FORAGE YIELD, SOIL FERTILITY AND CARBON DYNAMICS OF CALLIANDRA (*Calliandra calothyrsus* Meissn.) IN COCONUT PLANTATION

by

JILNA JOY

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THESIS

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DEPARTMENT OF SILVICULTURE AND AGROFORESTRY
COLLEGE OF FORESTRY
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KERALA, INDIA

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DECLARATION

I, hereby declare that this thesis entitled "FORAGE YIELD, SOIL FERTILITY AND CARBON DYNAMICS OF CALLIANDRA (*Calliandra calothyrsus* Meissn.) IN COCONUT PLANTATION" 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 me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Place: Vellanikkara

Date: 30/08/2017

Jilna Joy

(2015-17-002)

CERTIFICATE

Certified that this thesis entitled "FORAGE YIELD, SOIL FERTILITY AND CARBON DYNAMICS OF CALLIANDRA (*Calliandra calothyrsus* Meissn.) IN COCONUT PLANTATION" is a record of research work done independently by Ms. Jilna Joy, under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

Place: Vellanikkara

Date: 30/8/17

Dr. Asha K. Raj.
(Major Advisor, Advisory Committee)
Assistant Professor
Department of Silviculture and Agroforestry
College of Forestry
Kerala Agricultural University
Vellanikkara

CERTIFICATE

We, the undersigned members of the advisory committee of Ms. Jilna Joy, a candidate for the degree of Master of Science in Forestry with major in Silviculture and Agroforestry, agree that the thesis entitled "FORAGE YIELD, SOIL FERTILITY AND CARBON DYNAMICS OF CALLIANDRA (*Calliandra calothyrsus* Meissn.) IN COCONUT PLANTATION" may be submitted by Ms. Jilna Joy, in partial fulfilment of the requirement for the degree.

Dr. Asha K. Raj.
(Chairman, Advisory Committee)
Assistant Professor
(Silviculture and Agroforestry)
College of Forestry
Vellanikkara

Dr. Kunhamu. T. K.
(Member, Advisory Committee)
Professor and Head
(Silviculture and Agroforestry)
College of Forestry
Vellanikkara

Shri. K.P. Pradeep
(Member, Advisory Committee)
Associate Professor (Agronomy)
Instructional Farm
College of Horticulture,
Vellanikkara

Dr. V. Jamaludheen
(Member, Advisory Committee)
Professor
(Silviculture and Agroforestry)
College of Forestry
Vellanikkara

R. C. Pandalai

EXTERNAL EXAMINAR
(Name and Address)

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Jilna Joy

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INTRODUCTION

INTRODUCTION

A major constraint to dairy farming in the tropics is the seasonal fluctuation in forage yield and poor plant nutrient quality of fodder grasses. Adequate forage with good nutritive value is available in the wet season, but during dry season forage availability is inadequate both in terms of quantity and quality. Fodder grasses contains less crude protein compared to fodder trees. Since livestock farming is a major means of subsidiary income for small farmers and agricultural labourers in Kerala, our state also faces the problem of scarcity of nutrient rich fodder. It is estimated that the state produces only 60 per cent of the fodder requirement for livestock (Kerala State Planning Board, 2011). Further, the heavy dependence of livestock farmers on costly concentrates reduce their profit to a considerable extent. Hence, cultivation of nutrient rich fodder on farm itself is highly warranted for ensuring sustainable and profitable milk production. Fodder trees with their nutrient rich foliage serve as a potential source of quality green fodder to livestock especially during lean periods. So, growing suitable fodder trees in the farm at modest management levels, in place of buying costly concentrate feed, is a better option for farmers for profitable milk production.

Calliandra (*Calliandra calothyrsus* Meissn.), a native of Central America, is a multipurpose leguminous tree grown primarily for forage. The suitability of calliandra, as a promising fodder tree by virtue of its nutritive foliage and ability to withstand severe pruning has already been reported (Pye-Smith, 2010). Since the agro-climatic requirements of calliandra suit well to that of humid tropical Kerala, there is a good scope for utilizing calliandra as a source of quality fodder in the state. However, due to land constraints in Kerala, the possibility of growing calliandra as a monocrop in open lands is rather limited. Only alternative is to integrate with the existing cropping systems in the state. Coconut, being the most prominent plantation crop in Kerala stretching over an area of 0.82 M ha (Economic Review Kerala, 2015), any attempt to integrate forage trees like calliandra with coconut would be a desirable strategy for profitable animal rearing.

Usually, low density planting patterns are followed for fodder trees in semi-arid and arid regions due to the constraints in soil nutrients and moisture. But, species like calliandra permit high density intensive cultivation in close hedge rows in humid high rainfall tropical condition like Kerala. However, inspite of great potential, fodder tree cultivation in coconut garden is not yet practiced by farmers due to lack of sufficient knowledge on the standard management practices like tree density and harvesting schedule for optimization of calliandra productivity when intercropped under coconut. Hence, an intercropping trial has been initiated at Kerala Agricultural University (KAU) to optimize the tree density and pruning interval of hedge row grown calliandra for maximizing forage yields.

Observations regarding fodder yield after one year reveals the promising nature of the fodder tree in the acidic soils of Kerala. However, calliandra being a tree species with fast growth and extensive deep rooting system, as the age advances, interaction within the species as well as with the main crop coconut, leads to either complementary or competitive effects and ultimately influences the yield of both the trees. Moreover, adoption of recurrent pruning over years may have a detrimental effect on tree health and longevity. Hence, a sound understanding of the long-term effects of tree density and pruning frequency on growth, yield and longevity of calliandra, as well as its effect on coconut yield is important in determining sustainable production strategies for the fodder production system.

In addition to fodder production, the integration of trees in agricultural farms offers multiple ecosystem services like improvement of soil properties, carbon storage and associated climate change mitigation. Being a leguminous tree, calliandra can fix nitrogen and supply it to the component crops. It has been recognized that agroforestry practices contribute to CO_2 emission reductions through carbon storage potential in the multiple plant species as well as in the soil and thereby take prominent role in global climate change mitigation (Nair and Nair, 2003). This aspect is one of the promising, but least studied ecological service of agroforestry systems. There is ample opportunity for the subsistence farmers to benefit economically from these systems through the clean development mechanism (CDM) projects. This however requires information on above ground and below ground carbon storage potential of agroforestry systems which is lacking.

With this background, a field study has been envisaged with the following objectives:

- To assess the influence of tree density and pruning interval on forage yield and carbon storage potential of three-year old calliandra intercropped in coconut gardens.

- The study also explores the variation in coconut productivity and soil fertility changes associated with intercropping calliandra in coconut plantations.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Integration of protein rich fodder tree calliandra in the existing cropping systems like coconut garden is an excellent option for enhancing quality forage production in a land crunch state like Kerala. However, in spite of great potential, fodder tree cultivation in coconut garden is not yet practiced by farmers mainly because of the insufficient knowledge on the standard management practices to maximize production from the system. Trials conducted on various fodder trees indicated that, the management aspects such as tree density and harvest interval influences forage productivity, yield of the component crops and soil fertility aspects of the system, in addition to several environmental benefits like carbon sequestration, which should be considered while establishing and managing high density fodder banks.

The aim of the present study is to evaluate the effect of stand management practices like tree density and pruning intervals of calliandra on fodder and coconut yield; and carbon dynamics and soil fertility changes of calliandra - coconut system over three-year period. Relevant literature pertaining to the above aspects is reviewed hereunder.

2.1 DAIRY SECTOR IN INDIA AND KERALA

Since time immemorial, livestock sector has been an integral part of India's agricultural and rural economy, supporting livelihood of more than two-thirds of the rural population. Livestock sector contributes to national economy in general and to agricultural economy in particular. A major share of the income of small farm households comes from this sector alone. India's livestock sector, being one of the largest in the world, generated outputs worth Rs. 2075 billion that comprised 4% of the Gross Domestic Product (GDP) and 26% of the agricultural GDP in 2010-11 (Planning Commission, 2012).

The share of livestock sector in the agricultural GDP of the Kerala State during 2014-15 was 27.62%, while in 2013-14 its contribution was 25.25%. Milk production in Kerala was 21.19 lakh MT in 2006-07 and increased to 27.11 lakh MT in 2014-15. Kerala contributed only 1.85% to the annual milk production of the country during 2014-15 (Kerala State Planning Board, 2015).

There was an increase in milk production of around 20 million Mg in 1960s to 115 million Mg in 2010-11. The per capita availability of milk is far below the requirement of 280 g, although there was an increase from 128 g/day in 1980-81 to 267 g/day in 2010-11. By the end of 12th Plan, demand for milk is expected to increase to 141 million Mg. Meat production from the recognized sources is estimated to be 3.96 million Mg and has increased at 4.1% annually during the last 5 years. Despite significant increase in livestock production, per capita consumption of milk (69 kg) and meat (3.7 kg) in 2007 has been much lower against corresponding world averages of 85 and 40 kg. The average yield of milk and meat in our country is also 20-60% lower than that of the global average (Planning Commission, 2012).

2.2 MAJOR CONSTRAINTS IN THE DAIRY FARMING

Deficiency of good quality feed and fodder is the major constraint in realizing the production potential of the livestock. Ogunbosoye and Babayemi (2010) reported that inadequate feed supply is a major obstacle for livestock production during the dry periods in the tropics and this has led to the poor performance of ruminants. India is lagging behind in the production of green fodder by 35%, dry fodder by 11% and concentrates feed by 28% (Planning Commission, 2012). Mathukia *et al.* (2016) reported that the requirement for dry and green fodder are 650.7 and 761.5 million tonnes (Mt) respectively and there is a shortage of 40.4% dry fodder and 24.7% green fodder.

In India, only 4.4% of the total cultivated area is set aside for fodder crops and the annual total forage production is 846 Mt (Mathukia *et al.*, 2016). By the year 2050, the demand of green and dry fodder will rise to 1012 and 631 million mega grams respectively. In the year 2050, there will be 18.4 % deficit in green fodder and 13.2%

deficit in dry fodder. Green forage supply has to grow at 1.69% annually to meet out the deficit (IGFRI, 2015). In addition, the common grazing lands faces quantitative and qualitative deterioration. Hardly fodder is grown in 5% of the cropped area (Planning Commission, 2012). The state of Kerala also produces only 60 per cent of the roughage requirement for cattle in Kerala (Kerala State Planning Board, 2011). Insufficient quantity and quality nutrition is one of the major hindrances in livestock production in Kerala (Ajith *et al.*, 2012).

2.3 SCOPE OF FODDER TREES IN ANIMAL NUTRITION

A major hindrance in the field of dairy farming in the tropics is the seasonal fluctuation of forage yield as well as the quality of grasses. When the quality of grasses falls well below the requirement during a long dry spell, fodder trees can provide sufficient crude protein to complement low quality pastures and other crop residues. Fodder tree leaves are richer in calcium and phosphorus than fodder grasses and deficiencies of these minerals are often reflected in reproductive problems of ruminant animals (Paterson *et al.,* 1998). Pye-Smith (2010) reports that, in addition to fodder supply, the fodder trees can also improve soil fertility, provide nectar for bees, supply year-round firewood and their pruning remains could be used as stakes for supporting beans, tomatoes and peas.

Forage based economical feeding strategies can supplement the dairy sector by reducing the cost of livestock production as the feed alone comprises 60-70% of the total milk production cost (IGFRI, 2015). Trees and legumes are capable of providing high quality fodder in the dry season (Adejumo, 1992). Trees and shrubs are persistent and have the potential to retain their leaves during prolonged drought periods and produce more edible dry matter compared to herbaceous plants (Sanchez and Sanchez, 2002). In addition, the microclimate of the site is enriched through efficient nutrient cycling and pumping when trees are planted in mixtures (Haines and DeBell, 1979).

Nitrogen fixing trees possess the added advantage of fixing substantial quantities of atmospheric nitrogen (Huxley, 1985). Jamala *et al.* (2013) claimed that leguminous species contain 25 to 50% more crude protein than non-leguminous plants. Fodder trees have multiple roles in farming systems such as feed, fire wood and as human and veterinary medicines (Luseba and Van der Merwe, 2006). The forage species contain appreciable amounts of nutrients that are lacking in other feeds such as grasses during dry periods as they have deep root systems that enable the extraction of water and nutrients from deeper horizons in the soil profile (Aregawi *et al.*, 2008).

Most fodder trees have high crude protein content and it ranges from 10 to more than 25% on a dry matter basis (Moleele, 1998). This reliable protein resource can be utilized for developing a sustainable feeding system and enhance livestock productivity. According to Jamala *et al.* (2013), forage intake increases intake of total dry matter and crude protein, improves the digestibility of low-quality forages, increases survival (i.e., lower mortalities, especially over the dry season) and productivity.

2.4 CALLIANDRA – A PROMISING FODDER TREE

Calliandra (*Calliandra calothyrsus),* a small leguminous tree originates from Central America and Mexico. The tolerance of *C. calothyrsus* to acid soils has encouraged its use as fodder tree in the humid tropics (Berhe and Mohamed-Saleem, 1996; Palmer *et al.,* 1989; Ty, 1996). The trees grow well in the areas with rainfall exceeding 1100 mm (Roothaert and Paterson, 1997). The high palatability of calliandra to various livestock, including cattle, goats, sheep, rabbits and chickens has been reported (Roothaert *et al.,* 1998; Franzel *et al.,* 2003; Nyeko *et al.,* 2004). Freshly harvested leaves of *C. calothyrsus* have been found to be highly palatable for livestock (Palmer and Schlink, 1992; Paterson *et al.,* 1996; Shelton *et al.,* 1996). Studies at Maseno in Kenya has shown that *C. calothyrsus* can be successfully utilised as a concentrate for milking animals (Van der Veen, 1993). According to Palmer *et al.*

(1995), research done in Australia claimed that the digestibility and voluntary feed intake of calliandra was higher when fed fresh than for dried or wilted plant material.

For dairy cows one kg of concentrates can be successfully replaced by 3 kg of fresh *Calliandra calothyrsus* (Paterson *et al.* 1996; Pye-Smith, 2010). One kilogram of dried calliandra supplies roughly the equal amount of digestible protein as that of one kg of dairy meal, and this increases milk production by approximately 0.75 litres (Pye-Smith, 2010). Roothaert *et al.* (1998) suggests that an additional 3 kg of fresh calliandra could increase the production of milk by 0.6 kg. In Sri Lanka, studies reported that up to 30% of the concentrates can be replaced with *C. calothyrsus* leaves without affecting feed intake (Perera and Perera, 1996). Feeding trials conducted in Kerala reveals that in cross bred dairy cows, 20% of the concentrates can be substituted with calliandra without affecting the milk yield and animal health (Jayaprakash *et al.,* 2016).

Roothaert *et al.* (1998) claimed that 500 calliandra trees can feed one cow for a year at the rate of six kg fresh calliandra daily. The dry matter component of the total edible portion of the foliage contains about 24% crude protein and 1 kg dry fodder of calliandra contains the same amount of nitrogen as 1.5 kg of dairy meal with 16% crude protein. Calliandra also increased butterfat content by about 0.5% (Paterson *et al.,* 1998). In an exploration of farmer's experiences in the management and utilization of calliandra as a fodder shrub in Uganda, the majority of farmers feeding calliandra to cows (86%) reported that it increases milk production and 8% of the farmers observed increased butter content of milk feeding on calliandra and most of them considered calliandra as profitable in their dairy enterprise (Nyeko *et al.,* 2004). According to Pye-Smith (2010), a farmer having a cow and 500 calliandra trees who uses it as a substitute for dairy meal would increase his net annual income by US$101 - US$122 and one who decides to use it as an additional supplement to the usual feed, would increase his net annual income by US$62 - US$115.

A constraint for feeding calliandra is its low digestibility in the rumen if the material is dried or wilted (Palmer and Schlink, 1992). According to Kaitho *et al.* (1993), unlike fodder trees such as *Gliricidia sepium*, *Tithonia diversifolia, Erythrina sp.* and *L. leucocephala,* calliandra possess higher proportion of by-pass protein than the rumen degradable protein. It is assumed that the high content of polyphenolic compounds in *C. calothyrsus* may be the reason for the protection of the protein from degradation in the rumen by the micro flora. Calliandra can be a good dietary ingredient for highly productive dairy cows that need some amount of by-pass protein (Roothaert and Paterson, 1997).

2.5 FORAGE YIELD OF FODDER TREES

Under a wide range of conditions in block-planting arrangements, fodder tree species of the genera *Calliandra* and *Leucaena* have given annual yields from 5–15 Mg ha^{-1} of edible dry matter (DM) (Karanja *et al.,* 1996). In a study conducted in western highlands of Kenya, leafy biomass yields were compared for *Leucaena leucocephala, Calliandra calothyrsus* and *Sesbania sesban,* maintained as hedges at a height of 0.5 m. In the initial year of establishment, the fresh yields were 11.2, 17.2 and 20.3 Mg ha^{-1}, respectively for the three species. However, in the next 8 months calliandra reported the highest yield (36.7 Mg ha^{-1}), followed by leucaena (24.3 Mg ha^{-1}) and sesbania showed the lowest (10.8 Mg ha^{-1}).

2.5.1 Effect of tree density on forage yield of fodder trees

In general, when the planting is done in higher densities, leaf and wood yield per unit area increases and the individual tree yield decreases (Ella *et al*., 1989). Higher leaf dry matter yields (5.4 Mg ha^{-1} $year^{-1}$) were reported from fodder trees at a density of 40,000 plants ha^{-1} compared to 15,000 plants ha^{-1} (Pathak *et al*., 1980). Castillo *et al*. (1979) did a comparison of four densities (3000, 5000, 6000, and 10,000 plants ha^{-1}) and concluded that significant higher yields were obtained from the two highest densities. Savory and Breen (1979) also reported the highest forage yield from the high density stands of 60,000 plants ha^{-1} compared to lower densities (10,000 and 30,000 plants ha^{-1}).

Density trials of mulberry and subabul fodder banks in coconut gardens of Kerala also reveal the significant improvement in fodder yield from lower planting density of 27,777 plants ha^{-1} (25.68 and 28.44 Mg ha^{-1} yr^{-1} for subabul and mulberry respectively) to higher planting density of 49,382 plants ha^{-1} (45.70 and 45.12 Mg ha^{-1} yr^{-1} for subabul and mulberry respectively) during the initial year of growth (Raj *et al.*, 2016).

2.5.2 Effect of pruning frequency on forage yield of fodder trees

Cutting calliandra six months before the height of the dry season gave maximum yield during that season (Roothaert and Paterson, 1997). On average, farmers prune calliandra trees six times a year in Kabale district of Uganda when used for fodder production (Gerrits, 2000). Research in East Africa showed that cutting calliandra every 6 weeks or every 12 weeks produces same amount of leaf matter and the longer cutting interval had the added advantage of small-diameter fuelwood production for farmers (Pye-Smith, 2010). Roothaert *et al.* (1998) reports that the cutting interval for calliandra fodder trees could be as short as 2 months in rainy season and could be as long as 4 months in dry season and recommends 1 m as optimum cutting height.

In density trials of fodder blocks, maximum production was obtained for 12 week cutting frequency (Ella *et al.*, 1989). Paterson *et al.* (1996) and Shelton *et al.* (1996) have also come up with the recommendation of cutting frequencies of 8-12 weeks for fodder trees for maximum yield. In the humid tropics of Kerala, mulberry and subabul fodder blocks underneath coconut garden, yielded maximum edible fodder under shorter pruning interval of 8 weeks when compared to the longer interval of 12 and 16 weeks (Raj *et al.*, 2016).

Apart from fodder yields, pruning frequency has profound influence on leaf-stem ratio of the forage which influences the palatability of the fodder. Raj *et al.* (2016) reported higher leaf-stem ratio in mulberry and subabul, when pruned at shorter intervals of 8weeks compared to longer intervals. Studies conducted in calliandra at Karnataka (Basavaraju and Rao, 1995) revealed maximum foliage yields from calliandra at cutting interval of 60 days compared to higher intervals. Similar observation was also reported by Ella *et al.* (1989) for subabul, calliandra and gliricidia.

2.6 INTEGRATION OF FODDER TREES IN COCONUT PLANTATIONS

Due to acute land scarcity, the possibility for growing fodder tree banks under open conditions is very limited in Kerala. The best alternative is to integrate fodder tree cultivation with the existing cropping system. Coconut is the dominant cropping system in Kerala with an area of 7.9 lakh hectare (Kerala State Planning Board, 2015). There is good scope for growing fodder trees as intercrops in the widely spaced coconut gardens. Studies conducted in Sri Lanka confirm that fodder crops can be grown under coconut plantation. By proper maintenance of the intercrops through fertilization, irrigation and weeding, the main crop also gets benefitted. The suitability of cultivation of various fodder trees like subabul, mulberry, glyricidia and calliandra under coconut plantations was confirmed by several studies (Raj *et al.*, 2016).

Numerous studies also indicate the successful intercropping of fodder trees under various plantations. Reports from ICRAF (1992) indicate that the growth of subabul and calliandra is not generally reduced due to the presence of taller, timber and fuel wood species like *Grevillea robusta* or *Casuarina equisetifolia*, even though the growth of the upper-storey species may be decreased due to competition from the fodder species during the early stages. Benjamin *et al.* (1990) assessed yield performance of different fodder trees under various shade treatments and expressed it as a percentage of yield at 100% light transmission and the relative order of shade tolerance was *Gliricidia sepium* (94%), *Calliandra calothyrsus* (85%), *Leucaena leucocephala* (84%), *Sesbania grandiflora* (76%), *Acacia villosa* (70%) and *Albizia chinensis* (66%).

