[b] (4.8)	37.21[b] (5.85)	139.13 (2.55)	140.85 (18.59)
F	15.709	112.907	12.688	11.500	0.876	0.141
P	0.004	0.000	0.007	0.009	0.464	0.872

Values in parenthesis indicate Standard Error
Values with same superscript in a column do not differ significantly
DAP- Days after planting

4.7 SOIL CARBON SEQUESTRATION

4.7.1 Bulk density

The data on soil bulk density (g cm^{-3}) n rubber, cashew and tree-less open plots are presented in Table 34 and Fig.22.

Generally, bulk density showed an increasing trend with the increase in depth upto 1m from the surface layer. In rubber bulk density varied from 1.14 g cm^{-3} at 0-20 cm to 1.27 g cm^{-3} at 81-100 cm. There was a percentage increase of 13.91 from first layer to the lowest layer. In cashew bulk density increased from 1.15 g cm^{-3} at 0-20 cm to 1.31 g cm^{-3} at 81-100 cm with a percentage increase of 11.40 from first layer to the lowest layer. In treeless open plot, bulk density varied from 1.17 g cm^{-3} at 0-20 cm to 1.35 g cm^{-3} at 81-100 cm depth. There was a percentage increase of 15.38 from first layer to the lowest layer. Among the landuse systems, bulk density followed a uniform trend with treeless open plot recording highest values at each depth level followed by cashew and lowest in rubber.

4.7.2 Organic matter

The data on percentage of soil organic matter in rubber, cashew and tree-less open plots are presented in Table 35 and Fig.23.

In rubber plot, organic matter percentage varied from 1.39 at 0-20 cm to 0.59 at 81-100 cm depth. The percentage of organic matter decreased with increasing depth. A trend similar to rubber plot was noticed in cashew plot showing a decrease in organic matter with increasing depth. Organic matter varied from 1.37 percent at 0-20 cm to 0.63 percent at 81-100 cm depth in cashew. In open plot, organic matter percentage varied from 1.11 at 0-20 cm to 0.36 at 81-100.

Among the systems, both cashew and rubber exhibited similar organic matter percentage at 0-20 cm depth, which was distinctively higher than in the open plot. The difference of organic matter in various landuse systems across different soil depths was not significant. Generally, the highest amount of organic matter percentage in whole soil upto 1m depth was noted in cashew followed by rubber and open.

4.7.3 Organic carbon concentration

The data on soil organic carbon concentration in rubber, cashew and tree-less open plots are presented in Table 36 and Fig.24.

Organic carbon percentage followed the similar trend as that of organic matter percentage. The values showed a decreasing trend with increase in soil depth. Although inconsiderable variation was in rubber, the highest percentage was present in 0-20 cm soil depth. In rubber, the organic carbon percent varied from 0.81 at 0-20 cm to 0.34 percent at 81-100 cm. In cashew and open, the variation ranged from 0.79 to 0.37 and 0.64 to 0.21 respectively. The total organic carbon percentage in whole soil of 1m depth was maximum in cashew followed by rubber and open, on the similar lines to that of organic matter percentage.

4.7.4 Soil carbon stocks (Carbon sequestration)

The data on soil carbon stocks (SCS) in rubber, cashew and tree-less open plots are presented in Table 37 and Fig.25.

In rubber, uppermost layer recorded the highest SCS value, which decreased to a minimum at the lowermost layer of 1m depth. The SCS was recorded 18.38, 16.28, 11.00, 10.39 and 8.69 Mg ha^{-1} at 0-20, 20-40, 40-60, 61-80 and 81-100 cm correspondingly. The value at 0-20 cm differed considerably from that of lowest more layer but was on par with intermediate layers. There was a decrease of 53 percent in SCS from uppermost to lowermost layer. A total of 64.74 Mg ha^{-1} was recorded in whole soil upto 1m, 20 percent more than exhibited by open plot.

In cashew plot, again decrease in SCS was noticed with increasing depth upto 1 m. Upper most layer recorded maximum SCS value of 18.28 differing significantly from subsequent soil depths. The other layers recorded 15.61, 13.59, 11.65 and 9.57 Mg ha^{-1} of carbon stocks in the order of 21-40, 41-60, 61-80 and 81-100 cm soil depth respectively. Percentage decrease of 48 percent was noticed from topmost (0-20 cm) to lowermost layer (81-100 cm). The total SCS in whole soil layer upto 1m amounted to 68.7 Mg ha^{-1}, which is 24 percent more than that of SCS recorded in open plot.

Soil carbon stocks in treeless open plot generally reduced with increase in soil depth. Observations revealed the carbon stocks of 15.07, 13.41, 10.77, 7.15 and 5.64 Mg ha^{-1} in soil layers from 0-20, 20-40, 40-60, 61-80 and 81-100 cm recorded respectively. This amounts to a total of 52.04 Mg ha^{-1} carbon in whole soil upto 1m. There was a decrease of 62.5 percent in SCS from uppermost to lowermost layer.

Table 34. Soil bulk density (g cm^{-3}) at whole soil depth of 1m in rubber, cashew and tree-less open plots

Depth (cm)	Rubber	Cashew	Open	F	p
0-20	1.14^{c} (0.13)	1.15^{c} (0.07)	1.17^{b} (0.09)	2.233	0.129
21-40	1.16^{b} (0.08)	1.18^{c} (0.1)	1.23^{b} (0.11)	2.651	0.166
41-60	1.20^{b} (0.06)	1.22^{b} (0.14)	1.29^{b} (0.21)	1.295	0.336
61-80	1.21^{b} (0.09)	1.24^{a} (0.16)	1.34^{b} (0.06)	0.821	0.523
81-100	1.27^{a} (0.08)	1.31^{a} (0.06)	1.35^{a} (0.19)	1.527	0.270
F	64.22	46.27	68.26		
p	0.041	0.045	0.034		

Values in parenthesis indicate Standard Error
Values with same superscript in a column do not differ significantly
DAP- Days after planting

Table 35. Soil organic matter (OM) at whole soil depth of 1m in rubber, cashew and tree-less open plots

Depth	Rubber	Cashew	Open	F	p
0-20	1.39 (0.08)	1.37^{a} (0.08)	1.11^{a} (0.05)	1.763	0.189
21-40	1.21 (0.09)	1.14^{a} (0.07)	0.94^{a} (0.13)	0.977	0.462
41-60	0.79 (0.06)	0.96^{b} (0.07)	0.72^{b} (0.17)	2.168	0.146
61-80	0.74 (0.05)	0.81^{b} (0.04)	0.46^{b} (0.08)	2.397	0.120
81-100	0.35 (0.08)	0.63^{c} (0.03)	0.36^{b} (0.06)	1.450	0.288
F	0.504	5.22	6.572		
p	0.627	0.049	0.031		

Values in parenthesis indicate Standard Error
Values with same superscript in a column do not differ significantly
DAP- Days after planting

Table 36. Organic carbon percentage at whole soil depth of 1m in rubber, cashew and tree-less open plots

Depth	Rubber	Cashew	Open	F	p
0-20	0.81 (0.13)	0.79^{a} (0.04)	0.64^{a} (0.05)	3.211	0.633
21-40	0.70 (0.07)	0.66^{a} (0.21)	0.55^{a} (0.02)	1.139	0.372
41-60	0.46 (0.11)	0.56^{b} (0.05)	0.42^{a} (0.07)	0.514	0.438
61-80	0.43 (0.06)	0.47^{b} (0.12)	0.27^{b} (0.13)	1.291	0.252
81-100	0.34 (0.08)	0.37^{b} (0.06)	0.21^{b} (0.08)	0.906	0.812
F	1.879	16.097	11.53		
p	0.463	0.033	0.047		

Values in parenthesis indicate Standard Error
Values with same superscript in a column do not differ significantly
DAP- Days after planting

Table 37. Soil organic carbon (Mg ha^{-1}) stocks at whole soil depth of 1m in rubber, cashew and tree-less open plots

Depth	Rubber	Cashew	Open	F	p
0-20	18.38[a] (1.08)	18.28[a] (1.05)	15.07[a] (0.78)	2.170	0.146
21-40	16.28[b] (1.16)	15.61[b] (1.02)	13.41[a] (0.94)	1.741	0.217
41-60	11.00[b] (0.96)	13.59[b] (0.89)	10.77[b] (0.24)	2.646	0.097
61-80	10.39[b] (0.64)	11.65[b] (0.78)	7.15[b] (0.93)	2.013	0.169
81-100	8.69[c] (0.77)	9.57[b] (0.45)	5.64[b] (0.16)	0.526	0.735
Mean	12.95	13.74	10.41		
F	10.557	18.993	6.053		
p	0.029	0.016	0.041		

Values in parenthesis indicate Standard Error
Values with same superscript in a column do not differ significantly
DAP- Days after planting

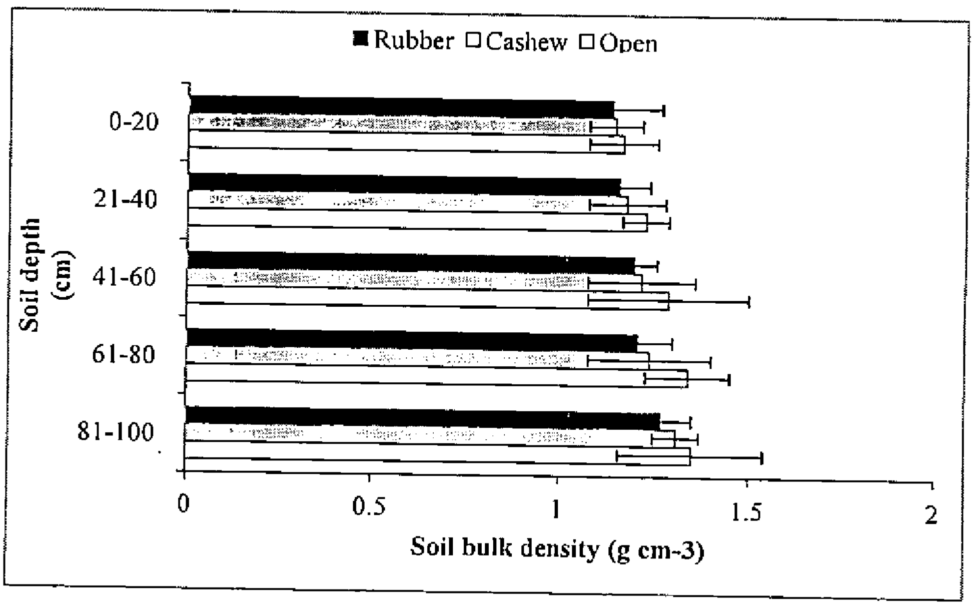

Fig.22. Soil bulk density (g cm^{-3}) at whole soil depth of 1m in rubber, cashew and tree-less open plots

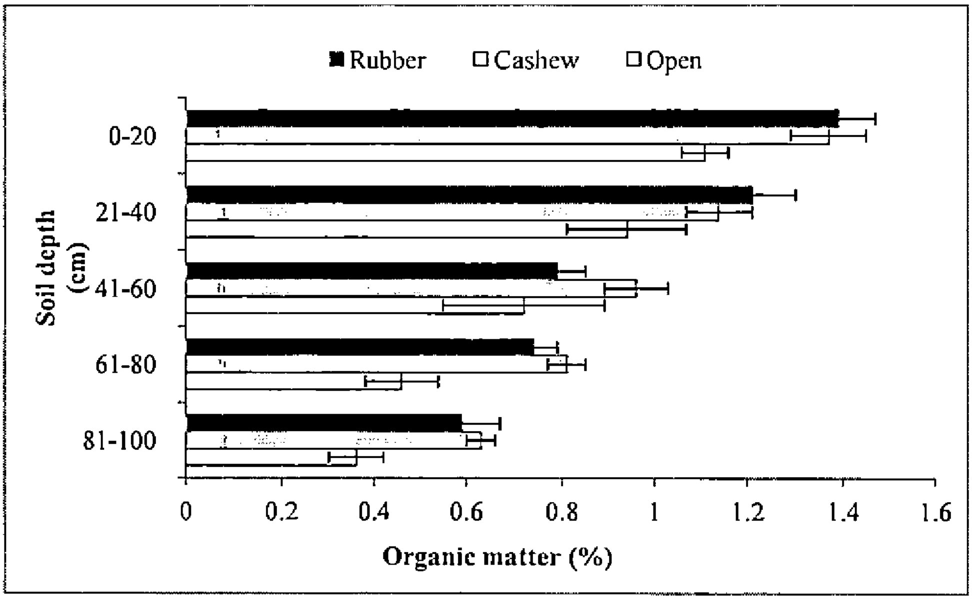

Fig.23. Soil organic matter (OM) at whole soil depth of 1m in rubber, cashew and tree-less open plots

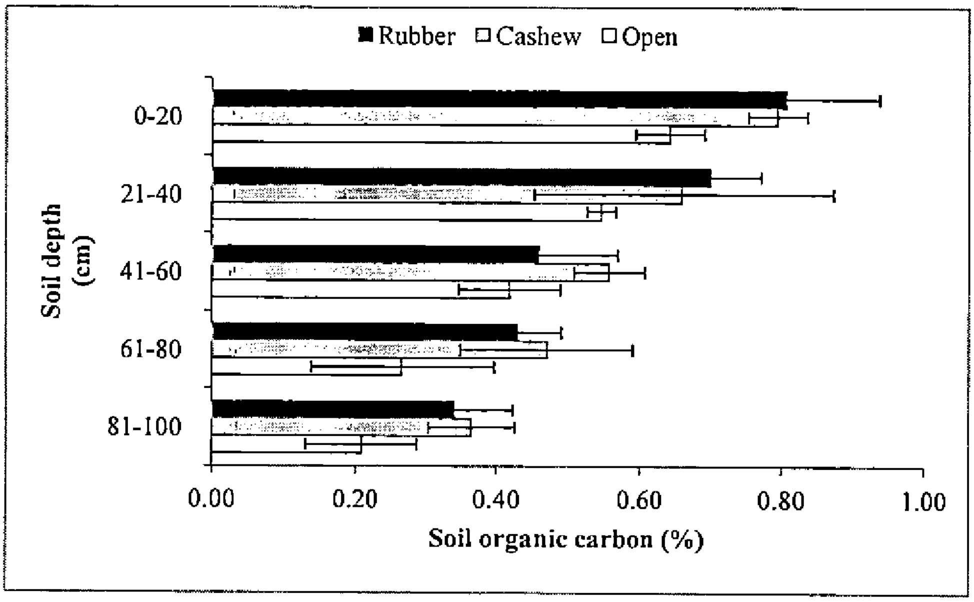

Fig.24. Organic carbon percentage at whole soil depth of 1m in rubber, cashew and tree-less open plots