In a study conducted in Bali, calliandra when grown as an intercrop in coconut plantations produced 598 g tree^{-1} leaf dry matter, 564 g tree^{-1} stem dry matter and a total dry matter content of 1162 g tree^{-1}when harvested at an interval of eight weeks for six harvests after planting (Oka Nurjaya *et al.,* 1990). In a study for evaluating the growth of tree legumes under coconut in North Sulawesi, calliandra reported highest total yield of more than 3300 g tree^{-1} over nine harvests and it produced 2231 g tree^{-1} leaf dry matter and 1120 g tree^{-1} stem dry matter (Kaligis *et al.*, 1990).

Gliricidia and subabul, planted at 2.0 x 0.9 m spacing in double rows in mature coconut plantations and lopped at an interval of three-months, produced 7-10 Mg ha^{-1} and 12-16 Mg ha^{-1} green matter and 8-15 Mg ha^{-1} and 14-20 Mg ha^{-1} fresh fuel wood in the first and second years of planting at four sites of the Coconut Triangle in Sri Lanka (Liyanage and Jayasundera, 1987). Liyanage and Abeysoma (1996) found that when *C. calothyrsus* was planted under coconut plantations in Sri Lanka, the green fodder production was 745 kg ha^{-1} and the green mulch increased the nut yield up to 24%.

2.7 CARBON SEQUESTRATION POTENTIAL OF COCONUT-FODDER TREES INTERCROPPING SYSTEM

Increasing greenhouse gases and alarming rate of climate change is a reality in the present-day world. It is the need of the hour to find cheap methods to sequester carbon (C) and agroforestry is thus the emerging trend for mitigating climate change. Tree/crop systems in agroforestry practices possess the ability to sequester C in the standing biomass as well as soil. Although studies have been done to understand the rate of increase of soil organic C in some agroforestry systems, little is known about C sequestered in various tree/crop intercropping systems.

Trees are important carbon sinks because they can hold large amount of carbon per unit area in comparison with other kinds of vegetation (Lasco *et al.*, 2002). On an average, carbon locked in agroforestry systems is estimated as 9, 21, 50 and 63 Mg C

ha^{-1} in semi-arid, sub-humid, humid and temperate regions (Montagnini and Nair, 2004). Coconut, a perennial tree crop having 50-60 years of lifespan, possess the potential to serve as a carbon reservoir (Jayasekara & Jayasekara, 1995; Mialet-Serra *et al.,* 2005; Ranasinghe & Silva, 2007; Roupsard *et al*., 2008a, b). Carbon sequestration potential of coconut plantations differs with its age, variety, inter-crop, cover crop, type of management etc.

In a study, Navarro *et al*. (2008) reported that 19-22-year-old Vanuatu Red Dwarf x Vanuatu Tall, a high-yielding hybrid of coconut stored a total carbon stock of 34.13 Mg ha^{-1} and a part of it, i.e., 5.0 Mg ha^{-1} was contributed by coarse and fine roots. In addition, he also reported that the grass cover stored 1.8 Mg ha^{-1}. Studies also show that 25-year-old Tall x Tall coconut (*Cocos nucifera* L. variety *typica*) plantations of Sri Lanka can sequester 17–25 Mg C ha^{-1}. It was also found that soil carbon stock contributed around 42 - 63% and grass only 2–3% of the total carbon stocks in the ecosystem. Of the total carbon stored in the coconut palms, the stem constituted 55-70% (sinks of long term) and the rest were accounted in the canopy, leaves and nuts (sinks of short term) (Ranasinghe and Thimothias, 2012). On comparison with the biomass of coconut, more carbon stocks were observed in the soil of coconut plantations (Roupsard *et al.,* 2008b).

Cultivation of legumes under coconut improves soil moisture holding capacity, soil organic carbon content, soil microbial activity, soil fertility as well as the productivity (Fernando, 1999; Dinesh *et al*., 2006). According to Smith *et al.* (2007), practice of growing nitrogen fixing plants and trees is recommended as climate change mitigation strategies by the IPCC. *Gliricidia sepium*, which is far better in CO_2 fixation compared to coconut, is recommended as an intercrop in coconut plantations of Sri Lanka (Fernando and Jayalath, 2003; Gunathilake, 2004). In a study conducted in Kerala, carbon stocks in the harvested fodder biomass of mulberry under high density planting (40,000 trees ha^{-1}) accounted to 10.30 and 30 Mg ha^{-1} respectively during 1^{st} and 2^{nd} year of its growth. Carbon sequestered in the standing tree stumps and roots of

2-year-old mulberry was 21 and 26 Mg ha^{-1} respectively (Varsha, 2015). The results indicated higher carbon capture and storage by high density stands of fodder trees.

2.8 SOIL CARBON STOCKS IN COCONUT-FODDER TREES INTERCROPPING SYSTEM

The terrestrial carbon pool possesses great significance since it is one of the largest carbon pool storing approximately 1500 pg, that is almost three times the quantity contained in the whole vegetation in the world or twice the quantity contained in the atmosphere (Batjes, 1996; IPCC WGI, 2001).

Comparisons of N fixers with non-N fixers shows 20-100% more soil C under N fixers (Johnson 1992; Rhoades *et al.,* 1998). In an experiment conducted in gliricidia and maize intercropping system in Malawi, 11 and 8 Mg ha^{-1} soil organic carbon were sequestered in the surface soil layer (0–20 cm) in 10 and 7-year-old intercropping systems respectively. The values were higher when compared to sole maize plots. When compared with grass fallow of 7 years age, grass fallow had higher organic carbon in the top 0–40 cm than the gliricidia-maize intercropping system but much lower in the sub-soil below 40 cm. Gliricidia-maize intercropping system possessed 26 Mg C ha^{-1} in top 200 cm more than the grass fallow. Gliricidia-maize intercropping system sequestered 123-149 Mg C ha^{-1} in the soil (0–200 cm depth), through root turnover as well as pruning application (Makumba *et al.,* 2007).

The organic carbon content in the soil was 0.57%, 0.64%, 0.69% and 0.81% and the soil carbon stocks were 18, 20.21, 21.79 and 27 Mg ha^{-1} for different age groups of 5, 10, 15 and 20 years coconut plantations. The surface soil (0-20 cm) recorded the highest organic carbon content (%) when compared to the sub-surface horizons. He also added that the total carbon in standing biomass ranged between 4.57 to 142.84 Mg ha^{-1} for the above-mentioned coconut plantations. The available nitrogen in coconut plantation was in the range of 85 – 117 mg kg^{-1} and the available phosphorous was reported as 12.5 mg kg^{-1} (Selvaraj *et al.,* 2016).

Organic carbon content in the soils of high density mulberry monoculture during the 2nd year of its growth in various depths of 0-20cm, 21-40 cm, 41-60 cm, 61-80 cm and 81-100 cm was reported as 1.06%, 0.82%, 0.87%, 0.76% and 0.74% respectively. Soil carbon stocks in the above-mentioned study at corresponding depths were 29.81, 24, 25.7, 23.01 and 22.07 Mg ha^{-1} respectively with the highest value in the surface layer of 0-20 cm. The corresponding values were significantly lower for tree less control plots (Varsha, 2015). In another study in Kerala, soil organic carbon (SOC) was found to be higher (1.14-1.63%) in coconut-fodder tree integrated system (coconut + mulberry/subabul) rather than the sole coconut crop (0.79%), in the initial year of establishment (Raj, 2016).

2.9 SOIL FERTILITY DYNAMICS IN COCONUT-FODDER TREES INTERCROPPING SYSTEM

The incorporation of trees in cropping systems increases soil fertility, improves soil structure, and reduces soil erosion. As compared to pure agricultural systems, agroforestry systems contribute towards improved nutrient cycling and sustainability through greater mineralization of nutrients from unavailable reserves, addition of nutrients in plant litter/tree residues, more closed nutrient cycles as a result of greater uptake by plant roots and less leaching losses and achieving a balanced supply of nutrients including micronutrients.

Rao *et al.* (1998) reported that increase in soil fertility is due to nitrogen input into the system through biological nitrogen fixation, reduced soil erosion, reduced leaching of nutrients and uptake from deep soil layers. Gunasena *et al.* (1991) have reported that *Gliricidia sepium* and *Leucaena leucocephala* increased soil fertility due to decomposition of leaf litter. The nutrient content (especially N and P) and the lignin and polyphenol concentrations of litter strongly influence its rate of decomposition and nutrient release to the soil (Szott *et al.*, 1991). Several experiments on *L. leucocephala* conducted in Sri Lanka revealed its adaptability under coconut in different agroclimatic zones (Liyanage, 1990). The beneficial effects of subabul on soil properties were demonstrated by significant improvement on Ultisols in terms of increased organic carbon content (45%) and water holding capacity (82%) and reduced bulk density (3%) over the control.

In a study conducted in Sri Lanka in order to improve degraded soil conditions of Andigama series by integrating nitrogen fixing trees in coconut plantation, higher root biomass distribution of calliandra was found to be in A and AB horizons. The growth and proliferation of coconut root decreased with increasing soil depth. The lateral root growth was higher than the vertical root growth in coconut. Coconut root growth was enhanced in the A horizon of calliandra interplanted plots (Vidhana Arachchi and De S Liyanage 1998). Dierolf *et al.* (1989) found that, in an alley cropping system where calliandra was maintained as hedges, 78% of the total fine root weight was distributed in the top 0-15 cm of soil and 9% in the 15-30 cm layer. Surprisingly, they still obtained roots at depths of 150 cm and suggested that the tree is capable of recycling nutrients from deeper soil horizons. Hariah *et al.* (1992) reported that the roots of *C. calothyrsus* were mainly confined to the top 10 cm of the soil and it possessed few major roots below 1 m.

The results of an experiment in Gowa, south Sulawesi showed that in a combination of fodder grasses with fodder trees production system, least reduction in growth of *Panicum maximum* was observed when planted under calliandra than those planted under subabul or gliricidia (Catchpoole and Blair, 1990). It was found that there was little nitrogen transfer from the leguminous trees to the fodder grass, but that the total nitrogen yield in the various systems raised from 103 kg ha^{-1} in the pure fodder grass control to 901 kg ha^{-1} in the tree-grass combinations (Catchpoole and Blair, 1990). According to Cattet (1996) and Tassin *et al.* (1995), pore diameter and hydraulic conductivity increases at saturation, particularly uphill from the hedge of calliandra even up to 50 cm. Conversely, in a study, lower moisture content was recorded under *C. calothyrsus* pasture (42.7%) compared to pure *Panicum maximum* pasture (51.4%) (Vasquez, 1987).

There was no improvement in soil C, N, P, K, Ca or Mg in alleys between *C. calothyrsus* maintained as hedges and applied as mulch in various inter cropping systems (Rosecrance *et al.,* 1992; Heineman *et al.,* 1997). It was also reported that *C. calothyrsus* mulch decreased soil pH and increased soil aluminium levels (Heineman *et al.,* 1997). On the contrary, Wong *et al.* (1995) found that *C. calothyrsus* prunings, when harvested and applied to maize and beans plots, lowered the aluminium concentration in the soil compared to control plots and observed increased grain yield that could be attributed to reduction in aluminium toxicity in those plots. Noble and Palmer (1998) also claimed that the *C. calothyrsus* ash caused least soil acidification when compared to ash obtained from *Leucaena* spp. or *Stylosanthes* spp.

Soil bulk density was found to be significantly lower in nitrogen fixing trees integrated areas in coconut plantation of Sri Lanka. In AB and B horizons of calliandra intercropped areas, total and readily available water fraction was higher when compared to control plots due to increased root activity and organic matter deposition (Vidhana Arachchi and De S Liyanage 1998). Studies conducted by KAU in coconut-fodder trees mixed cropping systems report that the bulk density (BD) of the soil in surface layer (0-20 cm) varies between 1.32 to 1.41 g cm^{-3} in the intercropped area of various combinations of planting densities and pruning interval and the least BD was observed in the sole coconut plot. The water holding capacity (WHC) ranged between 41.02%-50.43% in the intercropped area and highest WHC was observed in the control plot of coconut trees alone (52.54%). The soil pH was found in the range of 4.92-6.59 in the intercropped area and the soil pH in the sole coconut plantation was 5.72 (Raj, 2016).

In a study conducted in Kerala, soil organic carbon (SOC) was found to be higher (1.63%) in coconut-fodder tree integrated system (coconut + mulberry/ subabul) rather than the sole coconut crop (0.79%), in the initial year of establishment (Raj, 2016). Available nitrogen, phosphorus and potassium content in the soils of best intercropped treatment were 651 kg ha^{-1}, 14.33 kg ha^{-1} and 601 kg ha^{-1} and the corresponding values in sole coconut plots were 559 kg ha^{-1}, 3 kg $ha^{-1}$and 454 kg ha^{-1} respectively at the end of first year of growth (Raj, 2016).

Soil physical properties and nutrient status of 2-year-old high density mulberry monoculture for fodder production was studied in Kerala. The bulk density of soils under mulberry trees was found to be 1.39-1.47 g cm^{-3} at various depths of 0-100 cm depth. Soil pH also increased with increasing soil depth. Water holding capacity of the soils also increased at various depths (Varsha, 2015) in mulberry plots when compared to treeless control. The study also indicated that the tree based systems favorably influenced the nitrogen and potassium content in soil.

Research has demonstrated that inclusion of trees within agricultural systems can improve water quality (Lowrance, 1992). Water quality benefits of maintaining trees and other vegetation on farms and ranches are realized by reducing runoff, maintaining long-term water cycle, and recharging ground water aquifers (Wu *et al.,* 2001; Stednick, 1996). Soil physical properties, namely infiltration rate, pore space and water holding capacity improved with tree planting. Soil organic carbon and available nutrients increased, while soil pH decreased with tree planting. Bhardwaj *et al.* (2001) studied the influence of tree density of *Populus deltoids* on soil properties. They observed that organic carbon content in the soil decreased with decrease in density, and also an increase was observed in nitrogen, phosphorus and potassium content of the soil with increase in density.

MATERIALS AND METHODS

MATERIALS AND METHODS

The present study entitled "Forage yield, soil fertility and carbon dynamics of calliandra (*Calliandra calothyrsus* Meissn.) in coconut plantation" was carried out at Instructional Farm, College of Horticulture, Vellanikkara during the year 2016-2017. The major objective of the study was to assess the influence of tree density and pruning interval on forage yield and carbon storage potential of three-year old calliandra intercropped in coconut gardens. The study also explored the variation in coconut productivity and soil fertility changes associated with intercropping calliandra in coconut plantations.

3.1 LOCATION

The proposed study forms part of a pre-existing field trial involving intercropping of calliandra in mature coconut plantation (7.6 x 7.6 m spacing), located at Instructional Farm, College of Horticulture, Vellanikkara, established during 2014-2015. The performance of the fodder tree was evaluated under varying management regimes of tree densities and pruning intervals.

3.2 CLIMATE AND SOIL

Vellanikkara experiences a warm humid climate. The area is benefited both by the southwest and northeast monsoons, with a greater share from southwest monsoon. The mean maximum temperature ranged from 29.8 to 36.1^0 C in the months of June and March respectively. While the mean minimum temperature varied from 21.6 to 26.2^0 C in the months of July and April respectively. The soil of experimental site was deep well drained sandy clay loam of Ultisol order (Typic plinthustult – Vellanikkara series midland laterite – Ustic moisture regimes (dry period – February to May) and Isohyperthermic temperature regimes). Initial soil tests indicated acidic soil reaction (pH: 5.5), with medium levels of organic carbon (1.2%), available nitrogen (0.16 g kg^{-1}), exchangeable potassium (0.11 g kg^{-1}) and low level of phosphorus (3.39 mg kg^{-1}).

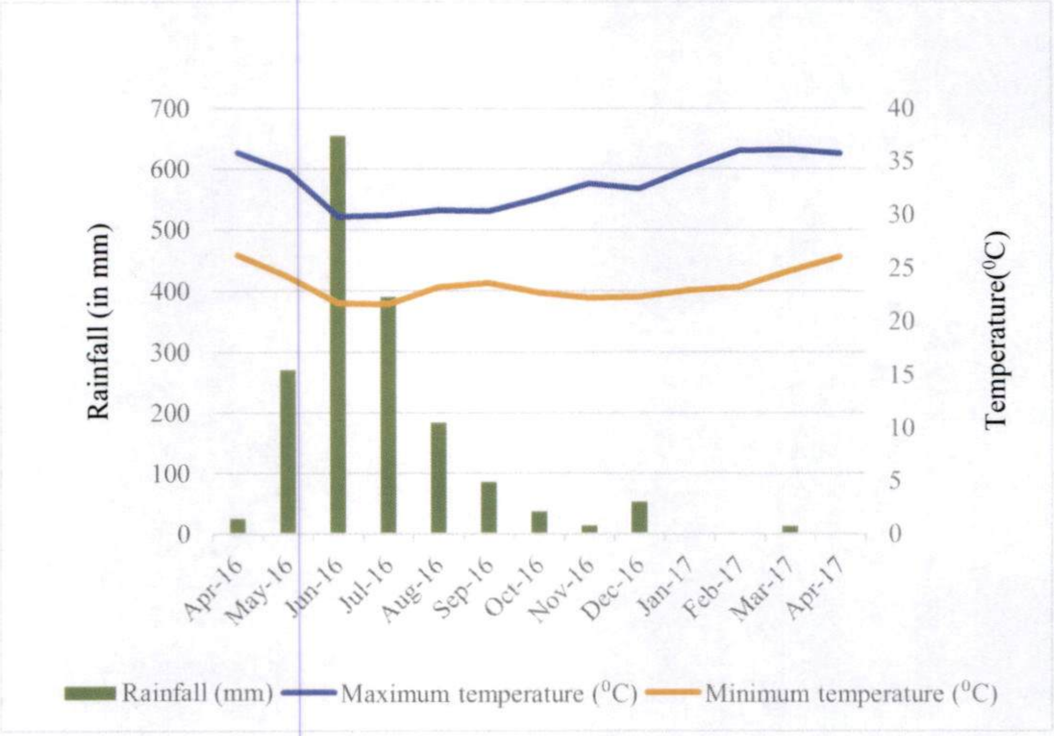

Fig. 1. Mean monthly rainfall and temperature data from April 2016 – April 2017 at Vellanikkara, Kerala

3.3 MATERIALS

3.3.1 Crop

The fodder tree, Calliandra (*Calliandra calothyrsus* Meissn) was intercropped in the interspaces of coconut variety, West Coast Tall, aged 37 years in this study.

3.3.1.1 *Calliandra*

Calliandra (*Calliandra calothyrsus* Meissn.) is a multipurpose fast growing leguminous tree native to Central America and Mexico, and naturalized throughout the tropics. The tree has multifarious uses as the provision of fodder for ruminants, green manure, fuel wood, shade, land rehabilitation, erosion control, and honey production (Palmer *et al.,* 1995). It is adapted to areas with annual precipitation between 1000 and 4000 mm, mean annual temperature above 20°C, and elevations up to 1800 meters. Calliandra has particular relevance in the humid tropics and on acidic soils where other agroforestry trees fail to perform well (Powell, 1995). The dry matter component of the total edible portion of the forage contains about 24% crude protein (Paterson *et al.,* 1998). For dairy cows, 1 kg of concentrate feed can be successfully replaced by 3 kg of fresh calliandra fodder (Paterson *et al.,* 1996; Pye-Smith, 2010).

3.3.2 Manures and fertilizers

Farm yard manure (FYM) at the rate of 20 Mg ha^{-1} and N, P_2O_5 and K_2O each at the rate of 50 kg ha^{-1} were applied uniformly for all treatments. FYM was applied as a basal dose before the onset of south west monsoon. Fertilizers were applied through N: P: K mixture (18: 18: 18) in two split doses before onset of south west and north-east monsoons.

3.4 METHODS

The field experiment was superimposed on an existing intercropping trial involving calliandra interplanted with coconut (7.6 x 7.6 m spacing), at varying tree densities and pruning intervals established during 2014-2015. The experimental details of the initial trial were as follows:

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3.4.1 Design and layout of the experiment

Experimental design : Factorial RBD (Randomized Block Design)

Number of treatments : 9

Number of replications : 3

Size of each plot : 4 m x 3 m

3.4.2 Details of treatments

The treatments consisted of two management factors; tree density and pruning frequency at three levels each, in all possible combinations, the details of which are given below.

3.4.2.1 Factors

3.4.2.1.1 Tree density (3 levels)

D1 – 27,777 plants ha^{-1} (60 x 60 cm)

D2 –22,222 plants ha^{-1} (75 x 60 cm)

D3 – 17,777 plants ha^{-1} (75 x 75 cm)

3.4.2.1.2 Pruning interval (3 levels)

I1 – 8 weeks interval

I2 – 12 weeks interval

I3 – 16 weeks interval

The layout plan of the trial is shown in the figure below.