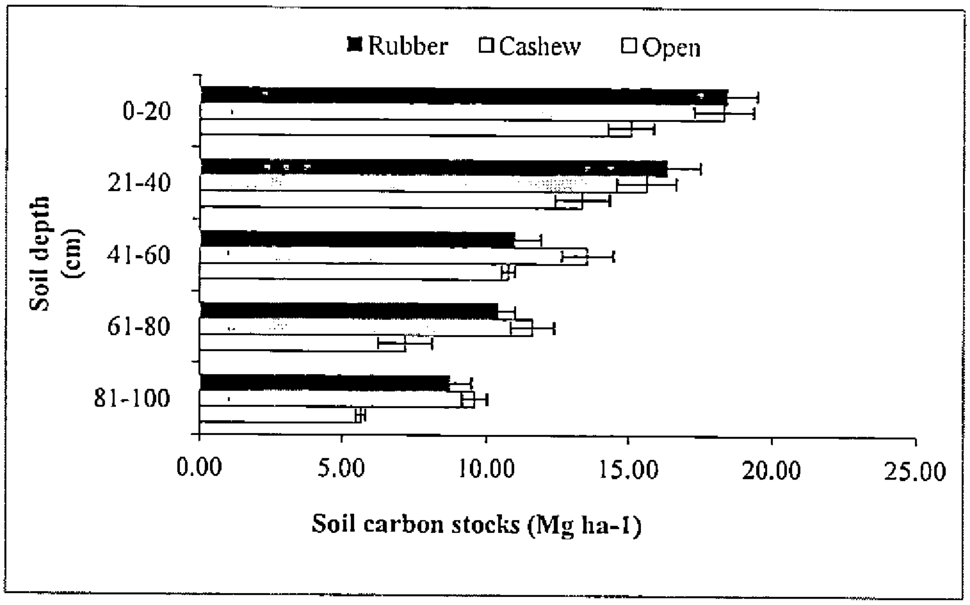

Fig.25. Soil organic carbon stocks (Mg ha^{-1}) at whole soil depth of 1m in rubber, cashew and tree-less open plots

With respect to the two land management systems, at 0-20 cm soil depth, rubber recorded the highest (18.38 Mg ha^{-1}) SCS followed by cashew (18.28 Mg ha^{-1}) and open plot (15.07 Mg ha^{-1}). An increase of 21 and 22 percent compared to open plot was noticed in cashew and rubber respectively at this depth. In the next layer i.e. 21-40 cm the rubber showed highest value followed by cashew and open. This amounts to a percentage decrease of 6.73 and 33.38 of SCS in cashew and rubber correspondingly in comparison to open. At 41-60 cm cashew recorded the maximum value of 13.59 Mg ha^{-1} followed by rubber (11.00 Mg ha^{-1}) and open (10.77 Mg ha^{-1}). Further, at 61-80 cm cashew plot exhibited highest SCS value succeeded by rubber (10.39 Mg ha^{-1}) and open (7.15 Mg ha^{-1}) amounting to a percentage increase of 63 and 45 percent in cashew and rubber respectively. At the lowermost layer, maximum SCS was exhibited by cashew plot followed by rubber and open. This translates to 70 and 54 percent reduction in cashew and rubber respectively compared to open.

4.8 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=0.56 to 0.91), regression equations were developed linking these two variables. Linear, quadratic and logarithmic equations gave good fit with high R^2 values 0.56, 0.91 and 0.82 respectively. However, 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 0.80 to 0.96. Except for quadratic equation statistical soundness was observed with all. Correlation in galangal was sound with high R^2 values 0.90 to 0.97. Statistical soundness were observed with all 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.

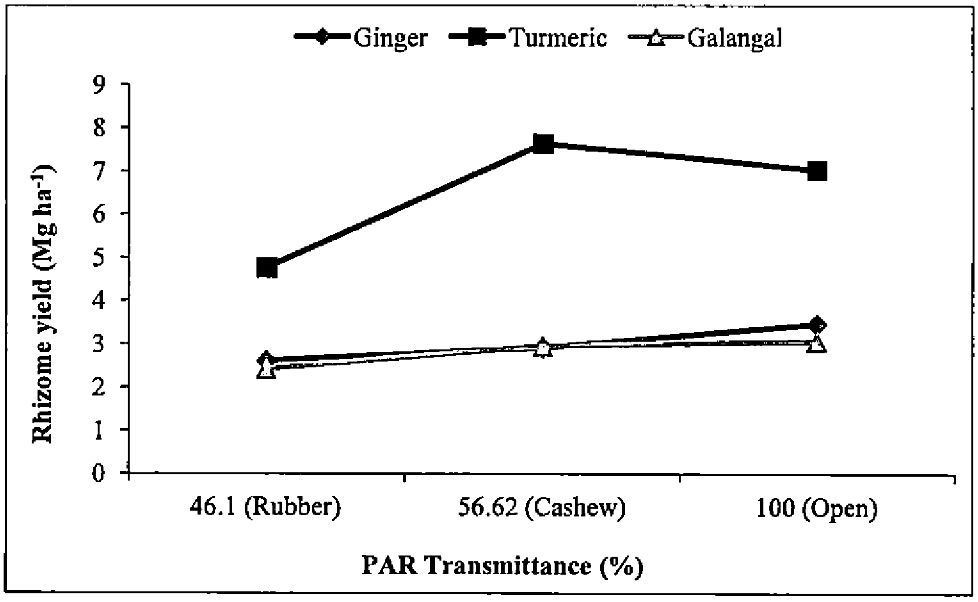

Fig. 26. Understorey PAR and rhizome yield under various land use systems

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

Sl. No	Model	Coefficients			R^2
		a_0	a_1	a_2	
		Ginger			
1	$Y = a_0 + a_1*D$	2.76^{ns}	0.048^{ns}	-	0.56
2	$Y = a_0 + a_1*D + a_2*D^2$	5.81^{ns}	-0.099^{ns}	-0.001	0.91
3	$\ln Y = a_0 + a_1* \ln D$	-3.975^{ns}	1.59^{ns}	-	0.83
		Turmeric			
1	$Y = a_0 + a_1*D$	2.320^{*}	0.054^{*}		0.87
2	$Y = a_0 + a_1*D + a_2*D^2$	-25.026^{ns}	0.78^{ns}	-0.005	0.96
3	$\ln Y = a_0 + a_1* \ln D$	-10.904^{*}	4.015^{*}		0.80
		Galangal			
1	$Y = a_0 + a_1*D$	2.7*	0.004**		0.97
2	$Y = a_0 + a_1*D + a_2*D^2$	3.015*	-0.005*	5.208E-005*	0.90
3	$\ln Y = a_0 + a_1* \ln D$	1.808**	0.269**		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

5. DISCUSSION

The field study to explore the understorey productivity of three medicinal herbs *viz.* ginger, turmeric and galangal under mature rubber and cashew plantations involved detailed investigations on the growth attributes of the intercrops and the biophysical factors that influence the understorey productivity. The salient results are discussed hereunder.

5.1 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 systems (Cannell *et al.*, 1996). Trees minimize intercept solar radiation reaching to understory crops. The extent of shade varies according to crown dimensions, tree phenology and leaf density. In the present study, the spacing in rubber and cashew plantations was 4.5×4.5m and 8×8 m respectively. The stand leaf area index of 1.98 and 1.43 was recorded in rubber and cashew plots respectively (Fig. 19).

In agroforestry practices, LAI and crown development are of utmost importance for standardization of spacing. The higher LAI may distress the understorey crop growth in tree-based systems. This was substantiated by lesser dry matter production and rhizome yield for understorey crops in rubber and cashew compared to treeless open plot (Tables 11 and 12). On the similar lines, Bhimappa (2014) noticed lesser dry matter production and rhizome yield in close spacing compared to wide spacing of bamboo. Nissen *et al.* (1999) reported that both shading and belowground competition decreased the yield of *Brasicca oloracea* in eucalyptus based alleycropping system in Philippines. Low understory PAR levels resulting from high level of LAI significantly reduced yield of winter wheat near tree row in China (Chirko *et al.*, 1999). Greater light extinction when stand LAI is more has been reported by Kumar *et al.* (2001) also.

5.2 PHOTOSYNTHETICALLY ACTIVE RADIATION (PAR)

The functional relationship between PAR availability and the understorey productivity is a major consideration in polyculture systems involving woody perennials. This is particularly true in humid tropical conditions where the understorey availability of solar radiation is limited by the high density multi-tier configuration of tree crowns. The important factor to be considered is the light use efficiency. The available light, its efficiency with which intercepted light is converted into biomass, sets the biomass yield limit (Long *et al.*, 2006). In rubber plot, mean photosynthetic photon flux density (PPFD) above the canopy ranged from 191 μ moles $m^{-2}sec^{-1}$ (8 a.m) to 1469.5 μ moles $m^{-2}sec^{-1}$ (1-2 p.m) while corresponding below canopy PPFDs were 79 μ moles $m^{-2}sec^{-1}$ to 885.5 μ moles $m^{-2}sec^{-1}$. In case of cashew plot, mean above canopy PPFD values ranged from 311 μ moles $m^{-2}sec^{-1}$ (8 a.m) and 1494 μ moles $m^{-2}sec^{-1}$ (1-2 p.m) whereas respective below canopy PPFDs were 129 μ moles $m^{-2}sec^{-1}$ (8 a.m) and 1105 μ moles $m^{-2}sec^{-1}$ (1-2 p.m). Mean mid day (12 –1p.m) understorey photosynthetic Photon Flux Density (PPFD) levels were 1072.5 moles μ $m^{-2}sec^{-1}$ in rubber and 1275 μ moles $m^{-2}sec^{-1}$ in cashew (Table 16). This amounts to 44.1% and 56.62 % of light availability (PAR) near the ground surface in rubber and cashew plots respectively. 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.

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). Perhaps crown characteristics (density, leaf arrangement etc) are more important than the quantitative spread of crown. With respect to crown characteristics, Agetsuma (1989) found that leaf density and leaf angle had positive curvilinear relationships with understorey light intensity. 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. In cashew trees, growth habits differ with varieties and eco-types. Upright and open canopy in cashew facilitates better penetration of solar radiation within the canopy (Salam and Peter, 2010). The lower stand leaf area index and wider spacing in cashew trees in the present study also substantiate better light availability in the cashew plot. However, in rubber relatively higher stand leaf area index and closer spacing may have contributed to decreased understorey PAR.

The present results on canopy light interception converge to the generalization that information on factors such as PAR and LAI are indispensable for optimizing understorey productivity in polyculture systems.

5.3 GROWTH PERFORMANCE OF THE INTERCROPS

5.3.1 Plant height

Plant height has been reported as a growth variable sensitive to shading. In the present study involving different land management systems, different understorey crops behaved very distinctively. For instance, ginger performed better in terms of plant height in rubber (69.13 cm) and turmeric in cashew plot recording 118.75 cm height. With respect to leaf spread, galangal exhibited maximum (31.53 cm) values in rubber plot. On the other hand, ginger, turmeric and galangal grown in open condition recorded 59.33, 76.13 and 103.08 cm, thus exhibiting lowest values.

Several studies reveal the possible explanations for such differences. Perhaps the understorey crops might exhibit competition under low light regimes leading to vertical elongation to capture the available PAR. 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 open conditions.

The general effect of shading on plants was studied by Ross (1976) and he 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. Bai and Nair (1982) observed positive influence of shading on plant height in ginger, coleus and sweet potato. Yet in another study, Verghese (1989) reported that in ginger, plant height increased with increase in shade intensity from zero to 75 percent at 60 DAP only, after which plants grown at 25 percent shade had the highest plant height, whereas in turmeric, with increase in shade, plant height increased upto medium shade of 50 percent and then decreased. Increase in plant height with increasing shade intensities in ginger were also reported by Jayachandran *et al.* (1991), Ancy (1992), Ajithkumar (1999) and Sreekala (1999). Such increase in plant height growth compared to open has been reported for ginger when grown under various land management systems (Amin *et al*, 2010; Bhuiyan *et al*, 2012). Latha *et al.* (1995) also observed increase in plant height in turmeric with increasing shade intensity.

5.3.2 Tiller production

Tillering has a close bearing on overall crop productivity. The present study revealed highest tiller production in open grown ginger and turmeric plants. Rubber and cashew produced 24.43 and 15.14 % less number of tillers in ginger respectively compared to open, whereas 28.33 and 30.04% in turmeric in the same order (Table 5). Such inverse response in tiller production to shading has been reported from many studies. For instance, reduction in tillering due to shading was observed by Moursi *et al.* (1976) in wheat and Verghese (1989) in ginger and turmeric. However, Prameela (1990) observed non significant effect of shade on tiller production in colocasia.

A plausible explanation for the reduced tillering 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 low R: FR ratio reduces the phytochrome photo-equilibrium (Pr: Pfr) (Smith, 2000) and has been related to reduced tillering (Casal *et al.*, 1990; Barnes and Bugbee, 1991). 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). At high shade intensity, an increase in plant height is seen and this may have resulted in the diversification of energy for that rather than to increase the tiller number. Possibly this could be due to higher auxin production in plant grown under shaded condition which ultimately suppressed the growth of tillers (Miah *et al.*, 1999). In such situations, probably the plant may allocate more resources towards growth in height, giving lesser allocation towards tiller production (Sreekala, 1999). Thus, the reduced photosynthetic light availability under heavy shade may be suppressing the growth and development of tillers also.

In the present study, contrary to ginger and turmeric, performance of galangal showed lowest tiller production in open conditions and highest in shaded condition especially under rubber. Similar results have been obtained in other crops. For instance, reports suggest shade increased tiller number for ginger (Wilson and Ovid, 1993). There are findings suggesting better ginger growth under tree cover managed under shaded conditions (higher density) compared to growth in treeless open plot (Jaswal *et al.*, 1993., Thomas, 1996; Newman *et al.*, 1998). Bhuiyan *et al.* (2012) also found lowest leaf production in ginger and turmeric in open and maximum in shaded conditions. The variable behaviour in tiller production suggests that there is considerable variation among crops as regards light compensation point and productivity under varying light intensities.