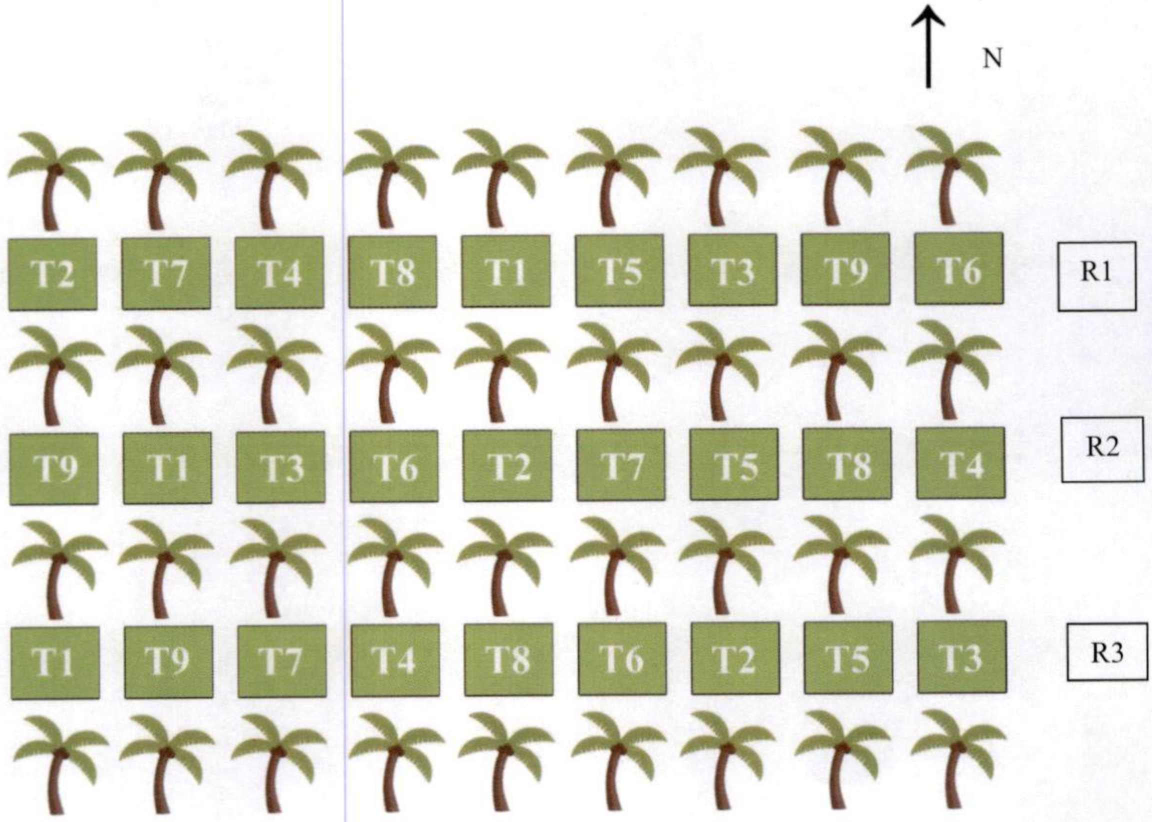


Fig. 2. Layout plan of the field trial

Treatment combinations

T1 – D1I1

T2 – D2I1

T3 – D3I1

T4- D1I2

T5- D2I2

T6- D3I2

T7- D1I3

T8- D2I3

T9- D3I3

D1, D2 and D3 – Tree densities of 27,777,22,222 and 17,777 trees ha^{-1}

I1, I2 and I3 – Pruning frequencies of 8, 12 and 16 weeks interval.

R - Replication

3.4.3 Field culture

The intercropping trial of calliandra in coconut was established during April 2014. The field area (excluding coconut basin of 2 m radius) was ploughed twice and the layout was done allocating a plot size of 4 m x 3 m (12 sq.m) for each treatment. Pits were taken at prescribed spacing for each treatment and seedlings of 3-month-old calliandra seedlings were transplanted to the main field with the onset of pre-monsoon showers. Manures and fertilizers were applied each year as detailed in 3.3.2. Plants were weeded as and when required. Irrigation was given at weekly intervals during summer months.

3.4.4 Harvesting of fodder

After attaining a height over 1 m, an initial uniform cut was given to all plants in June 2014, at 1m height from the ground . Subsequent cuttings were taken as per harvest intervals and annually six, four and three cuts were given for intervals of 8, 12 and 16 weeks respectively, for a period of three years.

3.5 OBSERVATIONS

Observations on the yield parameters of three-year-old calliandra was recorded during 2016-17. Data on the fodder yield during the first and second year of growth was collected from the previous harvest observations during 2014-16.

3.5.1 Annual green fodder yield

Biomass from 5 trees/ plot avoiding border plants was measured directly at each harvest. Biomass was separated into leaf, edible green stem and inedible brown stem and their individual fresh weights and total biomass was determined. Thereafter, yield from all harvests in a year was pooled to get annual yields and using the net harvested area and fresh weight, annual green fodder yield was scaled to the area of calliandra under one-hectare coconut garden. The area under calliandra in one-hectare coconut garden is 7827 sq. m, after excluding the functional area of coconut palms, in a radius of 2 m around its basin. The yield observations were collected for three years from June 2014 to 2017.

3.5.2 Annual dry fodder yield

Three sub-samples taken from the leaf and stem samples of calliandra of each harvest were oven-dried at 70^0C for 48 hours for dry matter (DM) determination. The fresh fodder yields from each harvest were multiplied with the DM content, summed up to get annual dry fodder yield and was expressed on hectare basis as described above.

3.5.3 Leaf – stem ratio

The annual dry leaf yield was divided with annual dry stem yield for various treatments and expressed as leaf-stem ratio.

3.5.4 Survival percentage of trees for various treatments

Number of trees in each treatment plot was counted after the experimental period and survival percentage was calculated.

3.5.5 Incidence of pest and diseases

No serious pest and disease incidence was noticed in calliandra during the experimental period.

3.5.6 Annual coconut yield per hectare

Bimonthly records of nut yield were taken from palms with and without calliandra and annual yield was estimated and expressed on hectare basis.

Calliandra intercropped in coconut garden

A bunch of harvested fodder

Edible foliage

Edible green stem

Inedible brown stem

Plate 1. Harvested biomass of calliandra intercropped in coconut plantation, Vellanikkara, Kerala

Quadrat Sampling

Stump biomass

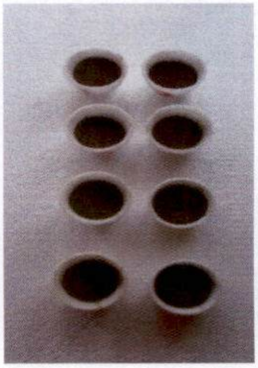
Soil Profile

Core Sampling

Root biomass

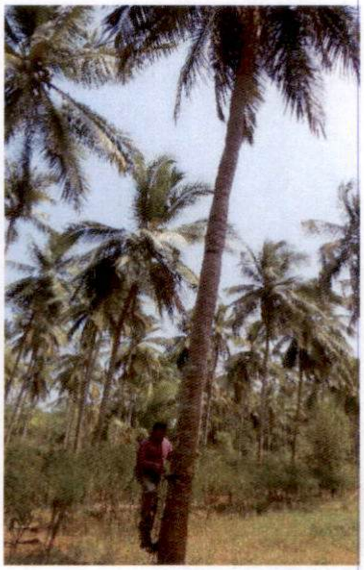
Carbon estimation in muffle furnace

Powdered stem sample for carbon estimation



Powdered leaf sample for carbon estimation

Plate 2. Estimation of carbon stocks in calliandra at Vellanikkara, Kerala



Different size classes of existing nuts on coconut palms

Taking observation from coconut palms

Taking biomass readings of leaf of coconut palms

Analysis of nitrogen in soil

Digestion chamber

Soil nutrient analysis

Plate 3. Estimation of carbon stocks in coconut palms and soil nutrient analysis at Vellanikkara, Kerala

3.5.7 Assessment of carbon storage potential of calliandra - coconut intercropping system

3.5.7.1 Above ground harvested dry fodder biomass during three-year period

The above ground harvested fodder dry fodder biomass from various treatments of calliandra during three-year period was estimated by pooling the annual dry fodder yield of the corresponding treatments during three years and scaled to hectare basis.

3.5.7.2 Above ground fresh and dry standing biomass of callliandra

As calliandra was harvested at 1m height from the ground, the left over woody stump constitutes the above ground standing biomass of calliandra. A quadrat (1 sq. m) from each plot excluding border plants was selected for taking observations on standing biomass. The standing biomass from calliandra in various plots at the end of the 3-year period was collected through destructive sampling and their fresh weight determined in the same manner as that of harvested biomass and scaled to hectare basis. Then sub samples taken from the fresh standing biomass samples were oven-dried at 70^0C for 48 hours for dry matter (DM) determination and dry standing biomass per hectare for various treatments were estimated.

3.5.7.3 Below ground fresh and dry root biomass

The soil below the quadrats used for taking plant observation was excavated to 1 m depth to record the root biomass from 1cu.m volume of the soil. The roots were pulled out completely, washed to remove the soil and fresh weight was determined. The mean fresh root weight was multiplied with the allotted area in the different treatments and was expressed as fresh root biomass production on hectare basis. After recording root fresh weights, the sub samples were dried to constant weights at 70^0 C for dry matter determination and was expressed on hectare basis.

3.5.7.4 Carbon stocks in the whole plant biomass of calliandra

The oven dried plant samples (leaves, stem and roots fractions of fodder trees) were ground thoroughly to pass through 2 mm sieve and used for analyzing the carbon concentrations in the various tissue types, by igniting in muffle furnace at 550^0 C for 6 hours (Gaur, 1975). Carbon content in the individual tissue types were multiplied with the corresponding component dry biomass (Nair *et al.*, 2010) and summed up to calculate the overall plant carbon stocks of various treatments. This was also computed on hectare basis.

3.5.7.5 Carbon stocks in coconut palms

Carbon stocks in the intercropped coconut palms and sole coconuts were estimated by compiling carbon content in the coconut bole, leaves, harvested nuts in the third year and existing nuts in the palms, as detailed below. Due to practical difficulties in estimating root biomass, carbon stocks in roots were not assessed.

At the end of the experiment, the intercropped palms and the sole coconut palms were climbed to count the number of nuts in each developing bunch (9-10 bunches per palm). In each bunch, the dry weight per nut was estimated destructively by taking triplicate samples. The dry weight of each bunch was estimated by the mean nut weight and number of nuts per bunch and the total dry weight of nuts on a palm was obtained by summing the weight of all the bunches. The carbon content of the dry mass was assumed to be 0.5 g C g_{DM}^{-1} (Matthews, 1993; Navarro *et al.*, 2008). Carbon stocks in the harvested nuts were also estimated destructively using triplicate samples in the similar manner.

According to George (2017), the average oven dry density for the stem portion of coconut palms of variety West Coast Tall of age 37 years in Ollukkara block and Malayoram agroclimatic zone of Thrissur district of Kerala is 509.60 kg m^{-3}. The stem dry weight of a palm was estimated by multiplying the volume of the stem with the density (the shape of the coconut stem was assumed to be cylindrical and tapering of the stem towards the top was not taken into account). The bole height and the girth of the coconut palms were measured using Haga altimeter and measuring tape respectively and the corresponding volume was calculated using mathematical formula.

Dry weight of total fronds per palm was estimated by using the actual dry weight (dry) of the most mature frond and the crown leaf load (Navarro *et al.*, 2008). The carbon content of the dry mass was assumed to be 0.5 g C g_{DM}^{-1} (Matthews, 1993; Navarro *et al.*, 2008). The total carbon stock per ha was determined by extrapolating the stock per palm for 173 palms.

3.5.7.6 Soil carbon stocks

The soil sampling was done from the same 1 sq. m quadrats that were taken for recording plant observations. The soil below the quadrats was excavated to 1 m depth, and soil samples were collected from five soil depths (0-20 cm, 21-40 cm, 41-60 cm, 61-80 cm and 81-100 cm) from each plot. A total of 27 soil profile pits were excavated for taking soil samples of 9 treatments. Triplicate samples were collected from different depths, with sample size in proportion to their area and mixed to get the composite sample. Sub sample from the composite sample were used for carbon analysis by using Walkley and Black's permanganate oxidation method (Walkley and Black, 1934). Also, triplicate soil samples were collected at different depths from control plots (sole coconut plantation) to get the composite sample and subsamples were used for analysis.

Soil samples were collected separately from all the soil depths using a core sampler for estimation of bulk density. Soil mass for each soil depth was computed from the bulk density and soil C sequestration calculated for each soil depth by multiplying soil mass with soil organic C-content (%) (Anderson and Ingram, 1989). Soil carbon stocks in individual soil depths were summed up to get the overall soil carbon sequestration under various treatments.

3.5.8 Soil analysis

To study the comparative changes in soil physical properties and nutrient contents of different treatments, triplicate samples drawn from composite samples at various depths as detailed above were analysed for pH, bulk density, water holding capacity and soil total and available N, P and K contents following standard analytical methods.

3.7.8.1 Soil physical properties

3.7.8.1.1 Bulk density

Bulk density was estimated by taking out a core of undisturbed soil by using a core sampler (Gupta and Dhakshinamurthi, 1980). The core was taken out without pressing the cylinder too hard on soil so that the natural bulk density of soil may not get disturbed. The soil was oven dried and weight was determined. The volume of soil was calculated by measuring the volume of cylinder ($\pi r^2 h$). The bulk density was calculated by dividing the oven dry weight of soil samples (g) by volume of soil.

3.7.8.1.2 Water holding capacity (WHC)

A known quantity of soil was allowed to fully saturate and equilibrate with water and from the water held in the soil after free draining, the water holding capacity was determined (Jackson, 1958).

$$\text{WHC on dry basis (\%)} = \frac{\text{Saturated weight (g) - Dry weight (g)} \times 100}{\text{Dry weight (g)}}$$

3.7.8.1.3 Soil pH

Soil pH was calculated using an aqueous suspension of soil (soil and water in 1:2.5 ratio) using an Elico pH meter (Model Li 613) as described by Jackson (1973).

3.7.8.2 Soil nutrient analysis

3.7.8.2.1 Total nitrogen

The total nitrogen concentration in the soil was determined by digesting 1g of soil in 5ml of sulphuric acid in presence of digestion mixture (Na_2SO4: CuSO4: Selenium in 10: 4: 1 ratio) and the N concentration in the digest was determined by micro kjeldhal method (Jackson, 1958)

3.7.8.2.2 Available nitrogen

Available nitrogen in soil was determined by alkaline permanganate method (Subbiah and Asija, 1956).

3.7.8.2.3 Total phosphorus

Total phosphorus was extracted by di-acid digestion and then estimated colorimetrically by vanadomolybdate (blue colour) method. The extracted P was estimated using spectrophotometry.

3.7.8.2.4 Available phosphorus

Available phosphorus was extracted using Bray-I extractant (Bray and Kurtz, 1945) and the P concentration was colorimetrically assayed (Chloromolybdic acid blue colour method). The reducing agent was ascorbic acid (Jackson, 1973).

3.7.8.2.5 Total potassium

Total potassium was extracted by di-acid digestion (9:4 mixture HNO3: HclO4) and potassium in soil extract was estimated by flame photometer method.

3.7.8.2.6 Available potassium

Available potassium was determined by flame photometry using 1 N neutral normal ammonium acetate solution as the extractant (Jackson, 1973). All nutrient concentrations were expressed on oven dry basis.

3.5.9 Economics

Cost of cultivation for various systems and the returns from the economical yield were used for the calculation of B:C ratio.

3.5.10 Statistical analysis

The data were subjected to statistical analysis by analysis of variance (ANOVA) in SPSS version 21.0 (SPSS Inc., USA) to ascertain the significance of various parameters. The Duncan's Multiple Range Test (DMRT) was used to test the differences among treatment means at 5% significance level.

RESULTS

RESULTS

The study on Forage yield, soil fertility and carbon dynamics of calliandra (*Calliandra calothyrsus* Meissn.) in coconut plantation carried out at Vellanikkara revealed significant information on the influence of tree density and pruning interval on forage yield and carbon storage potential of three-year old calliandra intercropped in coconut gardens. The study also explored the variation in coconut productivity and soil fertility changes associated with intercropping calliandra in coconut plantations. The salient results are presented hereunder.

4.1 EFFECT OF TREE DENSITY AND PRUNING INTERVAL ON FODDER YIELD OF CALLIANDRA UNDER COCONUT PLANTATION

4.1.1 Survival percentage of fodder trees as influenced by tree density and pruning interval

The data given in table 1 and 2 indicates the survival percentage of fodder trees under varying tree densities and pruning intervals. Tree density as well as pruning interval had no significant effect on survival percentage of fodder trees. However, comparatively lower survival percentage (94.82 %) was observed at higher tree density (27,777 plants ha^{-1}). On comparing different treatments, survival percentage ranged between 94-97%, but was not statistically significant.

4.1.2 Annual fresh fodder yield

Main effect of tree densities and pruning intervals on annual fresh fodder yield are given in table 1. Tree density had significant effect on fodder yield. Total fodder yield increased from 43.44 to 55.40 Mg ha^{-1} yr^{-1} from lower to higher tree density classes. Total fodder yield of lower two tree densities, 22,222 plants ha^{-1} (45.13 Mg ha^{-1} yr^{-1}) and 17,777 plants ha^{-1} (43.44 Mg ha^{-1} yr^{-1}) were found to be on par. The leaf and edible stem fractions also showed the similar trend.

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On the other hand, pruning intervals had significant effect on different kinds of stem fractions rather than the edible fodder yield. The total stem yield varied significantly between 16.72 Mg ha^{-1} yr^{-1} (8 weeks interval) to 26.41 Mg ha^{-1} yr^{-1} (16 weeks interval). Highest leaf yield was obtained for 12 weeks pruning interval (27.21 Mg ha^{-1} yr^{-1}), but was not statistically significant. In general, edible forage fraction was found to be higher in shorter pruning intervals of 8 and 12 weeks, than the longer interval.

Interaction effect of tree densities and pruning intervals showed no significant effect on forage yield of calliandra (Table 2). On comparing the various fractions of fodder biomass, maximum leaf, edible stem, inedible stem and total fodder yield was obtained as 31.57 Mg ha^{-1} yr^{-1} (27,777 plants ha^{-1} + 12 weeks pruning interval), 15.22 Mg ha^{-1} yr^{-1} (27,777 plants ha^{-1} + 8 weeks pruning interval), 19.99 Mg ha^{-1} yr^{-1} (27,777 plants ha^{-1} + 16 weeks pruning interval) and 59.63 Mg ha^{-1} yr^{-1} (27,777 plants ha^{-1} + 16 weeks pruning interval) respectively.

4.1.3 Annual dry fodder yield and leaf-stem ratio

Table 3 depicts the effect of tree densities and pruning intervals on annual fractional and total dry fodder yield and leaf-stem ratio of calliandra. Plant density had statistically significant effect on leaf and edible stem yield. Highest leaf yield was obtained for the highest tree density of 27,777 plants ha^{-1} and the other two lower tree densities were found to be on par. Similar trend was observed in different stem fractions also. Total dry fodder yield increased from 13.87 to 16.97 Mg ha^{-1} yr^{-1} from the lowest to the highest density. Even though leaf-stem ratio declined with decreasing tree density, differences were not statistically significant.

Pruning interval showed profound influence on dry fodder yield of stem fractions. Total stem yield increased with longer pruning intervals from 4.10 Mg ha^{-1} yr^{-1} (8 weeks) to 9.88 Mg ha^{-1} yr^{-1} (16 weeks). Total dry fodder yield also increased from 11.13 to 18.41 Mg ha^{-1} yr^{-1} from shorter to longer pruning intervals. Cutting interval had no significant effect on dry leaf fodder yield. Leaf-stem ratio showed significant variation under different pruning intervals, with highest leaf-stem ratio (1.74) under shortest pruning interval (8 weeks) and presented a declining trend at prolonged cutting intervals.

Table 4 shows the effect of different treatment combinations on fractional and total dry fodder yield and leaf-stem ratio of calliandra. Among various treatments, highest leaf, edible stem, inedible stem and total dry fodder yield were recorded as 9.89 Mg ha^{-1} yr^{-1}(27,777 plants ha^{-1} + 12 weeks pruning interval), 3.95 Mg ha^{-1} yr^{-1}(27,777 plants ha^{-1} + 12 weeks pruning interval), 7.87 Mg ha^{-1} yr^{-1}(27,777 plants ha^{-1} + 16 weeks pruning interval) and 20.50 Mg ha^{-1} yr^{-1}(27,777 plants ha^{-1} + 16 weeks pruning interval) respectively.

Comparing dry edible stem fodder yield and leaf yield, the best management practice in calliandra is to plant at closer spacing and practice pruning at an interval of 12 weeks. Even though maximum total annual dry fodder yield was obtained for 16 weeks and highest planting density, highest amount of palatable fodder comprising of leaf and edible stem was reported for highest planting density and 12 weeks cutting interval.

4.2.1 Harvested dry fodder biomass from calliandra over three -year period

Main effect of tree densities and pruning intervals on harvested dry fodder biomass from calliandra over three- year period is given in table 5. Leaf, stem and total dry fodder biomass (6.55, 7.31 and 13.86 Mg ha^{-1} yr^{-1} respectively) was significantly higher for the highest tree density during the first year. Similar trend was also observed during the second year (8.23, 7.45 and 15.68 Mg ha^{-1} yr^{-1} of leaf, stem and total dry yield respectively for the highest density stand), but differences were not significant among the density classes.