5.3.3 Leaf production

An examination of observations in present investigation revealed enhancement in leaf production with increasing PAR transmittance in case of ginger and turmeric. In both the crops, number of leaves per tiller was recorded highest in treeless open plot (14.58 and 8.29 in ginger and turmeric respectively). Sreekala (1999) observed lower number of leaves in ginger under heavy shade. Decrease in number of leaves with increase in shade intensity was observed in ginger and turmeric by Verghese (1989). These findings are in line with the results obtained in the present study. The decrease in number of leaves in lesser PAR transmittance conditions appears to be because of shade-induced reduction in tillering. The low availability of photosynthates, which results from the low irradiance, might be the possible reason for the retarded growth under heavy shade (Meyer and Anderson, 1952).

Notwithstanding such findings in ginger and turmeric in the present investigation, galangal exhibited highest leaf production in shaded conditions (Table 6) compared to open. The reduction in leaf production may be due to decrease in the number of tillers and vice versa. Similar results have been reported by Aclan and Quisumbing (1976) and Ancy (1992). They observed a reduced number of leaves per tiller in ginger, grown under full sunlight. In turmeric Bhuiyan *et al.*, (2012) found lowest number of leaves per tiller in ginger and turmeric grown under full sunlight compared to shade grown plants. In contrast to earlier findings, no evidence of increase in leaf production in galangal under open conditions was detected in the present study as against the findings by Latha (1994) and Kumar *et al.* (2005) in open grown galangal.

5.3.4 Rhizome production

Rhizome production in ginger and galangal was considerably higher in treeless open (3.46 and 3.06 Mg ha^{-1}) followed by cashew (2.91and 2.95 Mg ha^{-1}) and least by rubber (2.61 and 2.42 Mg ha^{-1}). However, the turmeric rhizome yields were highest in cashew (7.63 Mg ha^{-1}) (Table 12). The average productivity of different intercrops under different growth regimes was comparable to other systems.

The dominant role of PAR on understorey productivity is quite explicit in this study (Fig. 26). 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). In addition, the belowground root competition for water and minerals may also contribute to this variability in productivity. The understorey growth rate is proportional to the amount of radiation intercepted by the canopy (Kasanga and Monsi, 1954). 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 (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 3 m^2).

The PAR recorded in rubber and cashew was 44.1 and 56.62 % respectively which correspond to the shade levels of 55.9 and 43.38 % in the same order. Such a response of rhizome production across different PAR regimes is the indication of close relationship between the photosynthetic pathway, which plants exhibit, and the PAR. The important aspects governing the crop productivity are the type of photosynthetic pathway. i.e. C_3 or C_4 and influence of shade or the amount of incident PAR. C_3 plants become light saturated at approximately 50% of full sunlight whereas C_4 plants become light saturated at nearly full sunlight (Nair, 1993). 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 (Reynolds *et al.*, 2006).

Since Zingiberaceae family exhibits C_3 pathway this relationship is explicitly shown by the selected crops in the present study. For instance, the PAR transmission of 56.67% (cashew) is within the tolerance limit whereas PAR of 46.6% (rubber) is not. This probably could be the reason for turmeric showing enhanced yield in cashew and interestingly even more than open, which further implies towards a PAR suitability of 56.67 % (or near) for better yield of turmeric. On the other hand, stabilized and a comparable rhizome production in ginger and galangal over wider PAR regime (from 46% onwards) suggests their suitability across the given land use systems with broad light requirements. However, in case of turmeric, PAR suitability was narrower. Nevertheless, yield increase under partial shade (cashew) compared to treeless open suggests better integration of turmeric in such tree-based systems. The performance of turmeric in cashew is supported by the results of Bhuiyan *et al.* (2012). They also found partial shade condition (PAR 70-80%) had positive effect on turmeric rhizome yield producing highest values of 40.25 Mg ha^{-1} compared to other treatments.

Several workers have found better performance of crops under treeless open. Highest belowground biomass yield in galangal was observed in the 'no-canopy' treatment (Kumar *et al.*, 2005). There are reports about different values with respect to optimum shade requirement for ginger. For instance, many workers have reported that inanimate shade of 25 percent (illumination level of 75%) promotes ginger yield (Bai, 1981; Jayachandran *et al.*, 1991; Verghese, 1989; George, 1992). In an intercropping study on ginger with poplar, Jaswal *et al.* (1993) observed maximum yield at 46 percent light availability. Results of Thomas (1996) indicate modestly higher light requirement of ginger. Kunhamu *et al.* (2008) reported ginger rhizome yield increased with increasing intensity of thinning which suggests 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). Vikram and Hegde (2014) found significantly highest yield of turmeric in open conditions compared to cashew intercropping. Ghosh *et al.* (2006) reported the yield of ginger was significantly high in the open field (14.7 Mg ha^{-1}) compared to plots under agroforestry system.

Apart from the light factor, such aspects as intercrop variety, belowground root competition for resources, tolerance limits for various resources play a key role in deciding the overall productivity. Distinct variation in ginger yield has been observed with variety. For instance 'Varada' ginger variety (Kunhamu, 2006) has been reported to be less shade tolerant while 'Kuruppampady' ginger variety performed better under shade (Kumar *et al.* 2001). Screening of ginger cultivars for shade tolerance was done with six cultivars (Maran, Kuruppampadi, himachal, Rio-de-Janerio, Nedumangad and Amballore Local) under four shade levels (0, 25, 50 and 75%) by George (1992). Mohanty *et al.*(1981) also reported varietal differences for the character rhizome yield in ginger.

The same holds true with turmeric and galangal as well which exhibit varietal differences in terms of rhizome yield. Mukhopadhyay *et al.* (1986) reported varietal differences for the character rhizome yield in turmeric. Varietal adaptability to shade levels in turmeric was found to be the prime factor governing the yield of turmeric as intercrop. Wynad Local and T. Sunder were found adapted for cultivation in coconut garden under rainfed condition. In galangal, out of various varieties investigated, Latha (1994) found Ponnukkar to have performed well in rhizome yield compared to Palakkad and Vellanikkara.

5.4 CHLOROPHYLL CONTENT

Chlorophyll is the pigment that is vital for photosynthesis, which allows plants to absorb energy from light. In the present study, chlorophyll content in all crops was recorded consistently highest in rubber followed by cashew while the lowest in open plot. Differences were relatively appreciable in turmeric and galangal. The influence of understorey light availability on chlorophyll content is prominent in the present study. The observations revealed different chlorophyll content across land use systems.

The 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 of the fact that 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 *et al.* 2001). However sun plants when grown under shaded conditions produce lesser mesophyll cells with larger grana containing higher concentration of chlorophyll (Lambers *et al.*, 1998). It can be claimed that better utilization of carbohydrates takes place as degradation of carbohydrates is slowed in decreased respiration at lower temperature. The positive effect of shading on chlorophyll content in plants has already been reported (Bai, 1981; Ramanujam and Jose, 1984; Babu, 1993; Sreekala 1999; and Bjorkman and Holmgren, 1963). In ginger and turmeric, Verghese (1989) reported an increase in chlorophyll content with increase in shade intensity. Ancy (1992) also observed increased chlorophyll content with increasing shade. 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. The findings that the concentration of chlorophyll per unit area weight of leaf increased with decreasing light are in agreement with results of the present investigation.