Table 1. Effect of tree density and pruning interval on survival percentage and annual fresh fodder yield of calliandra under coconut plantation at Vellanikkara, Thrissur, Kerala

Factors	Survival %	Fractional and total fresh fodder biomass (Mg ha^{-1} yr^{-1})				
		Leaf	Edible stem	Inedible stem	Total stem	Total fodder
Tree density						
27,777 plants ha^{-1} (D1)	94.82 (±0.59)	29.99^{a} (±1.69)	13.74^{a} (±1.24)	11.67 (±2.70)	25.41 (±2.55)	55.40^{a} (±3.74)
22,222 plants ha^{-1} (D2)	96.89 (±0.89)	25.23^{b} (±1.31)	10.37^{b} (±0.68)	9.52 (±1.89)	19.90 (±1.78)	45.13^{b} (±2.88)
17,777 plants ha^{-1} (D3)	96.67 (±0.83)	23.49^{b} (±1.27)	10.06^{b} (±0.94)	9.90 (±1.98)	19.96 (±2.13)	43.44^{b} (±3.10)
F value	1.62^{ns}	4.81^{*}	5.56^{*}	0.66^{ns}	3.04^{ns}	3.98^{*}
p value	0.23	0.02	0.02	0.53	0.08	0.04
Pruning interval						
8 weeks (I1)	96.15 (±0.82)	25.79 (±1.53)	12.02^{a} (±1.10)	4.70^{c} (±0.39)	16.72^{b} (±1.37)	42.52 (±2.74)
12 weeks (I2)	96.07 (±0.90)	27.21 (±1.94)	12.95^{a} (±0.94)	9.17^{b} (±0.90)	22.13^{ab} (±1.73)	49.33 (±3.57)
16 weeks (I3)	96.15 (±0.82)	25.70 (±1.65)	9.20^{b} (±0.93)	17.22^{a} (±2.02)	26.41^{a} (±2.43)	52.12 (±4.00)
F value	0.00^{ns}	0.30^{ns}	5.09^{*}	20.10^{**}	7.15^{**}	2.32^{ns}
p value	1.00	0.74	0.02	<0.001	<0.01	0.13

** significant at $p<0.01$, * significant at $p<0.05$, ns= not significant at $p>0.05$, values with the same superscripts in a column do not differ significantly, values in parenthesis are standard error of means

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Table 2. Interaction effect of tree density and pruning interval on survival percentage and annual fresh fodder yield of calliandra under coconut plantation at Vellanikkara, Thrissur, Kerala

Treatments	Survival %	Fractional and total fresh fodder biomass (Mg ha^{-1} yr^{-1})				
		Leaf	Edible stem	Inedible stem	Total stem	Total fodder
Tree density X Pruning interval						
D1 X I1	94.44 (±1.11)	30.08 (±3.12)	15.22 (±2.25)	4.91 (±0.81)	20.13 (±3.05)	50.22 (±5.69)
D1 X I2	95.56 (±1.11)	31.57 (±3.68)	14.68 (±2.37)	10.10 (±2.34)	24.78 (±4.54)	56.35 (±8.07)
D1 X I3	94.44 (±1.11)	28.30 (±2.90)	11.33 (±1.82)	19.99 (±4.78)	31.32 (±4.03)	59.63 (±6.89)
D2 X I1	97.33 (±1.33)	23.24 (±1.06)	10.57 (±1.03)	4.40 (±1.02)	14.96 (±2.05)	38.20 (±2.58)
D2 X I2	96.00 (±2.31)	26.45 (±3.74)	12.18 (±0.90)	8.64 (±1.77)	20.81 (±2.65)	47.26 (±6.39)
D2 X I3	97.33 (±1.33)	26.00 (±1.57)	8.37 (±0.30)	15.54 (±2.69)	23.91 (±2.44)	49.91 (±3.82)
D3 X I1	96.67 (±1.67)	24.05 (±1.81)	10.28 (±0.90)	4.79 (±0.21)	15.08 (±0.68)	39.13 (±2.49)
D3 X I2	96.67 (±1.67)	23.60 (±1.24)	12.00 (±1.38)	8.79 (±0.77)	20.79 (±1.70)	44.39 (±2.81)
D3 X I3	96.67 (±2.67)	22.80 (±3.750	7.89 (±1.89)	16.12 (±3.64)	24.01 (±5.51)	46.81 (±9.26)
F value	0.21^{ns}	0.28^{ns}	0.19^{ns}	0.22^{ns}	0.10^{ns}	0.04^{ns}
p value	0.93	0.89	0.94	0.92	0.98	1.00

** significant at $p<0.01$, * significant at $p<0.05$, ns= not significant at $p>0.05$, values with the same superscripts in a column do not differ significantly, values in parenthesis are standard error of means, D1 – 27,777 plants ha^{-1}, D2 – 22,222 plants ha^{-1}, D3 – 17,777 plants ha^{-1}, I1 – 8 weeks, I2 – 12 weeks, I3 – 16 weeks pruning interval

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Table 3. Effect of tree density and pruning interval on annual dry fodder yield and leaf-stem ratio of calliandra under coconut plantation at Vellanikkara, Thrissur, Kerala

Factors	Fractional and total dry fodder biomass (Mg ha^{-1} yr^{-1})					Leaf-stem ratio
	Leaf	Edible stem	Inedible stem	Total stem	Total fodder	
Tree density						
27,777 plants ha^{-1} (D1)	9.04^a (±0.43)	3.60^a (±0.29)	4.33 (±1.08)	7.93 (±1.08)	16.97 (±1.34)	1.29 (±0.16)
22,222 plants ha^{-1} (D2)	7.69^b (±0.54)	2.72^b (±0.17)	3.62 (±0.83)	6.33 (±0.89)	14.02 (±1.37)	1.34 (±0.13)
17,777 plants ha^{-1} (D3)	7.28^b (±0.54)	2.74^b (±0.29)	3.86 (±0.88)	6.60 (±1.00)	13.87 (±1.47)	1.24 (±0.15)
F value	3.93^*	4.41^*	0.45^{ns}	1.98^{ns}	2.9^{ns}	0.44^{ns}
p value	0.04	0.03	0.65	0.17	0.08	0.65
Pruning interval						
8 weeks (I1)	7.02 (±0.41)	2.58^b (±0.21)	1.52^c (±0.12)	4.10^c (±0.27)	11.13^c (±0.61)	1.74^a (±0.10)
12 weeks (I2)	8.46 (±0.59)	3.56^a (±0.22)	3.31^b (±0.34)	6.87^b (±0.52)	15.33^b (±1.03)	1.24^b (±0.07)
16 weeks (I3)	8.53 (±0.53)	2.91^{ab} (±0.33)	6.98^a (±0.76)	9.88^a (±0.85)	18.41^a (±1.34)	0.88^c (±0.04)
F value	3.34^{ns}	4.33^*	26.05^{**}	22.41^{**}	12.71^{**}	34.05^{**}
p value	0.06	0.03	<0.001	<0.001	<0.001	<0.001

** significant at $p<0.01$, * significant at $p<0.05$, ns= not significant at $p>0.05$, values with the same superscripts in a column do not differ significantly, values in parenthesis are standard error of means

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Table 4. Interaction effect of tree density and pruning interval on annual dry fodder yield and leaf-stem ratio of calliandra under coconut plantation at Vellanikkara, Thrissur, Kerala

Treatments	Fractional and total dry fodder biomass (Mg ha^{-1} yr^{-1})					Leaf-stem ratio
	Leaf	Edible stem	Inedible stem	Total stem	Total fodder	
Tree density X Pruning interval						
D1 X I1	8.15 (±0.76)	3.30 (±0.29)	1.55 (±0.25)	4.85 (±0.53)	13.00 (±1.08)	1.71 (±0.21)
D1 X I2	9.89 (±0.83)	3.95 (±0.53)	3.58 (±0.85)	7.53 (±1.29)	17.42 (±1.97)	1.36 (±0.18)
D1 X I3	9.07 (±0.47)	3.56 (±0.73)	7.87 (±1.65)	11.43 (±1.07)	20.50 (±1.52)	0.80 (±0.03)
D2 X I1	6.28 (±0.53)	2.27 (±0.17)	1.47 (±0.29)	3.74 (±0.46)	10.02 (±0.70)	1.72 (±0.24)
D2 X I2	8.17 (±1.21)	3.21 (±0.26)	3.05 (±0.73)	6.27 (±0.97)	14.43 (±2.18)	1.31 (±0.02)
D2 X I3	8.63 (±0.76)	2.66 (±0.12)	6.33 (±1.21)	8.99 (±1.18)	17.62 (±1.62)	0.98 (±0.09)
D3 X I1	6.64 (±0.45)	2.18 (±0.13)	1.54 (±0.16)	3.72 (±0.03)	10.37 (±0.42)	1.79 (±0.13)
D3 X I2	7.32 (±0.58)	3.54 (±0.31)	3.29 (±0.27)	6.82 (±0.45)	14.14 (±0.95)	1.07 (±0.06)
D3 X I3	7.88 (±1.60)	2.50 (±0.63)	6.75 (±1.44)	9.24 (±2.06)	17.12 (±3.66)	0.86 (±0.02)
F value	0.41^{ns}	0.24^{ns}	0.17^{ns}	0.18^{ns}	0.02^{ns}	0.82^{ns}
p value	0.80	0.91	0.95	0.95	1.00	0.53

** significant at $p<0.01$, * significant at $p<0.05$, ns= not significant at $p>0.05$, values with the same superscripts in a column do not differ significantly, values in parenthesis are standard error of means, D1 – 27,777 plants ha^{-1}, D2 – 22,222 plants ha^{-1}, D3 – 17,777 plants ha^{-1}, I1 – 8 weeks, I2 – 12 weeks, I3 – 16 weeks pruning interval

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Third year observations also proved that highest tree density yielded maximum leaf, stem and total dry fodder biomass (9.04, 7.93 and 16.97 Mg ha^{-1} yr^{-1} respectively), with statistical significance only for the leaf yield, which was on par with that of the medium density stand (7.69 Mg ha^{-1} yr^{-1}). In addition, the data also reveals the improvement in forage yield of calliandra from 13.86 to 16.97 Mg ha^{-1} yr^{-1} with the advance of age over the three-year period.

Pruning interval has profound influence on stem and total dry fodder biomass during first year of study. Stem and total dry fodder biomass of 16 weeks interval (8.87 and 14.24 Mg ha^{-1} yr^{-1} respectively) proved to be statistically significant over the other two cutting intervals that were statistically comparable. During second year of study, pruning interval had significant effect on stem dry fodder biomass only. Stem dry fodder biomass of 16 weeks cutting interval (8.03 Mg ha^{-1} yr^{-1}) was significantly superior to other intervals. Observations on third year revealed statistically superior stem and total dry fodder biomass (9.88 and 18.41 Mg ha^{-1} yr^{-1} respectively) for the longest pruning interval. Even though leaf yield was maximum for the longest pruning interval during all the three years of observation (5.37, 7.87 and 8.53 Mg ha^{-1} yr^{-1} respectively), there was no statistical significance among different intervals.

Table 6 shows the interaction effect of different treatment combinations on harvested dry fodder biomass over three - year period. During first year, highest leaf dry fodder biomass was reported for the combination of 27,777 plants ha^{-1} and 12 weeks pruning interval (7.32 Mg ha^{-1} yr^{-1}) and highest stem and total dry fodder biomass (10.97 and 16.99 Mg ha^{-1} yr^{-1} respectively) was recorded for 27,777 plants ha^{-1} and 16 weeks pruning interval. Among various treatments, maximum stem and total dry fodder biomass of second (10.00 and 19.31 Mg ha^{-1} yr^{-1} respectively) and third year (11.43 and 20.50 Mg ha^{-1} yr^{-1} respectively) was obtained for the combination of 27,777 plants ha^{-1} and 16 weeks pruning interval. In the case of leaf dry fodder biomass, maximum production during first year (9.30 Mg ha^{-1} yr^{-1}) was observed for the combination of 27,777 plants ha^{-1} and 8 weeks pruning interval and that for third year of study (9.89 Mg ha^{-1} yr^{-1}) was reported for 27,777 plants ha^{-1} and 12 weeks pruning interval.

Table 11 represents the main effect of tree density and pruning interval on pooled harvested dry fodder biomass over three years period. Maximum pooled harvested dry fodder biomass (46.51 Mg ha^{-1}) was obtained for highest tree density, that was statistically significant and the values of other two lower densities were comparable. Highest pooled harvested dry fodder biomass (48.55 Mg ha^{-1}) was obtained for longest pruning interval and was found to be on par with the value of 12 weeks cutting interval (39.94 Mg ha^{-1}).

Table 12 depicts the effect of different treatments on pooled harvested dry fodder biomass over three- year period. Maximum pooled harvested dry fodder biomass over three years period (56.80 Mg ha^{-1}) was obtained for the combination of 27,777 plants ha^{-1} and 16 weeks pruning interval.

4.2.2 Carbon content in harvested dry fodder biomass over- three-year period

Table 7 shows the main effect of tree density and pruning interval on carbon content in harvested dry fodder biomass over three years period. Tree density had significant effect on leaf, stem and total carbon content in harvested dry fodder biomass when observed during first year. Leaf, stem and total carbon content in harvested dry fodder biomass of highest tree density of planting (3.61, 4.06 and 7.67 Mg ha^{-1} yr^{-1} respectively) was superior to the other two lower tree densities. Even though the carbon content in harvested dry fodder biomass of leaf, stem and total fodder was maximum for highest tree density (4.54, 4.18 and 8.71 Mg ha^{-1} yr^{-1} respectively) during second year of study, they were not statistically significant.

Third year of observations also projected that highest tree density contained maximum leaf, stem and total carbon content in harvested dry fodder biomass (4.98, 4.45 and 9.43 Mg ha^{-1} yr^{-1} respectively), but only carbon content in leaf dry fodder biomass was statistically significant. Carbon content in leaf dry fodder biomass at medium tree density (4.25 Mg ha^{-1} yr^{-1}) was comparable to the other two higher and lower tree densities. Also, as the age advances, there was an increasing trend in storage of carbon in leaf, stem and total dry fodder biomass.

Pruning interval has prominent influence on stem and total carbon content in harvested dry fodder biomass during first year of study. Carbon content in stem and total harvested dry fodder biomass of 16 weeks interval (4.97 and 7.95 Mg ha^{-1} yr^{-1} respectively) proved to be statistically significant over the other two cutting intervals that were statistically comparable. During second year of study, pruning interval had significant effect on carbon content of stem dry fodder biomass only. Carbon in stem dry fodder biomass of 16 weeks cutting interval (4.54 Mg ha^{-1} yr^{-1}) was significantly superior to other intervals. Third year of observations recorded statistically superior carbon content in stem and total dry fodder biomass (5.59 and 10.33 Mg ha^{-1} yr^{-1} respectively) for the longest pruning interval compared to other intervals. Even though carbon in leaf dry fodder biomass was maximum for the longest pruning interval during the three years of observation (2.99, 4.37 and 4.74 Mg ha^{-1} yr^{-1} respectively), the differences were only marginal among the different intervals.

Table 8 shows the effect of various treatment combinations on carbon content of harvested dry fodder biomass over three-year period. During first year, highest carbon content in leaf dry fodder biomass was reported for the combination of 27,777 plants ha^{-1} and 12 weeks pruning interval (4.03 Mg ha^{-1} yr^{-1}) and highest carbon content in stem and total dry fodder biomass (6.14 and 9.49 Mg ha^{-1} yr^{-1} respectively) was recorded for 27,777 plants ha^{-1} and 16 weeks pruning interval. Among various treatments, maximum carbon content in stem and total dry fodder biomass of second (5.66 and 10.82 Mg ha^{-1} yr^{-1} respectively) and third year (6.46 and 11.50 Mg ha^{-1} yr^{-1} respectively) was obtained for the combination of 27,777 plants ha^{-1} and 16 weeks pruning interval. In the case of carbon stored in leaf dry fodder biomass, maximum storage during first year (5.16 Mg ha^{-1} yr^{-1}) was observed for the combination of 27,777 plants ha^{-1} and 16 weeks pruning interval and that for third year of study (5.45 Mg ha^{-1} yr^{-1}) was reported for 27,777 plants ha^{-1} and 12 weeks pruning interval.

Table 11 represents the main effect of tree density and pruning interval on carbon in pooled harvested dry fodder biomass over three-year period. Maximum carbon in pooled harvested dry fodder biomass (25.81 Mg ha^{-1}) was obtained for highest tree density, that was statistically significant and the values of other two lower densities were comparable. Highest carbon content in pooled harvested dry fodder biomass (27.20 Mg ha^{-1}) was obtained for longest pruning interval and the lowest value was obtained for 8 weeks cutting interval (16.21 Mg ha^{-1}).

Table 12 depicts the effect of different treatments on carbon in pooled harvested dry fodder biomass over three years period. Maximum carbon in pooled harvested dry fodder biomass over three years period (31.80 Mg ha^{-1}) was obtained for the combination of 27,777 plants ha^{-1} and 16 weeks pruning interval.

4.3 EFFECT OF TREE DENSITY AND PRUNING INTERVAL ON STANDING BIOMASS of CALLIANDRA UNDER COCONUT PLANTATION

4.3.1 Standing biomass

The total standing biomass includes the left-over stump biomass after harvest and the below ground root biomass. The main effect of tree density and pruning interval on standing biomass is depicted in table 9. Tree density had significant effect on stump as well as total fresh standing biomass, with highest values (20.64 and 23.13 Mg ha^{-1} respectively) for the highest tree density. Lowest values of 14.81 and 16.77 Mg ha^{-1} were recorded for the stump and total biomass of lowest tree density respectively. Medium tree density reported fresh stump and total biomass as 17.33 and 19.48 Mg ha^{-1} respectively and were found to be on par with the other two densities. Maximum fresh root biomass was obtained for highest tree density as 2.49 Mg ha^{-1}, but was not statistically significant among different classes.

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Table 5. Effect of tree density and pruning interval on fractional and total harvested dry fodder yield of calliandra over three-year period under coconut plantation at Vellanikkara, Thrissur, Kerala

Factors	Fractional and total harvested dry fodder yield over three years (Mg ha^{-1})								
	First year			Second year			Third year		
	Leaf	Stem	Total	Leaf	Stem	Total	Leaf	Stem	Total
Tree density									
27,777 plants ha^{-1} (D1)	6.55^{a}	7.31^{a}	13.86^{a}	8.23	7.45	15.68	9.04^{a}	7.93	16.97
22,222 plants ha^{-1} (D2)	4.78^{b}	5.60^{b}	10.38^{b}	6.92	5.84	12.76	7.69^{ab}	6.33	14.02
17,777 plants ha^{-1} (D3)	3.66^{b}	4.34^{b}	8.00^{b}	6.49	5.98	12.47	7.28^{b}	6.6	13.87
F value	6.94^{**}	10.65^{**}	13.46^{**}	1.39^{ns}	1.11^{ns}	1.33^{ns}	3.93^{*}	1.98^{ns}	2.9^{ns}
p value	<0.01	<0.01	<0.001	0.28	0.35	0.29	0.04	0.17	0.08
Pruning interval									
8 weeks (I1)	4.32	3.77^{b}	8.09^{b}	6.22	4.10^{b}	10.32	7.02	4.10^{c}	11.13^{c}
12 weeks (I2)	5.30	4.61^{b}	9.91^{b}	7.56	7.14^{a}	14.70	8.46	6.87^{b}	15.33^{b}
16 weeks (I3)	5.37	8.87^{a}	14.24^{a}	7.87	8.03^{a}	15.90	8.53	9.88^{a}	18.41^{a}
F value	1.13^{ns}	35.94^{**}	15.52^{**}	1.31^{ns}	5.93^{*}	3.59^{ns}	3.34^{ns}	22.41^{**}	12.71^{**}
p value	0.35	<0.001	<0.001	0.30	0.01	0.06	0.06	<0.001	<0.001

** significant at $p<0.01$, * significant at $p<0.05$, ns= not significant at $p>0.05$, values with the same superscripts in a column do not differ significantly, 1st and 2nd year data given above does not form the part of this study and the data given above is collected from the previous harvest observations taken under AICRPAF (All India Co-ordinated Research Project on Agroforestry), for the sake of comparison with 3rd year data and for estimation of carbon stocks

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Table 6. Interaction effect of tree density and pruning interval on fractional and total harvested dry fodder yield of calliandra over three-year period under coconut plantation at Vellanikkara, Thrissur, Kerala

Treatments	Fractional and total harvested dry fodder yield over three years (Mg ha^{-1})								
	First year			Second year			Third year		
	Leaf	Stem	Total	Leaf	Stem	Total	Leaf	Stem	Total
Tree density X Pruning interval									
D1 X I1	6.29	4.09	10.38	7.20	5.17	12.38	8.15	4.85	13.00
D1 X I2	7.32	6.87	14.20	8.18	7.18	15.36	9.89	7.53	17.42
D1 X I3	6.03	10.97	16.99	9.30	10.00	19.31	9.07	11.43	20.50
D2 X I1	3.77	3.85	7.63	6.44	4.57	11.01	6.28	3.74	10.02
D2 X I2	4.85	4.28	9.13	7.55	6.71	14.26	8.17	6.27	14.43
D2 X I3	5.72	8.67	14.39	6.77	6.25	13.02	8.63	8.99	17.62
D3 X I1	2.90	3.36	6.26	5.01	2.57	7.57	6.64	3.72	10.37
D3 X I2	3.73	2.68	6.42	6.94	7.53	14.47	7.32	6.82	14.14
D3 X I3	4.36	6.98	11.34	7.53	7.83	15.37	7.88	9.24	17.12
F value	0.51^{ns}	1.57^{ns}	0.53^{ns}	0.25^{ns}	0.75^{ns}	0.50^{ns}	0.41^{ns}	0.18^{ns}	0.02^{ns}
p value	0.73	0.23	0.72	0.91	0.58	0.74	0.80	0.95	1.00

** significant at $p<0.01$, * significant at $p<0.05$, ns= not significant at $p>0.05$, values with the same superscripts in a column do not differ significantly, D1 – 27,777 plants ha^{-1}, D2 – 22,222 plants ha^{-1}, D3 – 17,777 plants ha^{-1}, I1 – 8 weeks, I2 – 12 weeks, I3 – 16 weeks pruning interval, 1st and 2nd year data given above does not form the part of this study and the data given above is collected from the previous harvest observations taken under AICRPAF (All India Co-ordinated Research Project on Agroforestry), for the sake of comparison with 3rd year data and for estimation of carbon stocks