5.5 OLEORESIN CONTENT

Oleoresin content is an important parameter for which rhizomatous plants such as ginger, turmeric and galangal are valued. Among the three intercrops oleoresin content was highest for turmeric (10.68 %) followed by ginger (4.49 %) and galangal (2.60%). The oleoresin content is species dependent. Interestingly, the oleoresin content was the highest under rubber and lowest in treeless open plot for all the three intercrops. In ginger, it varied from 4.02 in open to 4.49% in rubber, in turmeric from 9.92 in open to 10.68% under rubber and in galangal, the oleoresin content varied from 2.26 in open to 2.60% in rubber plot. The highest content exhibited by rubber-grown plants was consistently followed by cashew plot and in the same order lowest by open. The relatively more oleoresin content in rubber and cashew plots compared to open may be attributed to the variation in understorey light availability.

This suggests a trend of enhanced oleoresin percentage towards shading attributed to reduced PAR transmission. 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) and have reported similar findings in ginger. Ravishankar and Muthuswamy (1987); Babu and Jayachandran (1994) have also observed the ginger grown under shade produces better quality rhizomes.

Besides this, few studies opine that oleoresin yield may be independent of shade intensity. Studies by Latha (1994) support the observation that oleoresin and shade are independent. Kumar *et al.* (2001) have also noticed similar insensitivity of oleoresin to light in ginger. Corroboratory results have been reported by Verghese (1989), Ancy and Jayachandran (1993). Thomas (1996) in ginger noted highest oleoresin value (3.98 %) in open grown ginger. Regarding galangal Sureshkumar (1997) observed lower oleoresin content under the tree canopy than open. He noted values varying from 2.08 to 2.50 %.

Further, findings of the present study also suggest an inverse relationship between the rhizome yield and oleoresin content in the given medicinal crops. However, the generalization may be limited by varietal differences in the crops. Major factors of oleoresin content of rhizomes are variety, maturity and environment while shade alone has a major influence on this parameter (Kumar *et al.*, 2005). Nybe (1978) has reported significant variation in oleoresin percentage among ginger varieties. For instance, Rio de Janerio contained the maximum oleoresin (10.53 %) and Maran (10.05 %) while other varieties Waynad Manatody (4.91%), Himachal Pradesh (5.39%) and Vellanikkara of galangal better for oil yield out of various varieties under investigation (Latha, 1994).

5.6 NUTRIENT ACCUMULATION

The growth and development of understorey crops may depend on overstorey species, soil condition and in turn the accumulation of nutrients from the soil. The accumulation of N, P and K increased accordingly in the experimental plots. In general, maximum accumulation of nutrients was exhibited in open followed by cashew and the least by rubber barring few variations. The wider spacing in cashew (8x8 m) and a higher PAR of 56.62 % may be the reason for relatively more nutrient accumulation in crops under cashew than crops growing under rubber. Additionally, the process of nutrient accumulation at different growth stages is a function of climate, soil properties and crop variety (Thomas, 1996). Several studies reveal that understorey crop nutrient accumulation is strongly correlated with overstorey stand density, root length, understorey PAR and the amount of plant nutrient demand (Rowe *et al.*, 2001; Zhang, 1999 and Goa *et al.*, 2013).

A perusal of observations from the current study revealed accumulation increased in treeless open plot in general. Thus, a positive influence of light availabllity and less belowground competition may be presumed. 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 may 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 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 understorey crops.

Higher accumulation of N, P and K in the present investigation 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 open plot. On the similar lines, biomass productivity was in general highest in open grown crops. 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 (2013) in wide spacing of bamboo compared to closed spacing. Kattge *et al.* (2009) also reported the relationship between maximum photosynthetic capacity and accumulation of nutrient content by understorey crops as highly correlating. In contrast, Bai (1981) observed an increase in N, P and K content with increasing intensities of shade. Similar observations were noted by Sureshkumar (1997) in galangal.

Total nutrient accumulation is primarily a function of nutrient concentration and biomass production that explain the higher nutrient accumulation in open grown crops. Observations in the current study illustrate that 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 period, which corresponds to the period of maximum vegetative growth. Comparison of the Tables (29-33) suggests 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 pre-experimental spoil samples.

5.7 SOIL CARBON SEQUESTRATION

The total soil carbon stock corresponding to 1 m soil depth was found highest in cashew plot (68.74Mg ha^{-1}) followed by rubber (64.74 Mg ha^{-1}) and lowest in the treeless open plot (52.04 Mg ha^{-1}) respectively. Depth wise soil carbon stock showed decreasing trend with increase in depth in 1m soil profile. In open plot, it varied from 15.07 Mg ha^{-1} at 0-20 cm depth to 5.64 Mg C ha^{-1} at 81-100 cm. In the same order, it varied from 18.28 to 9.57 Mg ha^{-1} in cashew plot and 18.38 to 8.69 Mg ha^{-1}. A comparison study of soil carbon stock under different land use system in Kerala reported higher soil organic carbon stocks under tree based system such as 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 with tree species, which differ in biomass production, tissue nutrient concentrations and their effects on soil quality (Post and Kwon, 2000). The soil carbon stock estimated in the rhizosphere of five black pepper support trees *viz. Ailanthus triphysa, Erythrina variegate, Gliricidia sepium* and *Garuga pinnata* in the humid tropics of Kerala registered greater levels of soil organic C in the rhizosphere of *G. sepium* (26.5 g kg^{-1}), and the lowest level was registered under *A. triphysa* (21.6 g kg^{-1}; Dinesh *et al.*, 2010). Sreenivasan *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 under both the tree-based systems (rubber and cashew) and treeless open plots (Table 34). Bulk density at 0-20 cm depth in rubber, cashew and open was 1.14, 1.15 and 1.17 %, which correspondingly increased to 1.27, 1.31 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 is usually low in bulk density on account of 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 such as 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 36). Evaluation of percentage change in organic carbon concentration from 0-20 to 81-100 cm soil depth revealed decrease of 67, 53 and 58% in open, cashew and rubber plots respectively. 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 Sreenivasan *et al.* (2010) also observed the same trend in poplar based agroforestry system and coconut inter planted with MPTs respectively. Similar results were observed 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 litterfall and litter decomposition in the surface soil of plantations, which subsequently declined with soil depth.

Noteworthy observation is the soil carbon stock at the top most soil level. At 0-20 cm soil depth, cashew plot showed an increase of 20 % carbon stock whereas rubber plot showed 21% increase compared to treeless open plot. These observations suggest considerable increase in soil carbon content at shallow depths in tree-based ecosystems. Presence of high carbon stocks in polyculture systems, hence is a desirable characteristic for intercropping. The soil depth of 0-20 cm being the zone of intercrop growth, the zone assurse ample supply of nutrients and minerals to the intercrops as compared to treeless plots.

In the present study, higher carbon stocks in cashew plot could be attributed to influence of miscellaneous tree cover and other ruderal vegetation, which existed in this plot prior to establishment of cashew. (Schwartz *et al.*, 2000; Tilman *et al.*, 2001, Srivastava and Vellend 2005). Prior to the launching of the trial, the cashew plots were under miscellaneous shrub growth and trees such as *Macaranga peltata* had proliferated in the area. This may have contributed to increased carbon stocks in cashew plot.