Table 7. Effect of tree density and pruning interval on fractional and total carbon content in harvested dry fodder biomass of calliandra over three-year period under coconut plantation at Vellanikkara, Thrissur, Kerala

Factors	Carbon content in fractional and total harvested fodder biomass over three years (Mg ha^{-1})								
	First year			Second year			Third year		
	Leaf	Stem	Total	Leaf	Stem	Total	Leaf	Stem	Total
Tree density									
27,777 plants ha^{-1} (D1)	3.61^{a}	4.06^{a}	7.67^{a}	4.54	4.18	8.71	4.98^{a}	4.45	9.43
22,222 plants ha^{-1} (D2)	2.64^{b}	3.10^{b}	5.75^{b}	3.82	3.27	7.09	4.25^{ab}	3.54	7.79
17,777 plants ha^{-1} (D3)	2.02^{b}	2.41^{b}	4.43^{b}	3.58	3.34	6.92	4.01^{b}	3.69	7.70
F value	6.88**	10.54**	13.32**	1.38^{ns}	1.12^{ns}	1.32^{ns}	3.82*	1.97^{ns}	2.85^{ns}
p value	<0.01	<0.01	<0.001	0.28	0.35	0.29	0.04	0.17	0.09
Pruning interval									
8 weeks (I1)	2.37	2.06^{b}	4.43^{b}	3.41	2.27^{b}	5.67	3.85	2.26^{c}	6.11^{c}
12 weeks (I2)	2.92	2.54^{b}	5.46^{b}	4.16	3.98^{a}	8.14	4.66	3.82^{b}	8.48^{b}
16 weeks (I3)	2.99	4.97^{a}	7.95^{a}	4.37	4.54^{a}	8.91	4.74	5.59^{a}	10.33^{a}
F value	1.26^{ns}	37.05**	16.50**	1.44^{ns}	6.17*	3.87^{ns}	3.44^{ns}	23.15**	13.53**
p value	0.31	<0.001	<0.001	0.27	0.01	0.04	0.06	<0.001	<0.001

** significant at $p<0.01$, * significant at $p<0.05$, ns= not significant at $p>0.05$, values with the same superscripts in a column do not differ significantly

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Table 8. Interaction effect of tree density and pruning interval on fractional and total carbon content in harvested dry fodder biomass of calliandra over three-year period under coconut plantation at Vellanikkara, Thrissur, Kerala

Treatments	Carbon content in fractional and total harvested fodder biomass over three years ($Mg\ ha^{-1}$)								
	First year			Second year			Third year		
	Leaf	Stem	Total	Leaf	Stem	Total	Leaf	Stem	Total
Tree density X Pruning interval									
D1 X I1	3.45	2.25	5.69	3.95	2.86	6.80	4.46	2.68	7.14
D1 X I2	4.03	3.79	7.82	4.50	4.01	8.52	5.45	4.20	9.65
D1 X I3	3.34	6.14	9.49	5.16	5.66	10.82	5.03	6.46	11.50
D2 X I1	2.06	2.10	4.17	3.53	2.53	6.06	3.44	2.06	5.50
D2 X I2	2.68	2.35	5.03	4.16	3.74	7.90	4.50	3.48	7.98
D2 X I3	3.19	4.86	8.05	3.77	3.53	7.30	4.81	5.08	9.89
D3 X I1	1.59	1.84	3.43	2.74	1.41	4.15	3.64	2.05	5.69
D3 X I2	2.06	1.48	3.53	3.81	4.19	8.00	4.02	3.78	7.80
D3 X I3	2.42	3.91	6.33	4.19	4.43	8.62	4.38	5.22	9.60
F value	0.51^{ns}	1.53^{ns}	0.52^{ns}	0.24^{ns}	0.73^{ns}	0.50^{ns}	0.42^{ns}	0.18^{ns}	0.02^{ns}
p value	0.73	0.24	0.72	0.91	0.58	0.74	0.79	0.95	1.00

** significant at $p<0.01$, * significant at $p<0.05$, ns= not significant at $p>0.05$, values with the same superscripts in a column do not differ significantly, D1 – 27,777 plants ha^{-1}, D2 – 22,222 plants ha^{-1}, D3 – 17,777 plants ha^{-1}, I1 – 8 weeks, I2 – 12 weeks, I3 – 16 weeks pruning interval

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Pruning interval also had profound influence on fresh standing biomass. Maximum stump, root and total biomass (21.04, 2.42 and 23.46 Mg ha^{-1} respectively) were obtained for 12 weeks pruning interval and were statistically on par with the corresponding values (18.16, 2.50 and 20.66 Mg ha^{-1} respectively) of 16 weeks pruning interval. Lowest values of stump, root and total biomass (13.58, 1.67 and 15.25 Mg ha^{-1} respectively) were recorded for the shortest pruning interval.

Table 10 shows the interaction effect of various treatment combinations on fresh standing biomass. On comparing the treatments, maximum stump, root and total standing fresh biomass (25.46, 2.90 and 28.56 Mg ha^{-1} respectively) were obtained for the combination of 27,777 plants ha^{-1} and 12 weeks pruning interval, but was not statistically significant.

4.3.2 Dry standing biomass

The main effect of tree density and pruning interval on dry standing biomass is depicted in table 9. Tree density had significant effect on stump as well as total dry standing biomass. Highest stump and total biomass (10.77 and 12.02 Mg ha^{-1} respectively) was obtained for highest tree density. Medium tree density reported dry stump and total biomass as 9.28 and 10.40 Mg ha^{-1} respectively and were found to be on par with the other two tree densities. Maximum dry root biomass was obtained for highest tree density as 1.25 Mg ha^{-1}, but was not statistically significant.

Pruning interval also had evident influence on dry standing biomass allocation. Maximum stump, root and total standing dry biomass (11.07, 1.25 and 12.32 Mg ha^{-1} respectively) were obtained for 12 weeks pruning interval and were statistically on par with the corresponding values (9.61, 1.37 and 10.98 Mg ha^{-1}) of 16 weeks pruning interval. Lowest values of stump, root and total standing dry biomass (7.18, 1.01 and 8.83 Mg ha^{-1} respectively) were recorded for the shortest pruning interval.

The interaction effect of various treatment combinations on dry standing biomass was non-significant (Table 10). The maximum root biomass (1.53 Mg ha^{-1}) was

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recorded for the treatment comprising of tree density 22,222 plants ha^{-1} and 16 weeks pruning interval and maximum stump and total standing dry biomass (12.70 and 14.14 Mg ha^{-1} respectively) were obtained for the combination of 27,777 plants ha^{-1} and 12 weeks pruning interval.

4.3.3 Carbon content in standing biomass

The main effect of tree density and pruning interval on carbon content in standing biomass is depicted in table 9. Tree density had significant effect on carbon content in stump as well as total standing biomass. Highest carbon content in stump and total standing biomass (6.18 and 6.88 Mg ha^{-1} respectively) was obtained for highest tree density. Lowest values of 4.48 and 5.05 Mg ha^{-1} were recorded for carbon content in stump and total standing biomass of lowest tree density respectively. Medium tree density reported carbon content in stump and total standing biomass as 5.32 and 5.96 Mg ha^{-1} respectively and were found to be on par with the other two tree densities. Maximum carbon content in root standing biomass was obtained for highest tree density as 0.71 Mg ha^{-1}, but was not statistically significant.

Pruning interval also had prominent influence on carbon content in standing biomass. Maximum carbon content in stump, root and total standing biomass (6.35, 0.71 and 7.06 Mg ha^{-1} respectively) were obtained for 12 weeks pruning interval and were statistically on par with the corresponding values (5.51, 0.78 and 6.28 Mg ha^{-1} respectively) of 16 weeks pruning interval. Lowest values of carbon content in stump, root and total standing biomass (4.12, 0.43 and 4.55 Mg ha^{-1} respectively) were recorded for the shortest pruning interval.

Table 10 shows the interaction effect of various treatment combinations on carbon content in standing biomass. Maximum carbon content in root standing biomass (0.87 Mg ha^{-1}) was recorded for the treatment comprising of tree density 22,222 plants ha^{-1} and 16 weeks pruning interval and maximum carbon content in stump and total standing biomass (7.28 and 8.10 Mg ha^{-1} respectively) were obtained for the combination of 27,777 plants ha^{-1} and 12 weeks pruning interval, but was not statistically significant.

4.4 EFFECT OF TREE DENSITY AND PRUNING INTERVAL ON TOTAL PLANT BIOMASS AND CARBON STOCKS OF CALLIANDRA UNDER COCONUT PLANTATION

4.4.1 Total plant dry biomass over three-year period

Table 11 represents the main effect of tree density and pruning interval on total plant dry fodder biomass over three years period under coconut plantation. Maximum total plant dry fodder biomass (58.53 Mg ha^{-1}) was obtained for highest tree density, that was statistically significant and the values of other two lower densities were comparable. Highest total plant dry fodder biomass (59.53 Mg ha^{-1}) was obtained for longest pruning interval and was found to be on par with the value of 12 weeks cutting interval (52.26 Mg ha^{-1}).

Table 12 depicts the interaction effect of different treatment combinations on total plant dry biomass over three-year period under coconut plantation. Maximum total plant dry biomass (68.81 Mg ha^{-1}) was obtained for the combination of 27,777 plants ha^{-1} and 16 weeks pruning interval. In comparison, the control (sole coconut plantation with natural grasses in the interspaces) treatment recorded very low value of total plant dry biomass (1.40 Mg ha^{-1}) and was statistically inferior to all treatment combinations of calliandra.

4.4.2 Total carbon stocks in plant dry biomass over three-year period

Table 11 represents the main effect of tree density and pruning interval on total carbon in plant dry biomass of calliandra over three-year period under coconut plantation. Maximum total carbon in plant dry biomass (32.69 Mg ha^{-1}) was obtained for highest tree density, that was statistically significant and the values of other two lower densities were comparable. Highest total carbon in plant dry biomass (33.48 Mg ha^{-1}) was obtained for longest pruning interval and was found to be on par with the value of 12 weeks cutting interval (29.14 Mg ha^{-1}).

Table 12 depicts the effect of different treatment combinations on total carbon in plant dry biomass of calliandra over three-year period under coconut plantation. Maximum total carbon in plant dry biomass over three-year period (38.56 Mg ha^{-1}) was obtained for the combination of 27,777 plants ha^{-1} and 16 weeks pruning interval. On comparison with treatments, control (sole coconut plantation) recorded very low value of total carbon in plant dry biomass (0.77 Mg ha^{-1}) and was statistically inferior.

4.5 EFFECT OF TREE DENSITY AND PRUNING INTERVAL OF CALLIANDRA ON NUT YIELD OF COCONUT PALMS

4.5.1 Annual nut yield

Management aspects like tree density and pruning interval of intercropped calliandra had no significant effect on annual nut yield of coconut palms on the third year (Table 13). Highest annual nut yield (14,936 nuts ha^{-1}) was obtained for the treatment combination of 27,777 plants ha^{-1} and 8 weeks pruning interval, but was not statistically significant when compared to other treatments (Table 14). Similarly, there was no significant difference in annual nut yield between sole coconut palms (14,705 nuts ha^{-1}) and the palms intercropped with calliandra trees (14,590-14,936 nuts ha^{-1}).

4.5.2 Existing nuts of different size classes in coconut palms

Count on the existing number of nuts in the coconut palms gives an indication regarding the influence of intercropping callliandra on coconut yield over the past three-year period. The data revealed that the existing nuts in the sole coconut plots was significantly lower (15,455 nuts ha^{-1}) when compared to that of the coconut plots intercropped with calliandra trees (16,608-16,781 nuts ha^{-1}).

Table 9. Effect of tree density and pruning interval on standing biomass and carbon content of calliandra under coconut garden at Vellanikkara, Thrissur, Kerala

Factors	Standing biomass and carbon content (Mg ha^{-1})								
	Fresh standing biomass			Dry standing biomass			Carbon content		
	Stump	Root	Total	Stump	Root	Total	Stump	Root	Total
Tree density									
27,777 plants ha^{-1} (D1)	20.64^{a}	2.49	23.13^{a}	10.77^{a}	1.25	12.02^{a}	6.18^{a}	0.71	6.88^{a}
22,222 plants ha^{-1} (D2)	17.33^{ab}	2.15	19.48^{ab}	9.28^{ab}	1.12	10.40^{ab}	5.32^{ab}	0.64	5.96^{ab}
17,777 plants ha^{-1} (D3)	14.81^{b}	1.96	16.77^{b}	7.81^{b}	1.01	8.83^{b}	4.48^{b}	0.57	5.05^{b}
F value	3.92^{*}	1.85^{ns}	4.01^{*}	3.74^{*}	1.35^{ns}	3.77^{*}	3.74^{*}	1.35^{ns}	3.77^{*}
p value	0.04	0.19	0.04	<0.05	0.29	<0.05	<0.05	0.29	<0.05
Pruning interval									
8 weeks (I1)	13.58^{b}	1.67^{b}	15.25^{b}	7.18^{b}	0.77^{b}	7.95^{b}	4.12^{b}	0.43^{b}	4.55^{b}
12 weeks (I2)	21.04^{a}	2.42^{a}	23.46^{a}	11.07^{a}	1.25^{a}	12.32^{a}	6.35^{a}	0.71^{a}	7.06^{a}
16 weeks (I3)	18.16^{a}	2.50^{a}	20.66^{a}	9.61^{a}	1.37^{a}	10.98^{a}	5.51^{a}	0.78^{a}	6.28^{a}
F value	6.49^{**}	5.34^{*}	6.86^{**}	6.63^{**}	9.64^{**}	7.42^{**}	6.63^{**}	9.64^{**}	7.41^{**}
p value	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

** significant at $p<0.01$, * significant at $p<0.05$, ns= not significant at $p>0.05$, values with the same superscripts in a column do not differ significantly

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Table 10. Interaction effect of tree density and pruning interval on standing biomass and carbon content of calliandra in coconut garden at Vellanikkara, Thrissur, Kerala

Treatments	Standing biomass and carbon content (Mg ha^{-1})								
	Fresh standing biomass			Dry standing biomass			Carbon content		
	Stump	Root	Total	Stump	Root	Total	Stump	Root	Total
Tree density X Pruning interval									
D1 X I1	16.35	2.17	18.52	9.10	1.00	10.10	5.22	0.57	5.79
D1 X I2	25.46	2.90	28.36	12.70	1.45	14.14	7.28	0.82	8.10
D1 X I3	20.11	2.40	22.51	10.51	1.30	11.81	6.03	0.74	6.76
D2 X I1	12.83	1.41	14.24	6.70	0.65	7.35	3.84	0.37	4.21
D2 X I2	21.52	2.25	23.77	11.85	1.19	13.05	6.80	0.67	7.47
D2 X I3	17.65	2.79	20.44	9.27	1.53	10.80	5.32	0.87	6.18
D3 X I1	11.57	1.44	13.00	5.73	0.65	6.38	3.29	0.37	3.65
D3 X I2	16.15	2.12	18.26	8.67	1.10	9.78	4.97	0.63	5.60
D3 X I3	16.73	2.31	19.04	9.04	1.28	10.32	5.18	0.73	5.91
F value	0.42^{ns}	0.87^{ns}	0.42^{ns}	0.45^{ns}	0.80^{ns}	0.45^{ns}	0.45^{ns}	0.80^{ns}	0.45^{ns}
p value	0.8	0.50	0.79	0.77	0.54	0.77	0.77	0.54	0.77

** significant at $p<0.01$, * significant at $p<0.05$, ns= not significant at $p>0.05$, values with the same superscripts in a column do not differ significantly, D1 – 27,777 plants ha^{-1}, D2 – 22,222 plants ha^{-1}, D3 – 17,777 plants ha^{-1}, I1 – 8 weeks, I2 – 12 weeks, I3 – 16 weeks pruning interval

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Table 11. Effect of tree density and pruning interval on pooled harvested dry fodder biomass, total standing dry biomass and total carbon content of calliandra over three-year period, intercropped in coconut plantation at Vellanikkara, Thrissur, Kerala

Factors	Pooled harvested dry fodder biomass, total standing dry biomass and total carbon content ($Mg\ ha^{-1}$)					
	Pooled harvested dry fodder biomass	Pooled harvested carbon	Total standing dry plant biomass	Total carbon in standing biomass	Total plant dry biomass	Total plant carbon stocks over three years
Tree density						
27,777 plants ha^{-1} (D1)	46.51^{a}	25.81^{a}	12.02^{a}	6.88^{a}	58.53^{a}	32.69^{a}
22,222 plants ha^{-1} (D2)	37.17^{b}	20.63^{b}	10.40^{ab}	5.96^{ab}	47.57^{b}	26.58^{b}
17,777 plants ha^{-1} (D3)	34.35^{b}	19.05^{b}	8.83^{b}	5.05^{b}	43.18^{b}	24.11^{b}
F value	4.90^{*}	4.84^{*}	3.77^{*}	3.77^{*}	5.78^{*}	5.73^{*}
p value	0.02	0.02	<0.05	<0.05	0.01	0.01
Pruning interval						
8 weeks (I1)	29.54^{b}	16.21^{c}	7.95^{b}	4.55^{b}	37.48^{b}	20.76^{b}
12 weeks (I2)	39.94^{a}	22.08^{b}	12.32^{a}	7.06^{a}	52.26^{a}	29.14^{a}
16 weeks (I3)	48.55^{a}	27.20^{a}	10.98^{a}	6.28^{a}	59.53^{a}	33.48^{a}
F value	10.97^{**}	11.72^{**}	7.42^{**}	7.41^{**}	11.66^{**}	12.27^{**}
p value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

** significant at $p<0.01$, * significant at $p<0.05$, ns= not significant at $p>0.05$, values with the same superscripts in a column do not differ significantly

Table 12. Interaction effect of tree density and pruning interval on pooled harvested dry fodder biomass, total standing plant dry biomass and total carbon content over three years period at Vellanikkara, Thrissur, Kerala

Treatments	Pooled harvested dry fodder biomass, total standing plant dry biomass and total carbon content (Mg ha^{-1})					
	Pooled harvested dry fodder biomass	Pooled harvested carbon	Total standing dry plant biomass	Total carbon in standing biomass	Total plant dry biomass	Total plant carbon over three years
Tree density X Pruning interval						
D1 X I1	35.75	19.63	10.10	5.79	45.86	25.42
D1 X I2	46.98	25.98	14.14	8.10	61.12	34.08
D1 X I3	56.80	31.80	11.81	6.76	68.61	38.56
D2 X I1	28.66	15.73	7.35	4.21	36.01	19.94
D2 X I2	37.82	20.91	13.05	7.47	50.87	28.38
D2 X I3	45.03	25.24	10.80	6.18	55.83	31.42
D3 X I1	24.20	13.27	6.38	3.65	30.58	16.92
D3 X I2	35.02	19.34	9.78	5.60	44.80	24.94
D3 X I3	43.82	24.55	10.32	5.91	54.14	30.45
F value	0.06^{ns}	0.06^{ns}	0.45^{ns}	0.45^{ns}	0.05^{ns}	0.05^{ns}
p value	0.99	0.99	0.77	0.77	0.99	0.99
Control (sole coconut plantation)					1.40	0.77
F value					68.87^{**}	13.72^{**}
p value					<0.01	<0.01

** significant at p<0.01, * significant at p<0.05, ns= not significant at p>0.05, values with the same superscripts in a column do not differ significantly,

D1 – 27,777 plants ha^{-1}, D2 – 22,222 plants ha^{-1}, D3 – 17,777 plants ha^{-1}, I1 – 8 weeks, I2 – 12 weeks, I3 – 16 weeks pruning interval

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However, various management practices in calliandra had no significant influence on coconut productivity as indicated by the comparable nut counts in different treatments. (Table 13). Highest number of nuts in standing coconut palms (16,781 nuts ha^{-1}) was obtained for the treatment combination of 27,777 plants ha^{-1} and 8 weeks pruning interval as well as 22,222 plants ha^{-1} and 12 weeks pruning interval, but was not statistically significant when compared to other treatments (Table 14).

4.6 CARBON STOCKS IN COCONUT PALMS AS INFLUENCED BY CALLIANDRA INTERCROPPING AND MANAGEMENT ASPECTS

4.6.1 Carbon content in harvested nuts

Carbon content in the harvested nuts of the third year is given in table 13. Tree density, pruning interval and their interactions had no significant effect on carbon content of harvested nuts (Table 13, 14). Similarly, there was no significant difference between the carbon content of nuts in sole coconut palms (0.079 Mg ha^{-1}) and intercropped palms (0.079-0.080 Mg ha^{-1}).

4.6.2 Carbon stocks in the existing nuts on the palm

Tree density and pruning interval of callliandra had no significant effect on carbon content in existing nuts of coconut palms (Table 13). Highest carbon content in nuts (2.02 Mg ha^{-1}) was obtained for the treatment combination of 22,222 plants ha^{-1} and 8 weeks pruning interval, but was not statistically significant when compared to other treatments (Table 14). However, the overall carbon stocks (1.85-2.02 Mg ha^{-1}) in the existing nuts of calliandra intercropped palms were significantly higher when compared to that of the sole coconut palms (1.70 Mg ha^{-1}).

4.6.3 Carbon stocks in coconut leaves

The carbon stocks in the existing coconut leaves of calliandra – coconut system ranged from of 3.03-3.15 Mg ha^{-1} and was on par with that of sole coconut palms (2.99

Mg ha^{-1}). Various management regimes in callindra also had no significant influence on coconut leaves and carbon stocks (Table 13, 14).

4.6.4 Carbon stocks in coconut bole

As indicated in table 13, coconut bole accumulated 26.99-28.60 Mg ha^{-1} of carbon in coconut - calliandra intercropping systems under various management regimes and was on par with that of the sole coconut palms (27.62 Mg ha^{-1}). There was no statistically significant difference in carbon stored in bole of coconut palms among different treatment combinations (Table 14).

4.6.4 Total above ground carbon stocks in coconut palms

Management regimes like tree density and pruning interval in intercropped calliandra had no significant effect on total carbon stocks in coconut palms (Table 13). Highest total carbon storage in coconut palms (33.84 Mg ha^{-1}) was obtained for the treatment combination of 27,777 plants ha^{-1} and 16 weeks pruning interval, but was not statistically significant when compared to other treatments (Table 14). There was also no significant difference between the carbon stocks of sole coconut palms (32.39 Mg ha^{-1}) and that of the palms intercropped with calliandra (32.04-33.84 Mg ha^{-1}).

4.7 EFFECT OF TREE DENSITY AND PRUNING INTERVAL of CALLIANDRA ON SOIL CARBON

4.7.1 Soil organic carbon content

Table 15 represents the main effect of tree density and pruning interval on soil organic carbon content. The top 20 cm depth was found to have comparatively higher values. Decline in organic carbon content was observed with increasing depth. Tree density had significant effect on soil organic carbon content and the highest soil organic carbon percentage was observed for the tree density of 22,222 plants ha^{-1} (D2) throughout the profile with 1.25 percent in the top layer and mean value of 0.76 per cent for the overall profile.

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Table 13. Effect of tree density and pruning interval of intercropped calliandra on annual nut yield and fractional and total carbon content of coconut palms at Vellanikkara, Thrissur, Kerala

Factors	Annual nut yield and carbon content of coconut palms						
	Nut yield (ha^{-1})		Fractional and total carbon content of coconut palms ($Mg\ ha^{-1}$)				
	Annual nut yield	No. of nuts in standing palms	Harvested nuts	Nuts in standing palms	Leaves	Bole	Total
Tree density							
27,777 plants ha^{-1} (D1)	14820.33	16742.56	0.080	1.88	3.10	28.31	33.37
22,222 plants ha^{-1} (D2)	14724.22	16684.89	0.079	1.94	3.05	27.99	33.06
17,777 plants ha^{-1} (D3)	14647.33	16704.11	0.079	1.87	3.08	28.28	33.30
F value	3.34^{ns}	0.10^{ns}	3.34^{ns}	0.63^{ns}	0.20^{ns}	0.32^{ns}	0.24^{ns}
p value	0.06	0.91	0.06	0.54	0.83	0.73	0.79
Pruning interval							
8 weeks (I1)	14820.33	16684.89	0.080	1.92	3.10	28.18	33.28
12 weeks (I2)	14666.56	16742.56	0.079	1.90	3.08	28.24	33.30
16 weeks (I3)	14705.00	16704.11	0.079	1.87	3.05	28.16	33.16
F value	2.85^{ns}	0.10^{ns}	2.85^{ns}	0.34^{ns}	0.20^{ns}	0.02^{ns}	0.05^{ns}
p value	0.09	0.91	0.09	0.72	0.83	0.98	0.95

** significant at $p<0.01$, * significant at $p<0.05$, ns= not significant at $p>0.05$, values with the same superscripts in a column do not differ significantly

Table 14. Interaction effect of tree density and pruning interval of intercropped calliandra on annual nut yield and fractional and total carbon content of coconut palms at Vellanikkara, Thrissur, Kerala

Treatments	Annual nut yield and carbon content of coconut palms						
	Nut yield (ha^{-1})		Fractional and total carbon content of coconut palms ($Mg\ ha^{-1}$)				
	Annual nut yield (3rd year)	No. of existing nuts in palms	Harvested nuts	Nuts in standing palms	Leaves	Bole	Total
Tree density X Pruning interval							
D1 X I1	14935.67	16781.00	0.080	1.90	3.11	27.91	33.00
D1 X I2	14762.67	16723.33	0.080	1.90	3.15	28.14	33.27
D1 X I3	14762.67	16723.33	0.080	1.85	3.03	28.89	33.84
D2 X I1	14878.00	16608.00	0.080	2.02	3.07	28.55	33.71
D2 X I2	14647.33	16781.00	0.079	1.90	3.03	28.43	33.44
D2 X I3	14647.33	16665.67	0.079	1.90	3.07	26.99	32.04
D3 X I1	14647.33	16665.67	0.079	1.85	3.11	28.08	33.12
D3 X I2	14589.67	16723.33	0.079	1.90	3.07	28.14	33.19
D3 X I3	14705.00	16723.33	0.079	1.85	3.07	28.60	33.60
F value	0.88^{ns}	0.14^{ns}	0.88^{ns}	0.27^{ns}	0.28^{ns}	1.83^{ns}	1.55^{ns}
p value	0.50	0.97	0.50	0.89	0.89	0.17	0.24
Control	14705.00	15454.67	0.079	1.70	2.99	27.62	32.39
F value	0.08^{ns}	55.63^{**}	0.15^{ns}	4.68^{*}	1.14^{ns}	0.76^{ns}	1.57^{ns}
p value	>0.05	<0.01	>0.05	<0.05	>0.05	>0.05	>0.05

** significant at $p<0.01$, * significant at $p<0.05$, ns= not significant at $p>0.05$, values with the same superscripts in a column do not differ significantly, D1 – 27,777 plants ha^{-1}, D2 – 22,222 plants ha^{-1}, D3 – 17,777 plants ha^{-1}, I1 – 8 weeks, I2 – 12 weeks, I3 – 16 weeks pruning interval

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Soil carbon content in D1 was significantly lower than D2 but higher than D3. Pruning interval also had profound effect on soil organic carbon content. The highest soil organic carbon percentage was observed for 12 weeks pruning interval with 1.10 percent in the surface layer and mean value of 0.80 percent for overall depth.

Table 16 shows the interaction effect of various treatments on soil organic carbon content. Maximum overall mean soil organic carbon content (0.93 per cent) was observed for the treatment combination of 27,777 plants ha^{-1} and 12 weeks pruning interval. There was significant difference in soil organic carbon content between control (sole coconut plantation) and the different treatments. Control had very low mean value of soil organic carbon (0.55 per cent) than the various treatment combinations (0.51-0.93 per cent).

4.7.2 Soil carbon stocks

Table 17 represents the main effect of tree density and pruning interval of calliandra on soil organic carbon stocks. The top 20 cm depth was found to sequester maximum amount of carbon and the amount sequestered decreased with increase in depth. Tree density had significant effect on soil organic carbon stocks and the highest value was observed for the tree density of 22,222 plants ha^{-1} (D1) with total carbon 103.43 Mg ha^{-1}followed by D1 and D3. Pruning interval also had evident effect on soil organic carbon stocks. The highest soil organic carbon stock (114.27 Mg ha^{-1}) was observed for 12 weeks pruning interval, followed by I3 and I1.

Table 18 shows the interaction effect of various treatments on soil organic carbon stocks. At the soil surface layer, maximum soil organic carbon stock (37.91 Mg ha^{-1}) was observed for the treatment combination of 22,222 plants ha^{-1} and 8 weeks pruning interval and that was on par with the combination of 22,222 plants ha^{-1} and 16 weeks pruning interval (37.58 Mg ha^{-1}) and 27,777 plants ha^{-1} and 12 weeks pruning interval. Overall carbon stocks were significantly higher for D1I2 and D2I1. There was significant difference in total soil organic carbon stock between control (sole coconut

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plantation) and the different treatments. Control had very low carbon stocks (75.57 Mg ha^{-1}) in the profile than the various treatment combinations (68.80-131.84 Mg ha^{-1}).

4.8 EFFECT OF TREE DENSITY AND PRUNING INTERVAL OF CALLIANDRA ON CARBON STORAGE POTENTIAL OF CALLIANDRA – COCONUT SYSYTEM

4.8.1 Carbon storage potential of the system

The main effect of tree density and pruning interval on total carbon storage potential of the system is projected in table 19. Tree density and pruning interval had significant effect on total carbon storage potential of the system. The maximum total carbon storage was obtained for highest tree density (163.90 Mg ha^{-1}) and was on par with the medium tree density (163.10 Mg ha^{-1}). The largest amount of total carbon storage was recorded for 12 weeks pruning interval (176.71 Mg ha^{-1}) and the lowest amount was in 16 weeks pruning interval (157.71 Mg ha^{-1}).

On comparing the different treatment combinations (table 20), the highest amount of carbon capture (199.19 Mg ha^{-1}) was observed in the combination of 27,777 plants ha^{-1} tree density and 12 weeks cutting interval and the lowest value (118.84 Mg ha^{-1}) was recorded for 17,777 plants ha^{-1} and 8 weeks cutting interval. The carbon storage potential of control, sole coconut plantation (108.73 Mg ha^{-1}) was far behind when compared to the treatments.

Table 15. Effect of tree density and pruning interval on carbon content in soil at various depths at Vellanikkara, Thrissur, Kerala

Factors	Soil carbon content (%)					
	0-20 cm	21-40 cm	41-60 cm	61-80 cm	81-100 cm	Mean
Tree density						
27,777 plants ha^{-1} (D1)	1.07^{b} (±0.05)	0.80^{c} (±0.07)	0.58^{b} (±0.07)	0.51^{b} (±0.06)	0.49^{a} (±0.06)	0.69^{b} (±0.06)
22,222 plants ha^{-1} (D2)	1.25^{a} (±0.06)	0.83^{b} (±0.02)	0.65^{a} (±0.03)	0.60^{a} (±0.04)	0.49^{a} (±0.04)	0.76^{a} (±0.03)
17,777 plants ha^{-1} (D3)	0.94^{c} (±0.05)	0.84^{a} (±0.06)	0.54^{c} (±0.05)	0.47^{c} (±0.04)	0.45^{b} (±0.05)	0.65^{c} (±0.05)
F value	1755.02^{**}	113.71^{**}	875.03^{**}	763.17^{**}	75.11^{**}	936.58^{**}
p value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Pruning interval						
8 weeks (I1)	1.05^{b} (±0.09)	0.72^{c} (±0.04)	0.46^{c} (±0.05)	0.46^{c} (±0.06)	0.38^{c} (±0.03)	0.61^{c} (±0.05)
12 weeks (I2)	1.10^{a} (±0.04)	0.98^{a} (±0.05)	0.70^{a} (±0.04)	0.61^{a} (±0.05)	0.59^{a} (±0.06)	0.80^{a} (±0.05)
16 weeks (I3)	1.05^{b} (±0.07)	0.78^{b} (±0.02)	0.61^{b} (±0.04)	0.51^{b} (±0.04)	0.47^{b} (±0.04)	0.68^{b} (±0.04)
F value	194.82^{**}	3812.57^{**}	4344.28^{**}	876.83^{**}	1825.78^{**}	2542.62^{**}
p value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

** significant at $p<0.01$, * significant at $p<0.05$, ns= not significant at $p>0.05$, values with the same superscripts in a column do not differ significantly, values in parenthesis are standard error of means

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Table 16. Interaction effect of tree density and pruning interval on carbon content in soil at various depths at Vellanikkara, Thrissur, Kerala

Tree density	Soil Carbon (%)								
	0-20 cm			21-40 cm			41-60 cm		
	Pruning interval			Pruning interval			Pruning interval		
	I1	I2	I3	I1	I2	I3	I1	I2	I3
D1	0.96^{Bb}	1.27^{Aa}	0.97^{Bb}	0.59^{Cc}	1.08^{Aa}	0.73^{Bb}	0.38^{Bc}	0.84^{Aa}	0.53^{Bb}
D2	1.39^{Aa}	1.03^{Cc}	1.33^{Ab}	0.88^{Aa}	0.79^{Bb}	0.82^{Ab}	0.65^{Ab}	0.55^{Cc}	0.76^{Aa}
D3	0.81^{Cc}	1.14^{Ba}	0.86^{Cb}	0.68^{Bc}	1.07^{Aa}	0.79^{Ab}	0.37^{Bc}	0.73^{Ba}	0.54^{Bb}
F value	1090.10^{**}			1672.00^{**}			2781.38^{**}		
p value	<0.001			<0.001			<0.001		
Control	1.15 (±0.01)			0.66 (±0.01)			0.57 (±0.01)		
F value	50.00^{**}			116.67^{**}			2.57^{ns}		
p value	<0.01			<0.01			>0.05		
Tree density	61-80 cm			81-100 cm			Mean		
	I1	I2	I3	I1	I2	I3	I1	I2	I3
D1	0.33^{Bc}	0.76^{Aa}	0.45^{Bb}	0.31^{Bc}	0.74^{Aa}	0.43^{Bb}	0.51^{Bc}	0.93^{Aa}	0.62^{Bb}
D2	0.71^{Aa}	0.44^{Cc}	0.66^{Ab}	0.49^{Ab}	0.37^{Cc}	0.62^{Aa}	0.82^{Aa}	0.63^{Cb}	0.84^{Aa}
D3	0.35^{Bc}	0.63^{Ba}	0.43^{Bb}	0.33^{Bb}	0.67^{Ba}	0.37^{Cb}	0.51^{Bc}	0.84^{Ba}	0.60^{Bb}
F value	2019.77^{**}			1729.56^{**}			2964.77**		
p value	<0.001			<0.001			<0.001		
Control	0.18 (±0.01)			0.21 (±0.01)			0.55 (±0.01)		
F value	640.00^{**}			400.00^{**}			750^{**}		
p value	<0.01			<0.01			<0.01		

** significant at $p<0.01$, * significant at $p<0.05$, ns= not significant at $p>0.05$, values with the same small letters as superscripts indicates that they are on par row wise and values with the same capital letters as superscripts indicates that they are on par column wise, values in parenthesis are standard error of means, D1 – 27,777 plants ha^{-1}, D2 – 22,222 plants ha^{-1}, D3 – 17,777 plants ha^{-1}, I1 – 8 weeks, I2 – 12 weeks, I3 – 16 weeks pruning interval

Table 17. Effect of tree density and pruning interval on carbon stocks in soil at various depths at Vellanikkara, Thrissur, Kerala

Factors	Soil carbon stocks (Mg ha^{-1})					
	0-20 cm	21-40 cm	41-60 cm	61-80 cm	81-100 cm	Total
Tree density						
27,777 plants ha^{-1} (D1)	30.54^{b} (±1.32)	23.64^{b} (±2.03)	15.85^{c} (±2.26)	14.82^{b} (±1.86)	12.99^{a} (±1.60)	97.84^{b} (±8.87)
22,222 plants ha^{-1} (D2)	34.52^{a} (±1.64)	22.11^{c} (±0.88)	17.72^{a} (±0.80)	16.10^{a} (±1.32)	12.97^{a} (±0.93)	103.43^{a} (±4.84)
17,777 plants ha^{-1} (D3)	24.93^{c} (±1.24)	24.42^{a} (±1.90)	16.51^{b} (±2.07)	13.75^{c} (±2.07)	11.23^{b} (±1.49)	90.83^{c} (±8.70)
F value	2105.75**	165.91**	140.38**	130.38**	191.67**	378.16**
p value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Pruning interval						
8 weeks (I1)	29.40^{b} (±2.29)	20.41^{c} (±1.32)	14.05^{b} (±1.66)	12.92^{c} (±1.95)	9.97^{c} (±1.02)	86.75^{c} (±8.06)
12 weeks (I2)	31.19^{a} (±1.19)	27.36^{a} (±1.94)	22.13^{a} (±1.25)	18.46^{a} (±1.71)	15.13^{a} (±1.46)	114.27^{a} (±7.20)
16 weeks (I3)	29.40^{b} (±2.21)	22.40^{b} (±0.41)	13.90^{b} (±0.64)	13.29^{b} (±0.83)	12.09^{b} (±1.03)	91.07^{b} (±4.04)
F value	97.32**	1537.36**	3447.53**	902.50**	1266.70**	2079.89**
p value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

** significant at p<0.01, * significant at p<0.05, ns= not significant at p>0.05, values with the same superscripts in a column do not differ significantly, values in parenthesis are standard error of means

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Table 18. Interaction effect of tree density and pruning interval on carbon stocks in soil at various depths at Vellanikkara, Thrissur, Kerala

Tree density	Soil carbon stocks (Mg ha^{-1})								
	0-20 cm			21-40 cm			41-60 cm		
	Pruning interval			Pruning interval			Pruning interval		
	I1	I2	I3	I1	I2	I3	I1	I2	I3
D1	27.87^{Bb}	35.73^{Aa}	28.01^{Bb}	16.71^{Cc}	30.65^{Aa}	23.56^{Ab}	11.21^{Bb}	24.85^{Aa}	11.49^{Bb}
D2	37.91^{Aa}	28.08^{Cb}	37.58^{Aa}	25.43^{Aa}	19.71^{Bc}	21.18^{Bb}	20.62^{Aa}	17.23^{Bb}	15.31^{Ac}
D3	22.42^{Cb}	29.77^{Ba}	22.61^{Cb}	19.10^{Bc}	31.71^{Aa}	22.45^{ABb}	10.34^{Bc}	24.29^{Aa}	14.89^{Ab}
F value	993.70^{**}			1236.51^{**}			1354.41^{**}		
p value	<0.001			<0.001			<0.001		
Control	33.39 (±0.40)			17.81 (±0.24)			14.45 (±0.30)		
F value	207^{**}			935.22^{**}			169.63^{**}		
p value	<0.01			<0.01			<0.01		
Tree density	61-80 cm			81-100 cm			Total		
	I1	I2	I3	I1	I2	I3	I1	I2	I3
D1	9.18^{Bc}	21.77^{Aa}	13.52^{Bb}	7.88^{Ac}	18.83^{Aa}	12.25^{Bb}	72.85^{Bc}	131.84^{Aa}	88.83^{Bb}
D2	20.68^{Aa}	11.67^{Bc}	15.95^{Ab}	13.96^{Bb}	9.44^{Cc}	15.52^{Aa}	118.60^{Aa}	86.13^{Cc}	105.54^{Ab}
D3	8.89^{Bc}	21.95^{Aa}	10.39^{Cb}	8.05^{Ab}	17.13^{Ba}	8.50^{Cb}	68.80^{Bc}	124.85^{Ba}	78.83^{Cb}
F value	1305.35^{**}			1448.38^{**}			2268.45^{**}		
p value	<0.001			<0.001			<0.001		
Control	4.78 (±0.21)			5.14 (±0.32)			75.57 (±1.02)		
F value	2507.82^{**}			1775.5^{**}			1017.89^{**}		
p value	<0.01			<0.01			<0.01		

** significant at p<0.01, * significant at p<0.05, ns= not significant at p>0.05, values with the same small letters as superscripts indicates that they are on par row wise and values with the same capital letters as superscripts indicates that they are on par column wise, values in parenthesis are standard error of means, D1 – 27,777 plants ha^{-1}, D2 – 22,222 plants ha^{-1}, D3 – 17,777 plants ha^{-1}, I1 – 8 weeks, I2 – 12 weeks, I3 – 16 weeks pruning interval

Table 19. Effect of tree density and pruning interval of calliandra on carbon storage potential of coconut – calliandra intercropping system at Vellanikkara, Thrissur, Kerala

Factors	Carbon content in various components and total carbon of the coconut-fodder integrated system (Mg ha^{-1})			
	Carbon in plant	Carbon in coconut palms	Carbon in soil	Total
Tree density				
27,777 plants ha-1 (D1)	32.69^{a}	33.37	97.84^{b}	163.90^{a}
22,222 plants ha-1 (D2)	26.58^{b}	33.06	103.43^{a}	163.10^{a}
17,777 plants ha-1 (D3)	24.11^{b}	33.30	90.83^{c}	148.23^{b}
F value	5.73^{*}	0.24^{ns}	378.16^{**}	19.18^{**}
p value	0.01	0.79	<0.001	<0.001
Pruning interval				
8 weeks (I1)	20.76^{b}	33.28	86.75^{c}	140.79^{c}
12 weeks (I2)	29.14^{a}	33.30	114.27^{a}	176.71^{a}
16 weeks (I3)	33.48^{a}	33.16	91.07^{b}	157.71^{b}
F value	12.27^{**}	0.05^{ns}	2079.89^{**}	79.73^{**}
p value	<0.01	0.95	<0.001	<0.001

** significant at p<0.01, * significant at p<0.05, ns= not significant at p>0.05, values with the same superscripts in a column do not differ significantly

Table 20. Interaction effect of tree density and pruning interval of calliandra on carbon storage potential of coconut – calliandra intercropping system on soil carbon stocks at Vellanikkara, Thrissur, Kerala

Tree density	Carbon in plant			Carbon in coconut palms		
	Pruning interval			Pruning interval		
	I1	I2	I3	I1	I2	I3
D1	25.42	34.08	38.56	33.00	33.27	33.84
D2	19.94	28.38	31.42	33.71	33.44	32.04
D3	16.92	24.94	30.45	33.12	33.19	33.60
F value	0.05^{ns}			1.55^{ns}		
p value	0.99			0.24		
Control	0.77			32.39		
F value	13.72^{**}			1.57^{ns}		
p value	<0.01			>0.05		
	Carbon in soil			Total carbon in the system		
	I1	I2	I3	I1	I2	I3
D1	72.85^{Bc}	131.84^{Aa}	88.83^{Bb}	131.27^{Bc}	199.19^{Aa}	161.23^{Ab}
D2	118.60^{Aa}	86.13^{Cc}	105.54^{Ab}	172.25^{Aa}	147.95^{Cb}	169.00^{Aa}
D3	68.80^{Bc}	124.85^{Ba}	78.83^{Cb}	118.84^{Cc}	182.98^{Ba}	142.88^{Bb}
F value	2268.45^{**}			6.03^{*}		
p value	<0.001			<0.05		
Control	75.57			108.73		
F value	1017.89^{**}			186.68^{**}		
p value	<0.01			<0.01		

** significant at p<0.01, * significant at p<0.05, ns= not significant at p>0.05, values with the same small letters as superscripts indicates that they are on par row wise and values with the same capital letters as superscripts indicates that they are on par column wise, D1 – 27,777 plants ha^{-1}, D2 – 22,222 plants ha^{-1}, D3 – 17,777 plants ha^{-1}, I1 – 8 weeks, I2 – 12 weeks, I3 – 16 weeks pruning interval

4.9 SOIL FERTILITY STATUS OF COCONUT – CALLIANDRA INTERCROPPING SYSTEM

4.9.1 Soil physical properties

4.9.1.1 Bulk density

Table 21 represents the main effect of tree density and pruning interval on the bulk density of soil at various depths. Both tree density and pruning interval had significant effect on bulk density of soil. On comparing the mean values of main effects, least bulk density was observed for medium tree density (1.35 g cm^{-3}) and the longest pruning interval (1.32 g cm^{-3}). The interaction effect of different treatments on soil bulk density at various depths is depicted in table 22. Comparing the mean values, the bulk density of various treatment combinations was recorded in the range of 1.24 to 1.50 g cm^{-3} and that of control (sole coconut plantation) was 1.33 g cm^{-3}. The lowest mean bulk density was observed for the treatment combination of 22,222 plants ha^{-1} and 16 weeks pruning interval (1.24 g cm^{-3}). In general, no specific trend has been observed in bulk density across different soil depths as well as treatment combinations.