Tree species and management regimes also influence soil carbon content. A 6.5-year-old *Acacia mangium* stand at variable planting densities from humid Kerala showed higher SOC content in the range of 27.02 to 34.64 Mg C ha^{-1} at 0-15 cm soil depth (Kunhamu, 2006). However, for 6-year old poplar based agroforestry, Gupta *et al.*, (2009) reported a lower value of 13.3 Mg ha^{-1} (0-15 cm layer). Similar lower soil C content (18.2) Mg C ha^{-1} has been reported for cacao (*Theobroma cacao*) based agroforestry system in west Africa (Kumar,2004; Issac *et al.*, 2005) for 0-20 cm soil layer. In another study, Rytter (2012) reported soil C stocks to be 9.0 Mg C ha^{-1} for willow and 10.3 Mg C ha-1for poplar plantation over a period of 20-22 years.

In the present study, a relatively higher soil organic carbon was found in rubber plot compared to treeless open in the upper layers. As a semi deciduous crop, the rubber tree adds organic matter to the soil surface every year through litter decomposition during the winter period. Because wintering effects usually begin when tree are 4 to 5 years old (Geetha and Jacob, 2003), the SOC increase through leaf litter decomposition and becomes more significant as the rubber trees grow older. The influence of root distribution of rubber also might have contributed to higher soil carbon in upper layers. Rubber represents a tree species with moderate root spread. Soil zone lying within 3 m lateral distance and 30 cm soil depth account for almost 70 percent of total roots in the rubber trees (Sreenivasan *et al.*, 2004). Implicit in this is the addition of higher organic matter and organic carbon to the soil through dead and decaying roots.

A consistent decline in SOC content is discernible with soil depth in present study also (Table 37). Samritika (2013) reported a similar result. This is common in almost all cultivated mineral soils and is a reflection of the accumulation of higher quantities of litter at farthest soil depth (81-100 cm) in treeless open plot. In the similar order, SCS of 18.28 Mg ha^{-1} at 0-20 cm and 9.57 Mg ha^{-1} at 81-90 cm was recorded in cashew plot and 18.38 Mg ha-1 at 0-20 cm and 8.69 Mg ha-1 in rubber plot. A comparable result was found by Jangra *et al.*, (2010) where SOC was 17.09 Mg ha^{-1} (0-15 cm) and 8.64 Mg ha^{-1} at 60-100 cm soil depth. Samritika (2013) found 22.87 Mg C ha^{-1} at 0-20 cm depth and 9.43 Mg ha^{-1} at farthest soil depth (81-100 cm). Chauhan *et al*, (2011) also observed a similar increasing trend in soil organic carbon content with soil depth in all the poplar plantations and control plots.

In contrast, 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 on account of variable root distribution patterns (Kumar *et al.*, 1999).

The results of tree-based systems recording higher SOC compared to treeless open plot have been corroborated by several studies Samritika (2013), Thevasathan and Gordon, (2004); and Tumwebaze *et al.*, (2012). Drechsel *et al.*, (1991) observed an increase in SOC (0-10 cm) under improved fallows of 5- years in sub to-humid tropics. They observed SOC increase to be 3.41, 5.21, 12.46, and 5.20 Mg ha^{-1} under *Acacia auricuoliformis, Albizzia lebebck, Azadirachta indica and Casisa siamea* respectively. The decay and decomposition of dead roots causing constant addition of organic matter in plantation soil may be ascribed as primary reason for improved soil carbon status in wooded systems (Young. 1997 and Rai *et al.*, 2001).

The soil carbon dynamics and nutrient flux in the present study validate the influence of trees in building organic matter and carbon stocks, making tree-based systems more relevant for understory productivity.

5.8 PRACTICAL IMPLICATIONS OF THE STUDY

The understorey productivity studies in the two mature cropping systems such as rubber and cashew showed interesting observation on the possibility of integration of medicinal herbs at larger scales. Among the intercrops tried, probably, turmeric respond better under cashew where understorey light availability is relatively good. In systems like rubber, the crops such as ginger and galangal would be better because of their lesser sensitivity to shade as compared to turmeric. Obviously, the medicinal crops performed well under open condition. However, the suboptimal yields under competitive regimes offer additional returns to the farmer through intercropping leading to an overall higher combined yield from unit area. Furthermore, the intercrop management practices benefit the tree crops through efficient sharing of the common resources. The study clearly demonstrates the need for enhancing PAR levels for understorey productivity maximization in these two systems. However, there exists strong limitation on the canopy manipulation in these two systems, which could seriously influence the main crop yields.

Summary

6. SUMMARY

The research work entitled "Performance of selected medicinal herbs under rubber and cashew plantations" was undertaken during 2014-15 at Kerala Agricultural University, Vellanikkara, Thrissur to assess the productivity of three shade-tolerant herbaceous medicinal crops *viz. Zingiber officinale* (ginger), *Curcuma longa* L. (turmeric) and *Kaempferia galanga* L. (Lesser galangal) when grown as intercrops in mature rubber (*Hevea brasiliensis* Muell. Arg,) and cashew (*Anacardium occidentale* L.) plantations which form two major land management systems in Kerala State of India. The four objectives were: (i) comparison of productivity of the three medicinal plants, (ii) characterize the biochemical changes in the produce, (iii) study the biophysical, physicochemical and phytochemical factors and (iv) assess the soil carbon sequestration. Salient features of the study are as follows:

6.1 PRODUCTIVITY OF MEDICINAL PLANTS

6.1.1 Growth observations prior to harvest revealed considerably maximum plant height of ginger in rubber and that of turmeric in cashew. Leaf spread of galangal was maximum in rubber. Highest pseudostem length of ginger and turmeric was in rubber and cashew respectively. With respect to root length, all the intercrops exhibited maximum values in open plot.

6.1.2 Tiller production in ginger and turmeric was maximum in treeless open plot while that of galangal was in both cashew and rubber. Leaf production in all the crops was highest in treeless open.

6.1.3 Specific leaf area of all the understorey crops was highest in cashew plot followed by rubber and open plots.

6.1.4 Fresh aboveground weight was highest in open-grown plants. In intercropping condition, cashew-grown intercrops recorded invariably highest fresh aboveground weight. Belowground dry weight also followed the same trend with maximum in cashew.

6.1.5 Fresh rhizome weight per plant, of all intercrops, was highest in open plot among the land use systems. However, in intercropping conditions ginger recorded higher values in rubber plot and that of turmeric and galangal in cashew.

6.1.6 Per plant dry rhizome weight followed suit with ginger and galangal with higher weight from treeless open and that of turmeric from cashew plot.

6.1.7 Rhizome yield of ginger at the final harvest was higher in open (3.46 Mg ha^{-1}) followed by cashew (2.91) and rubber (2.61 Mg ha^{-1})

6.1.8 Rhizome yield of turmeric recorded highest in cashew (7.63 Mg ha^{-1}) followed by open (7.02 Mg ha^{-1}) and rubber (4.76 Mg ha^{-1}) respectively

6.1.9 Final rhizome yield of galangal was maximum (3.06 Mg ha^{-1}) in open whereas rubber and cashew recorded yield of 2.42 and 2.95 Mg ha^{-1} respectively.