4.9.1.2 Soil pH

Table 23 represents the main effect of tree density and pruning interval on the pH of soil at various depths. Both tree density and pruning interval had significant effect on pH of soil. On comparing the mean values of main effects, highest soil pH was observed for lowest tree density (5.55) and the longest pruning interval (5.48). The interaction effect of different treatments on soil pH at various depths is depicted in table 24. Comparing the mean values, the soil pH of various treatment combinations was recorded in the range of 4.93 to 5.86 and that of control (sole coconut plantation) was 5.50. The highest soil pH was observed for the treatment combination of 17,777 plants ha^{-1} and 16 weeks pruning interval (5.86).

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4.9.1.2 Water holding capacity

Table 25 represents the main effect of tree density and pruning interval on the water holding capacity of soil at various depths. Both tree density and pruning interval had significant effect on water holding capacity of soil. On comparing the mean values of main effects, highest soil water holding capacity was observed for medium tree density (33.04%) and the longest pruning interval (33.42%). The interaction effect of different treatments on soil water holding capacity at various depths is depicted in table 26. Comparing the mean values, the soil water holding capacity of various treatment combinations was recorded in the range of 30.14 to 33.93% and that of control (sole coconut plantation) was 34.56%. The highest soil water holding capacity was observed for the treatment combination of 17,777 plants ha^{-1} and 16 weeks pruning interval (33.93%).

4.9.2 Soil nutrient status

4.9.2.1 Total and available nitrogen concentration in soil

Table 27 shows the main effect of tree density and pruning interval of calliandra on the total nitrogen concentration of soil at various depths. Both tree density and pruning interval had significant effect on the total nitrogen concentration of soil. On comparing the mean values of main effects, highest soil total nitrogen concentration was observed for medium tree density (1.13 g kg^{-1}) and the longest pruning interval (1.08 g kg^{-1}).

The interaction effect of different treatments on soil total nitrogen concentration at various depths is depicted in table 28. Comparing the mean values, the soil total nitrogen concentration of various treatment combinations was recorded in the range of 0.99 to 1.16 g kg^{-1} and that of control (sole coconut plantation) was 1.11 g kg^{-1}. The highest soil total nitrogen concentration was observed for the treatment combination of 22,222 plants ha^{-1} and 8 weeks pruning interval (1.16 g kg^{-1}), but was not statistically significant. For all treatments nitrogen content decreased with depth.

Table 21. Effect of tree density and pruning interval of calliandra on soil bulk density at various depths at Vellanikkara, Thrissur, Kerala

Factors	Soil bulk density (g cm^{-3})					
	0-20 cm	21-40 cm	41-60 cm	61-80 cm	81-100 cm	Mean
Tree density						
27,777 plants ha^{-1} (D1)	1.44^a (±0.01)	1.49^a (±0.03)	1.36^c (±0.07)	1.46^a (±0.02)	1.33^a (±0.02)	1.41^a (±0.01)
22,222 plants ha^{-1} (D2)	1.38^b (±0.01)	1.34^c (±0.03)	1.39^b (±0.09)	1.34^c (±0.04)	1.32^b (±0.03)	1.35^c (±0.03)
17,777 plants ha^{-1} (D3)	1.34^c (±0.01)	1.44^b (±0.01)	1.49^a (±0.05)	1.41^b (±0.09)	1.22^c (±0.02)	1.38^b (±0.03)
F value	487.46^{**}	709.34^{**}	369.60^{**}	131.72^{**}	2060.65^{**}	163.72^{**}
p value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Pruning interval						
8 weeks (I1)	1.40^a (±0.01)	1.42^b (±0.01)	1.50^b (±0.03)	1.38^b (±0.03)	1.31^a (±0.03)	1.40^b (±0.02)
12 weeks (I2)	1.36^c (±0.02)	1.39^c (±0.04)	1.58^a (±0.03)	1.51^a (±0.06)	1.29^a (±0.00)	1.43^a (±0.02)
16 weeks (I3)	1.39^b (±0.02)	1.45^a (±0.05)	1.16^c (±0.06)	1.31^c (±0.05)	1.28^c (±0.04)	1.32^c (±0.03)
F value	84.13^{**}	110.75^{**}	3775.50^{**}	373.26^{**}	164.26^{**}	587.91^{**}
p value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

** significant at $p<0.01$, * significant at $p<0.05$, ns= not significant at $p>0.05$, values with the same superscripts in a column do not differ significantly, values in parenthesis are standard error of means

Table 22. Interaction effect of tree density and pruning interval of calliandra on soil bulk density at various depths at Vellanikkara, Thrissur, Kerala

Tree density	Soil bulk density (g cm^{-3})								
	0-20 cm			21-40 cm			41-60 cm		
	Pruning interval			Pruning interval			Pruning interval		
	I1	I2	I3	I1	I2	I3	I1	I2	I3
D1	1.45^{Aa}	1.41^{Ab}	1.44^{Aa}	1.42^{Bb}	1.43^{Bb}	1.63^{Aa}	1.49^{Ba}	1.48^{Ca}	1.09^{Bb}
D2	1.36^{Cb}	1.37^{Bb}	1.41^{Ba}	1.45^{Aa}	1.26^{Cc}	1.30^{Cb}	1.59^{Aa}	1.58^{Ba}	1.01^{Cb}
D3	1.39^{Ba}	1.31^{Cb}	1.31^{Cb}	1.40^{Bb}	1.49^{Aa}	1.43^{Bb}	1.42^{Cb}	1.68^{Aa}	1.38^{Ac}
F value	72.44^{**}			459.94^{**}			505.38^{**}		
p value	<0.001			<0.001			<0.001		
Control	1.46 (±0.01)			1.35 (±0.01)			1.28 (±0.01)		
F value	237.29^{**}			144.66^{**}			4251.54^{**}		
p value	<0.01			<0.01			<0.01		
Tree density	61-80 cm			81-100 cm			Mean		
	I1	I2	I3	I1	I2	I3	I1	I2	I3
D1	1.41^{Bb}	1.44^{Bb}	1.52^{Aa}	1.29^{Bb}	1.28^{Ab}	1.42^{Aa}	1.41^{Ba}	1.41^{Ba}	1.42^{Aa}
D2	1.47^{Aa}	1.34^{Cb}	1.20^{Bc}	1.42^{Aa}	1.29^{Ab}	1.25^{Bc}	1.46^{Aa}	1.37^{Cb}	1.24^{Cc}
D3	1.27^{Cb}	1.76^{Aa}	1.21^{Bc}	1.22^{Cb}	1.29^{Aa}	1.16^{Cc}	1.34^{Cb}	1.50^{Aa}	1.30^{Bc}
F value	459.37^{**}			1669.86^{**}			440.18**		
p value	<0.001			<0.001			<0.001		
Control	1.33 (±0.01)			1.26 (±0.01)			1.33 (±0.01)		
F value	28.76^{**}			1.14^{ns}			46.15^{**}		
p value	<0.01			>0.05			<0.01		

** significant at p<0.01, * significant at p<0.05, ns= not significant at p>0.05, values with the same small letters as superscripts indicates that they are on par row wise and values with the same capital letters as superscripts indicates that they are on par column wise, values in parenthesis are standard error of means, D1 – 27,777 plants ha^{-1}, D2 – 22,222 plants ha^{-1}, D3 – 17,777 plants ha^{-1}, I1 – 8 weeks, I2 – 12 weeks, I3 – 16 weeks pruning interval

Table 23. Effect of tree density and pruning interval on soil pH at various depths at Vellanikkara, Thrissur, Kerala

Factors	Soil pH					
	0-20 cm	21-40 cm	41-60 cm	61-80 cm	81-100 cm	Mean
Tree density						
27,777 plants ha^{-1} (D1)	5.53^b (±0.10)	4.80^b (±0.12)	5.09^b (±0.13)	5.16^b (±0.07)	5.09^c (±0.12)	5.14^c (±0.06)
22,222 plants ha^{-1} (D2)	5.51^b (±0.08)	5.44^a (±0.05)	5.09^b (±0.11)	5.46^a (±0.11)	5.44^b (±0.10)	5.39^b (±0.07)
17,777 plants ha^{-1} (D3)	5.68^a (±0.09)	5.45^a (±0.16)	5.47^a (±0.10)	5.51^a (±0.12)	5.62^a (±0.08)	5.55^a (±0.10)
F value	13.50^{**}	3081.44^{**}	27.30^{**}	56.24^{**}	113.88^{**}	220.36^{**}
p value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Pruning interval						
8 weeks (I1)	5.26^c (±0.03)	4.91^c (±0.10)	5.28^a (±0.05)	5.24^b (±0.05)	5.30^b (±0.03)	5.20^c (±0.01)
12 weeks (I2)	5.67^b (±0.06)	5.46^a (±0.05)	5.09^b (±0.12)	5.31^b (±0.05)	5.44^a (±0.09)	5.40^b (±0.06)
16 weeks (I3)	5.79^a (±0.09)	5.32^b (±0.21)	5.28^a (±0.18)	5.59^a (±0.16)	5.42^a (±0.20)	5.48^a (±0.14)
F value	123.11^{**}	1818.51^{**}	6.71^{**}	54.16^{**}	9.40^{**}	110.26^{**}
p value	<0.001	<0.001	<0.01	<0.001	<0.01	<0.001

** significant at p<0.01, * significant at p<0.05, ns= not significant at p>0.05, values with the same superscripts in a column do not differ significantly, values in parenthesis are standard error of means

Table 24. Interaction effect of tree density and pruning interval on soil pH at various depths at Vellanikkara, Thrissur, Kerala

Tree density	Soil pH								
	0-20 cm			21-40 cm			41-60 cm		
	Pruning interval			Pruning interval			Pruning interval		
	I1	I2	I3	I1	I2	I3	I1	I2	I3
D1	5.24^{ABc}	5.48^{Cb}	5.87^{Aa}	4.61^{Cb}	5.27^{Ba}	4.52^{Cb}	5.41^{Aa}	5.22^{Aa}	4.65^{Cb}
D2	5.19^{Bb}	5.68^{Ba}	5.65^{Ba}	5.27^{Ab}	5.52^{Aa}	5.54^{Ba}	5.26^{ABa}	4.64^{Bb}	5.35^{Ba}
D3	5.33^{Ab}	5.86^{Aa}	5.85^{Aa}	4.85^{Bc}	5.60^{Ab}	5.90^{Aa}	5.16^{Bc}	5.41^{Ab}	5.84^{Aa}
F value	7.74**			861.75**			36.86**		
p value	<0.01			<0.001			<0.001		
Control	5.60 (±0.03)			5.34 (±0.08)			5.43 (±0.04)		
F value	0.41^{ns}			14.19**			7.89*		
p value	>0.05			<0.01			<0.05		
Tree density	61-80 cm			81-100 cm			Mean		
	I1	I2	I3	I1	I2	I3	I1	I2	I3
D1	5.41^{Aa}	5.14^{Bb}	4.94^{Bc}	5.35^{Aa}	5.29^{Ba}	4.64^{Bb}	5.20^{Aa}	5.28^{Ba}	4.93^{Cb}
D2	5.14^{Bc}	5.38^{Ab}	5.86^{Aa}	5.22^{Ab}	5.25^{Bb}	5.84^{Aa}	5.22^{Ab}	5.29^{Bb}	5.65^{Ba}
D3	5.16^{Bc}	5.41^{Ab}	5.96^{Aa}	5.32^{Ab}	5.78^{Aa}	5.77^{Aa}	5.16^{Ac}	5.61^{Ab}	5.86^{Aa}
F value	67.64**			88.02*			128.80**		
p value	<0.001			<0.05			<0.001		
Control	5.40 (±0.04)			5.72 (±0.06)			5.50 (±0.04)		
F value	0.30^{ns}			48.02**			26.33**		
p value	>0.05			<0.01			<0.01		

** significant at p<0.01, * significant at p<0.05, ns= not significant at p>0.05, values with the same small letters as superscripts indicates that they are on par row wise and values with the same capital letters as superscripts indicates that they are on par column wise, values in parenthesis are standard error of means, D1 – 27,777 plants ha^{-1}, D2 – 22,222 plants ha^{-1}, D3 – 17,777 plants ha^{-1}, I1 – 8 weeks, I2 – 12 weeks, I3 – 16 weeks pruning interval

Table 25. Effect of tree density and pruning interval on soil water holding capacity at various depths at Vellanikkara, Thrissur, Kerala

Factors	Water holding capacity of soil (%)					
	0-20 cm	21-40 cm	41-60 cm	61-80 cm	81-100 cm	Mean
Tree density						
27,777 plants ha^{-1} (D1)	27.41^{c} (±0.48)	31.30^{c} (±0.92)	32.42^{b} (±0.48)	32.12 (±1.20)	35.50 (±0.37)	31.75^{b} (±0.57)
22,222 plants ha^{-1} (D2)	29.49^{a} (±0.52)	32.05^{b} (±0.91)	34.02^{a} (±1.60)	33.60 (±1.49)	36.05 (±0.46)	33.04^{a} (±0.88)
17,777 plants ha^{-1} (D3)	28.82^{b} (±0.40)	32.99^{a} (±0.57)	33.02^{b} (±0.75)	32.55 (±0.84)	35.34 (±0.69)	32.54^{a} (±0.51)
F value	264.18^{**}	212.63^{**}	9.14^{**}	1.31^{ns}	1.36^{ns}	8.79^{*}
p value	<0.001	<0.001	<0.01	>0.05	>0.05	<0.05
Pruning interval						
8 weeks (I1)	28.87^{a} (±0.53)	31.83^{b} (±0.78)	32.51^{b} (±0.59)	32.35 (±1.20)	35.62^{ab} (±0.40)	32.23^{b} (±0.52)
12 weeks (I2)	28.42^{b} (±0.37)	31.75^{b} (±0.55)	31.06^{c} (±0.31)	32.18 (±0.81)	34.96^{b} (±0.55)	31.67^{b} (±0.32)
16 weeks (I3)	28.42^{b} (±0.72)	32.76^{a} (±1.10)	35.89^{a} (±1.24)	33.74 (±1.49)	36.31^{a} (±0.54)	33.42^{a} (±0.95)
F value	15.87^{**}	94.00^{**}	86.43^{**}	1.66^{ns}	4.48^{*}	16.54^{**}
p value	<0.001	<0.001	<0.001	>0.05	<0.05	<0.001

** significant at $p<0.01$, * significant at $p<0.05$, ns= not significant at $p>0.05$, values with the same superscripts in a column do not differ significantly, values in parenthesis are standard error of means

Table 26. Interaction effect of tree density and pruning interval on soil water holding capacity at various depths at Vellanikkara, Thrissur, Kerala

Tree density	Soil water holding capacity (%)								
	0-20 cm			21-40 cm			41-60 cm		
	Pruning interval			Pruning interval			Pruning interval		
	I1	I2	I3	I1	I2	I3	I1	I2	I3
D1	27.33^{Bab}	28.67^{Aa}	26.22^{Cb}	34.41^{Aa}	30.83^{Bc}	31.30^{Bb}	33.81^{Aa}	31.26^{Ab}	32.21^{Cab}
D2	29.72^{Aab}	28.04^{Ab}	30.72^{Aa}	29.84^{Bb}	30.95^{Bb}	35.36^{Aa}	30.58^{Bb}	31.30^{Ab}	40.18^{Aa}
D3	29.58^{Aa}	28.56^{Aa}	28.32^{Ba}	31.24^{Bb}	33.46^{Aa}	34.27^{Aa}	33.13^{Ab}	30.62^{Ac}	35.29^{Ba}
F value	138.96^{**}			912.14^{**}			40.42^{**}		
p value	<0.001			<0.001			<0.001		
Control	27.35 (±0.69)			36.34 (±0.62)			37.48 (±0.68)		
F value	19.81^{**}			935.22^{**}			65.70^{**}		
p value	<0.01			<0.01			<0.01		
Tree density	61-80 cm			81-100 cm			Mean		
	I1	I2	I3	I1	I2	I3	I1	I2	I3
D1	35.69^{Aa}	31.87^{ABb}	28.79^{Bb}	36.00^{Aa}	35.69^{Aa}	34.80^{Ba}	33.45^{Aa}	31.66^{Aab}	30.14^{Cb}
D2	28.33^{Bb}	34.72^{Aa}	37.75^{Aa}	35.16^{Aa}	35.94^{Aa}	37.04^{Aa}	30.72^{Bb}	32.19^{Ab}	36.21^{Aa}
D3	33.03^{Aab}	29.94^{Bb}	34.67^{Aa}	35.69^{Aa}	33.24^{Bb}	37.08^{Aa}	32.53^{ABab}	31.17^{Ab}	33.93^{Ba}
F value	14.61^{**}			6.03^{*}			35.62^{**}		
p value	<0.001			<0.05			<0.001		
Control	35.13 (±0.64)			36.49 (±0.92)			34.56 (±0.62)		
F value	3.92^{ns}			1.73^{ns}			22.07^{**}		
p value	>0.05			>0.05			<0.01		

** significant at $p<0.01$, * significant at $p<0.05$, ns= not significant at $p>0.05$, values with the same small letters as superscripts indicates that they are on par row wise and values with the same capital letters as superscripts indicates that they are on par column wise, values in parenthesis are standard error of means, D1 – 27,777 plants ha^{-1}, D2 – 22,222 plants ha^{-1}, D3 – 17,777 plants ha^{-1}, I1 – 8 weeks, I2 – 12 weeks, I3 – 16 weeks pruning interval

Table 29 depicts the main effect of tree density and pruning interval on the available nitrogen concentration of soil at various depths. Both tree density and pruning interval had significant effect on the available nitrogen concentration of soil. On comparing the mean values of main effects, highest soil available nitrogen concentration was observed for medium tree density (0.18 g kg^{-1}) and the longest pruning interval (0.20 g kg^{-1}).

The interaction effect of different treatments on soil available nitrogen concentration at various depths is represented in table 30. Comparing the mean values, the soil available nitrogen concentration of various treatment combinations was recorded in the range of 0.16 to 0.21 g kg^{-1} and that of control (sole coconut plantation) was 0.16 g kg^{-1}. The highest soil available nitrogen concentration was observed for the treatment combination of 17,777 plants ha^{-1} and 16 weeks pruning interval (0.21 g kg^{-1}). Comparing different soil depths, N concentration was significantly higher in the deeper layers of calliandra intercropped plots than that of the sole coconut plots.

4.9.2.2 Total and available phosphorous concentration in soil

Table 31 shows the main effect of tree density and pruning interval on the total phosphorous concentration of soil at various depths. Both tree density and pruning interval had significant effect on the total phosphorous concentration of soil. On comparing the mean values of main effects, highest soil total phosphorous concentration was observed for highest tree density (351.41mg kg^{-1}) and the shortest pruning interval (378.16 mg kg^{-1}). Comparing various soil depths, P concentration was comparatively lower in 20-40cm depth than other areas, irrespective of treatments.

The interaction effect of different treatments on soil total phosphorous concentration at various depths is depicted in table 32. Comparing the mean values, the soil total phosphorous concentration of various treatment combinations was recorded in the range of 306.20 to 402.78 mg kg^{-1} and that of control (sole coconut plantation) was 351.53 mg kg^{-1}. The highest soil total phosphorous concentration was observed for the treatment combination of 27,777 plants ha^{-1} and 8 weeks pruning interval (402.78 mg kg^{-1}). Comparing soil depths, P concentration in 20-40 cm layer of calliandra intercropped plots were conspicuously lower than that of the contiguous sole coconut plots, whereas the reverse trend was observed in rest of the profile.