6.1.10 Net rhizome production of all the crops was highest in treeless open followed by rubber and cashew.

6.2 BIOCHEMICAL CHANGES IN THE PRODUCE

6.2.1 Chlorophyll content in all intercrops was highest in rubber plot followed by cashew and the lowest in open plot.

6.2.2 Oleoresin concentration in all the intercrops was maximum in rubber followed by cashew and open.

6.3 BIOPHYSICAL, PHYSICO-CHEMICAL AND PHYTOCHEMICAL FACTORS INFLUENCING PRODUCTIVITY

6.3.1 Mean mid day (12–1.00 p.m) understorey photosynthetic Photon Flux Density (PPFD) levels were 1072.5 moles μ $m^{-2}sec^{-1}$ in rubber and 1275 μ moles $m^{-2}sec^{-1}$ in cashew, with respective understorey PAR transmittance of 44.1 and 56.62 percent of full sunlight. Stand leaf area index (LAI) values of 1.98 and 1.43 were recorded for rubber and cashew.

6.3.2 Pre-experiment soil nutrient status showed a maximum C concentration for cashew followed by rubber. Highest nitrogen, phosphorus and potassium content was recorded in cashew followed by rubber and open.

6.3.3 Significantly highest soil nitrogen content in ginger beds was recorded in cashew followed by rubber and lowest was exhibited by open.

6.3.4 Highest P content was exhibited by cashew, which was on par with rubber and greater than open. Rubber exhibited maximum K content in ginger beds followed by open and cashew.

6.3.5 Highest amount of nutrients in turmeric beds was found in cashew plot followed by rubber and treeless open plot.

6.3.6 For galangal, cashew plot exhibited yet again highest nitrogen content significantly different from rubber and open. Highest P content was noticed again in cashew plot. Comparably lowest value was recorded in open plot. Similarly, highest K content was found in cashew plot and lowest by open.

6.3.7 Both the wooded land use systems *viz* rubber and cashew, had a vivid and rich soil nutrient status (N, P and K) as compared to the treeless open.

6.3.8 Among the three land-management systems cashew recorded significantly highest nitrogen content followed by rubber. Cashew plot recorded maximum P content on par with rubber and considerably different from tree-less open at 230 DAP. For K, the order was different with maximum in open (140.85 kg ha^{-1}) followed by rubber (131.95 kg ha^{-1}) and cashew (129.47 kg ha^{-1}).

6.3.9 Nutrient concentration (N, P & K) in the aboveground biomass of ginger was consistently highest in open grown plants du whereas that of turmeric registered higher values in cashew plot at all the sampling stages. In case of galangal, open plot gave highest nutrient concentration at harvesting stage.

6.3.10 Nutrient concentration in belowground portions of ginger and galangal showed highest concentration in open plot. On the other hand, turmeric recorded highest values of all nutrients in cashew plot.

6.3.11 Foliar nutrient accumulation (N, P & K) in ginger and turmeric was higher in open plot while that of galangal in cashew.

6.3.12 Belowground nutrient accumulation in ginger and galangal was maximum in treeless open throughout crop period. For turmeric, maximum accumulation was in cashew.

6.4 SOIL CARBON SEQUESTRATION

6.4.1 Bulk density showed an increasing trend with the increase in depth. Treeless open recorded highest bulk density at each soil depth followed by cashew rubber.

6.4.2 The highest amount of soil organic matter percentage, in whole soil upto 1m depth, was in cashew followed by rubber and the open plot.

6.4.3 Organic carbon percentage followed the same trend as that of organic matter percentage showing a decreasing trend with increase in soil depth. The total organic carbon percentage in whole soil of 1m depth was maximum in cashew followed by rubber and the open plot.

6.4.4 Soil carbon stocks in treeless open plot reduced with increase in soil depth. At the surface layer (0-20 cm soil depth), rubber and cashew recorded the highest SCS values of 18.38 Mg ha^{-1} and 18.28 Mg ha^{-1} whereas treeless open recorded the lowest (15.07 Mg ha^{-1}). In terms of whole soil depth of 1 m, cashew showed highest SCS of 68.7 Mg ha^{-1} followed by rubber (64.74 Mg ha^{-1}) and open (52.04 Mg ha^{-1}).

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PERFORMANCE OF SELECTED MEDICINAL HERBS UNDER RUBBER AND CASHEW PLANTATIONS

By

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ABSTRACT OF THE THESIS

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8. ABSTRACT

A field experiment was conducted at Vellanikkara, Thrissur, Kerala to assess the understorey productivity of three herbaceous medicinal crops *viz.* *Zingiber officinale* (ginger), *Curcuma longa* L. (turmeric) and *Kaempferia galanga* L. (Lesser galangal) under mature rubber (*Hevea brasiliensis* Muell. Arg,) and cashew (*Anacardium occidentale* L.) plantations. The biophysical attributes influencing the productivity of the land management systems and the biochemical changes in the products of understorey crops were studied. Additionally, soil carbon sequestration in both the given land use systems and the treeless open plot was estimated.

Mean mid day (12–1p.m) understorey photosynthetic photon flux density (PPFD) levels were more in cashew (1275 μ moles $m^{-2}sec^{-1}$) than rubber (1072.5 moles μ $m^{-2}sec^{-1}$) with respective understorey PAR transmittance of 56.62percent and 44.1percent of full sunlight. The stand leaf area index (LAI) values in rubber and cashew were 1.98 and 1.43 respectively.

Growth parameters of understorey crops varied noticeably among land use systems. Plant height and pseudostem length of ginger were greater in rubber and that of turmeric was in cashew. Leaf spread of galangal was higher in rubber. Root length of all crops was maximum in treeless open plot followed by cashew and rubber plantations. Ginger and turmeric exhibited highest tiller and leaf production in treeless open plot followed by cashew and rubber. However, higher tiller and leaf production in galangal were in rubber.

Rhizome yield varied appreciably among the land use systems over the growth period. Rhizome yield at final harvest for ginger and galangal was maximum in treeless open (3.46 and 3.06 Mg ha^{-1} respectively) while that of turmeric was in the cashew plot (7.63 Mg ha^{-1}) explicating the influence of PAR on understorey productivity. Regression equation relating PAR rhizome yields showed statistical reliability with high coefficient of determination (R^2) values.

Total chlorophyll content of understorey crops was highest in rubber followed by cashew and open. Oleoresin also showed such a trend with highest

percent of 10.68, 4.49 and 2.60 for turmeric, ginger and galangal respectively under rubber. However, nutrient accumulation in the above and below ground parts of all the crops was higher in cashew compared to rubber.

With respect to carbon sequestration, soil organic carbon stocks in the upper most layer (0-20 cm) were higher in rubber (18.38 Mg ha^{-1}) followed by cashew (18.28 Mg ha^{-1}) and treeless open plot (15.07 Mg ha^{-1}) validating the influence of trees in improving the soil through addition of organic matter. This zone being important from intercropping point of view, relevance of wooded land use systems for understorey productivity is emphasised. The total carbon stocks in 1m soil depth, were highest in cashew (68.70 Mg ha^{-1}) followed by rubber (64.74 Mg ha^{-1}) and open (52.04 Mg ha^{-1}).

It may be thus deduced from the present study that in terms of yield attributes, ginger, turmeric and galangal have better prospects in wooded land use system in general and the specific advantage of cashew over rubber was also obvious. This may be attributed to relatively better PAR transmission, higher nutrient accumulation and lesser root competition in cashew. Further, the better quality of rhizomes under comparably higher shade levels suggests their suitability in tree-based land use systems.