Table 33 depicts the main effect of tree density and pruning interval on the available phosphorous concentration of soil at various depths. Both tree density and pruning interval had significant effect on the available phosphorous concentration of soil. On comparing the mean values of main effects, highest soil available phosphorous concentration was observed for medium tree density (4.05 mg kg^{-1}) and the 12 weeks pruning interval (3.83 mg kg^{-1}). Comparing soil depths, available P content was significantly higher in surface layer than the remaining profile, whereas the reverse trend was observed in the case of total P concentration.

The interaction effect of different treatments on soil available phosphorous concentration at various depths is represented in table 34. Comparing the mean values, the soil available phosphorous concentration of various treatment combinations was recorded in the range of 3.05 to 4.67 mg kg^{-1} and that of control (sole coconut plantation) was 2.49 mg kg^{-1}. The highest soil available phosphorous concentration was observed for the treatment combination of 22,222 plants ha^{-1} and 12 weeks pruning interval (4.67 mg kg^{-1}). Similar to total P, the available P concentration at 20-40 cm depth of calliandra intercropped soils were comparatively lower than the corresponding layer of sole coconut plots.

4.9.2.3 Total and available potassium concentration in soil

Table 35 shows the main effect of tree density and pruning interval on the total potassium concentration of soil at various depths. Both tree density and pruning interval had significant effect on the total potassium concentration of soil. On comparing the mean values of main effects, highest soil total potassium concentration was observed for highest tree density (3.10 g kg^{-1}) and the shortest pruning interval (3.22 g kg^{-1}).

The interaction effect of different treatments on soil total potassium concentration at various depths is depicted in table 36. Comparing the mean values, the soil total potassium concentration of various treatment combinations was recorded in the range of 2.55 to 3.39 g kg^{-1} and that of control (sole coconut plantation) was 2.95 g kg^{-1}. The highest soil total potassium concentration was observed for the treatment combination of 27,777 plants ha^{-1} and 8 weeks pruning interval (3.39 g kg^{-1}), but was not statistically significant.

Table 37 depicts the main effect of tree density and pruning interval on the available potassium concentration of soil at various depths. Both tree density and pruning interval had significant effect on the available potassium concentration of soil. On comparing the mean values of main effects, highest soil available potassium concentration was observed for lowest tree density (0.11 g kg^{-1}) and all the pruning intervals were comparable (0.10 g kg^{-1}).

The interaction effect of different treatments on soil available potassium concentration at various depths is represented in table 38. Comparing the mean values, the soil available potassium concentration of various treatment combinations was recorded in the range of 0.08 to 0.12 g kg^{-1} and that of control (sole coconut plantation) was 0.06 g kg^{-1}. The highest soil available potassium concentration was observed for the treatment combination of 17,777 plants ha^{-1} and 8 weeks pruning interval (0.12 g kg^{-1}).

4.10 ECONOMICS

Economics and B:C ratio of fodder production as influenced by tree density and pruning interval in coconut plantation are projected in table 39. On comparison of different tree densities, the B:C ratio was maximum for the highest tree density (2.25) and minimum for the lowest tree density (1.75). The B:C ratio for the medium tree density (1.91) was found to be on par with the other two densities. Pruning interval had no significant effect on B:C ratio, even though a slight increment was observed at longer intervals than the shorter intervals. The B:C ratio of the coconut-fodder integrated system also followed a similar trend.

Comparing the economics of different treatments (table 40), the maximum B:C ratio for fodder production as well as coconut-fodder integrated system (2.33 and 2.71 respectively) was obtained for tree density of 27,777 plants ha^{-1} and 12 weeks pruning interval.

Table 27. Effect of tree density and pruning interval on total nitrogen concentration in soil at various depths at Vellanikkara, Thrissur, Kerala

Factors	Total nitrogen in soil (g kg^{-1})					
	0-20 cm	21-40 cm	41-60 cm	61-80 cm	81-100 cm	Mean
Tree density						
27,777 plants ha^{-1} (D1)	1.48^{b} (±0.03)	0.96^{b} (±0.04)	1.03 (±0.07)	0.96^{a} (±0.08)	0.93^{a} (±0.07)	1.07^{ab} (±0.05)
22,222 plants ha^{-1} (D2)	1.65^{a} (±0.06)	1.12^{a} (±0.07)	1.01 (±0.07)	1.03^{a} (±0.06)	0.86^{ab} (±0.07)	1.13^{a} (±0.06)
17,777 plants ha^{-1} (D3)	1.49^{b} (±0.03)	1.06^{a} (±0.06)	0.95 (±0.04)	0.78^{b} (±0.03)	0.78^{b} (±0.07)	1.01^{b} (±0.03)
F value	9.87^{**}	8.56^{**}	1.06^{ns}	11.34^{**}	5.71^{*}	6.30^{*}
p value	<0.01	<0.01	>0.05	<0.01	<0.05	<0.05
Pruning interval						
8 weeks (I1)	1.57 (±0.06)	01.10^{a} (±0.07)	1.01 (±0.06)	0.86 (±0.06)	0.82 (±0.08)	1.07 (±0.06)
12 weeks (I2)	1.49 (±0.03)	1.04^{ab} (±0.06)	1.00 (±0.06)	0.92 (±0.07)	0.86 (±0.07)	1.06 (±0.04)
16 weeks (I3)	1.56 (±0.05)	1.00^{b} (±0.04)	0.98 (±0.06)	1.00 (±0.08)	0.89 (±0.07)	1.08 (±0.05)
F value	1.87^{ns}	4.17^{*}	0.15^{ns}	3.41^{ns}	0.91^{ns}	0.20^{ns}
p value	>0.05	<0.05	>0.05	>0.05	>0.05	>0.05

** significant at $p<0.01$, * significant at $p<0.05$, ns= not significant at $p>0.05$, values with the same superscripts in a column do not differ significantly, values in parenthesis are standard error of means

Table 28. Interaction effect of tree density and pruning interval of calliandra on total nitrogen concentration in soil at various depths at Vellanikkara, Thrissur, Kerala

Treatments	Total nitrogen in soil (g kg^{-1})					
	0-20 cm	21-40 cm	41-60 cm	61-80 cm	81-100 cm	Mean
Tree density X Pruning interval						
D1 X I1	1.45	0.98	0.93	0.75	0.98	1.02
D1 X I2	1.45	0.93	1.07	1.07	0.79	1.06
D1 X I3	1.54	0.98	1.07	1.07	1.03	1.14
D2 X I1	1.73	1.12	1.12	0.98	0.84	1.16
D2 X I2	1.54	1.21	1.03	0.98	0.84	1.12
D2 X I3	1.68	1.03	0.89	1.12	0.89	1.12
D3 X I1	1.54	1.21	0.98	0.84	0.65	1.05
D3 X I2	1.49	0.98	0.89	0.70	0.93	1.00
D3 X I3	1.47	0.98	0.98	0.79	0.75	0.99
F value	1.73^{ns}	2.78^{ns}	2.34^{ns}	3.28^{ns}	3.08^{ns}	1.36^{ns}
p value	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05
Control	1.73	1.07	1.12	1.03	0.61	1.11
F value	9.00^{**}	0.18^{ns}	2.45^{ns}	1.45^{ns}	16.87^{**}	0.69^{ns}
p value	<0.01	>0.05	>0.05	>0.05	<0.01	>0.05

** significant at p<0.01, * significant at p<0.05, ns= not significant at p>0.05, values with the same superscripts in a column do not differ significantly, D1 – 27,777 plants ha^{-1}, D2 – 22,222 plants ha^{-1}, D3 – 17,777 plants ha^{-1}, I1 – 8 weeks, I2 – 12 weeks, I3 – 16 weeks pruning interval

Table 29. Effect of tree density and pruning interval on available nitrogen concentration in soil at various depths at Vellanikkara, Thrissur, Kerala

Factors	Available nitrogen in soil (g kg^{-1})					
	0-20 cm	21-40 cm	41-60 cm	61-80 cm	81-100 cm	Mean
Tree density						
27,777 plants ha^{-1} (D1)	0.20^{a} (±0.01)	0.16^{c} (±0.02)	0.17^{b} (±0.01)	0.19^{a} (±0.00)	0.18^{b} (±0.00)	0.17^{c} (±0.01)
22,222 plants ha^{-1} (D2)	0.17^{c} (±0.00)	0.19^{b} (±0.01)	0.19^{a} (±0.01)	0.19^{a} (±0.01)	0.19^{a} (±0.01)	0.18^{b} (±0.01)
17,777 plants ha^{-1} (D3)	0.18^{b} (±0.00)	0.20^{a} (±0.01)	0.19^{a} (±0.01)	0.18^{b} (±0.01)	0.19^{a} (±0.01)	0.19^{a} (±0.01)
F value	92.17^{**}	457.43^{**}	803.93^{**}	67.60^{**}	166.65^{**}	356.74^{**}
p value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Pruning interval						
8 weeks (I1)	0.20^{a} (±0.01)	0.15^{c} (±0.01)	0.16^{c} (±0.01)	0.17^{c} (±0.01)	0.16^{c} (±0.01)	0.17^{c} (±0.00)
12 weeks (I2)	0.18^{b} (±0.00)	0.20^{a} (±0.01)	0.19^{b} (±0.00)	0.18^{b} (±0.01)	0.18^{b} (±0.01)	0.19^{b} (±0.00)
16 weeks (I3)	0.17^{b} (±0.01)	0.19^{b} (±0.01)	0.20^{a} (±0.00)	0.21^{a} (±0.00)	0.21^{a} (±0.01)	0.20^{a} (±0.01)
F value	106.72^{**}	1212.53^{**}	2568.54^{**}	1527.60^{**}	704.48^{**}	2216.60^{**}
p value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

** significant at $p<0.01$, * significant at $p<0.05$, ns= not significant at $p>0.05$, values with the same superscripts in a column do not differ significantly, values in parenthesis are standard error of means

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Table 30. Interaction effect of tree density and pruning interval on available nitrogen concentration in soil at various depths at Vellanikkara, Thrissur, Kerala

Tree density	Available nitrogen in soil (g kg^{-1})								
	0-20 cm			21-40 cm			41-60 cm		
	Pruning interval			Pruning interval			Pruning interval		
	I1	I2	I3	I1	I2	I3	I1	I2	I3
D1	0.24^{Aa}	0.19^{Ab}	0.15^{Cc}	0.10^{Bc}	0.21^{Aa}	0.17^{Bb}	0.13^{Bb}	0.19^{Aa}	0.19^{Ba}
D2	0.18^{Ba}	0.17^{Ba}	0.17^{Ba}	0.17^{Ac}	0.18^{Bb}	0.20^{Aa}	0.17^{Ac}	0.20^{Ab}	0.21^{Aa}
D3	0.18^{Bb}	0.18^{Bb}	0.20^{Aa}	0.17^{Ab}	0.21^{Aa}	0.21^{Aa}	0.18^{Ac}	0.19^{Ab}	0.21^{Aa}
F value	188.17^{**}			326.75^{**}			213.90^{**}		
p value	<0.001			<0.001			<0.001		
Control	0.17 (±0.00)			0.17 (±0.00)			0.18 (±0.01)		
F value	8.7^{**}			22.5^{**}			0.006^{ns}		
p value	<0.01			<0.01			>0.05		
Tree density	61-80 cm			81-100 cm			Mean		
	I1	I2	I3	I1	I2	I3	I1	I2	I3
D1	0.17^{Bb}	0.19^{Aa}	0.20^{Ba}	0.16^{Bb}	0.19^{Aa}	0.18^{Ca}	0.16^{Bc}	0.19^{Aa}	0.18^{Cb}
D2	0.15^{Cb}	0.20^{Aa}	0.21^{Aa}	0.17^{Bc}	0.19^{Ab}	0.21^{Ba}	0.17^{Bc}	0.19^{Ab}	0.20^{Ba}
D3	0.19^{Ab}	0.14^{Bc}	0.21^{Aa}	0.20^{Ab}	0.16^{Bc}	0.22^{Aa}	0.18^{Ab}	0.17^{Bb}	0.21^{Aa}
F value	1055.20^{**}			463.18^{**}			825.06^{**}		
p value	<0.001			<0.001			<0.001		
Control	0.13 (±0.01)			0.14 (±0.01)			0.16 (±0.01)		
F value	373.20^{**}			0.61^{ns}			14.17^{**}		
p value	<0.01			>0.05			<0.01		

** significant at $p<0.01$, * significant at $p<0.05$, ns= not significant at $p>0.05$, values with the same small letters as superscripts indicates that they are on par row wise and values with the same capital letters as superscripts indicates that they are on par column wise, values in parenthesis are standard error of means, D1 – 27,777 plants ha^{-1}, D2 – 22,222 plants ha^{-1}, D3 – 17,777 plants ha^{-1}, I1 – 8 weeks, I2 – 12 weeks, I3 – 16 weeks pruning interval

Table 31. Effect of tree density and pruning interval on total phosphorous concentration in soil at various depths at Vellanikkara, Thrissur, Kerala

Factors	Total phosphorus in soil (mg kg^{-1})					
	0-20 cm	21-40 cm	41-60 cm	61-80 cm	81-100 cm	Mean
Tree density						
27,777 plants ha^{-1} (D1)	396.67^{a} (±26.25)	263.57^{b} (±11.78)	331.56^{a} (±14.13)	339.27^{a} (±14.10)	426.01^{a} (±20.40)	351.41^{a} (±14.13)
22,222 plants ha^{-1} (D2)	393.45^{a} (±13.27)	262.56^{b} (±4.69)	321.51^{b} (±13.81)	330.56^{c} (±15.07)	404.30^{c} (±17.35)	342.48^{b} (±12.35)
17,777 plants ha^{-1} (D3)	384.61^{b} (±18.87)	273.28^{a} (±10.09)	325.20^{b} (±11.04)	335.25^{b} (±11.91)	411.54^{b} (±15.38)	345.97^{b} (±13.40)
F value	14.13^{**}	10.51^{**}	8.75^{**}	13.59^{**}	126.00^{**}	14.03^{**}
p value	<0.001	<0.01	<0.01	<0.001	<0.001	<0.001
Pruning interval						
8 weeks (I1)	442.09^{a} (±20.25)	273.28^{a} (±11.37)	355.01^{a} (±11.34)	365.06^{a} (±11.08)	455.35^{a} (±16.81)	378.16^{a} (±11.67)
12 weeks (I2)	381.39^{b} (±15.97)	275.96^{a} (±9.16)	329.55^{b} (±11.35)	342.28^{b} (±11.52)	417.57^{b} (±14.11)	349.35^{b} (±10.83)
16 weeks (I3)	351.25^{c} (±5.53)	250.17^{b} (±2.80)	293.71^{c} (±4.94)	297.73^{c} (±4.91)	368.93^{c} (±5.75)	312.36^{c} (±3.33)
F value	775.63^{**}	60.33^{**}	320.98^{**}	838.98^{**}	1936.17^{**}	752.66^{**}
p value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

** significant at $p<0.01$, * significant at $p<0.05$, ns= not significant at $p>0.05$, values with the same superscripts in a column do not differ significantly, values in parenthesis are standard error of means

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Table 32. Interaction effect of tree density and pruning interval on total phosphorous concentration in soil at various depths at Vellanikkara, Thrissur, Kerala

Tree density	Total phosphorus in soil (mg kg^{-1})								
	0-20 cm			21-40 cm			41-60 cm		
	Pruning interval			Pruning interval			Pruning interval		
	I1	I2	I3	I1	I2	I3	I1	I2	I3
D1	500.37^{Aa}	352.05^{Bb}	337.58^{Bb}	235.09^{Cb}	309.45^{Aa}	246.15^{Bb}	384.82^{Aa}	319.50^{Bb}	290.36^{Bc}
D2	366.52^{Cb}	443.70^{Aa}	370.14^{Ab}	272.27^{Ba}	270.27^{Ba}	245.14^{Bb}	312.47^{Cb}	371.76^{Aa}	280.31^{Bc}
D3	459.37^{Ba}	348.43^{Bb}	346.02^{Bb}	312.47^{Aa}	248.16^{Cb}	259.21^{Ab}	367.74^{Ba}	297.40^{Cb}	310.46^{Ab}
F value	470.16**			120.89**			171.85**		
p value	<0.001			<0.001			<0.001		
Control	311.05 (±3.19)			326.54 (±1.00)			338.60 (±2.66)		
F value	649.12**			340.75**			15.34**		
p value	<0.01			<0.01			<0.01		
Tree density	61-80 cm			81-100 cm			Mean		
	I1	I2	I3	I1	I2	I3	I1	I2	I3
D1	390.85^{Aa}	331.56^{Bb}	295.39^{Ca}	502.78^{Aa}	409.93^{Bb}	365.32^{Bc}	402.78^{Aa}	344.50^{Bb}	306.96^{Bc}
D2	322.52^{Bb}	385.82^{Aa}	283.33^{Bc}	391.84^{Cb}	469.01^{Aa}	352.05^{Bc}	333.13^{Bb}	388.11^{Aa}	306.20^{Bc}
D3	381.80^{Aa}	309.45^{Cb}	314.48^{Ab}	471.43^{Ba}	373.76^{Cc}	389.43^{Ab}	398.56^{Aa}	315.44^{Cc}	323.92^{Ab}
F value	371.02**			958.67**			334.71**		
p value	<0.001			<0.001			<0.001		
Control	348.64 (±3.48)			432.84 (±4.18)			351.53 (±2.69)		
F value	31.08**			67.06**			4.40^{ns}		
p value	<0.01			<0.01			>0.05		

** significant at $p<0.01$, * significant at $p<0.05$, ns= not significant at $p>0.05$, values with the same small letters as superscripts indicates that they are on par row wise and values with the same capital letters as superscripts indicates that they are on par column wise, values in parenthesis are standard error of means, D1 – 27,777 plants ha^{-1}, D2 – 22,222 plants ha^{-1}, D3 – 17,777 plants ha^{-1}, I1 – 8 weeks, I2 – 12 weeks, I3 – 16 weeks pruning interval

Table 33. Effect of tree density and pruning interval on available phosphorous concentration in soil at various depths at Vellanikkara, Thrissur, Kerala

Factors	Available phosphorus in soil (mg kg^{-1})					
	0-20 cm	21-40 cm	41-60 cm	61-80 cm	81-100 cm	Mean
Tree density						
27,777 plants ha^{-1} (D1)	8.14^{a} (±0.91)	2.69^{b} (±0.44)	2.98^{c} (±0.40)	2.25^{b} (±0.31)	2.27^{b} (±0.38)	3.67^{b} (±0.12)
22,222 plants ha^{-1} (D2)	8.37^{a} (±0.43)	2.43^{c} (±0.21)	3.91^{a} (±0.32)	2.64^{a} (±0.26)	2.90^{a} (±0.24)	4.05^{a} (±0.21)
17,777 plants ha^{-1} (D3)	7.15^{b} (±0.91)	3.91^{a} (±0.48)	3.27^{b} (±0.42)	2.02^{c} (±0.44)	2.02^{b} (±0.32)	3.67^{b} (±0.20)
F value	27.19^{**}	99.74^{**}	96.07^{**}	36.34^{**}	15.48^{**}	19.29^{**}
p value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Pruning interval						
8 weeks (I1)	10.11^{a} (±0.56)	3.24^{a} (±0.48)	2.86^{c} (±0.39)	1.22^{c} (±0.18)	1.41^{a} (±0.22)	3.77 (±0.13)
12 weeks (I2)	7.70^{b} (±0.56)	2.95^{b} (±0.39)	3.27^{b} (±0.38)	2.73^{b} (±0.28)	2.48^{b} (±0.21)	3.83 (±0.27)
16 weeks (I3)	5.85^{c} (±0.04)	2.84^{b} (±0.48)	4.03^{a} (±0.34)	2.95^{a} (±0.22)	3.30^{a} (±0.20)	3.79 (±0.14)
F value	294.43^{**}	6.98^{*}	148.44^{**}	330.89^{**}	67.91^{**}	0.37^{ns}
p value	<0.001	<0.05	<0.001	<0.001	<0.001	>0.05

** significant at $p<0.01$, * significant at $p<0.05$, ns= not significant at $p>0.05$, values with the same superscripts in a column do not differ significantly, values in parenthesis are standard error of means

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Table 34. Interaction effect of tree density and pruning interval on available phosphorous concentration in soil at various depths at Vellanikkara, Thrissur, Kerala

Tree density	Available phosphorus in soil (mg kg^{-1})								
	0-20 cm			21-40 cm			41-60 cm		
	Pruning interval			Pruning interval			Pruning interval		
	I1	I2	I3	I1	I2	I3	I1	I2	I3
D1	11.70^{Aa}	6.82^{Bb}	5.92^{Bb}	1.90^{Cb}	4.38^{Aa}	1.79^{Bb}	2.10^{Bb}	2.34^{Bb}	4.50^{Aa}
D2	8.08^{Cb}	9.81^{Aa}	7.21^{Ab}	2.93^{Ba}	2.34^{Ba}	2.02^{Ba}	4.34^{Aa}	4.66^{Aa}	2.73^{Bb}
D3	10.56^{Ba}	6.47^{Bb}	4.42^{Cc}	4.89^{Aa}	2.14^{Bb}	4.70^{Aa}	2.14^{Bb}	2.81^{Bb}	4.85^{Aa}
F value	80.44^{**}			122.01^{**}			265.46^{**}		
p value	<0.001			<0.001			<0.001		
Control	3.48 (±0.17)			5.48 (±0.17)			2.02 (±0.14)		
F value	375.00^{**}			258.13^{**}			193.08^{**}		
p value	<0.01			<0.01			<0.01		
Tree density	61-80 cm			81-100 cm			Mean		
	I1	I2	I3	I1	I2	I3	I1	I2	I3
D1	1.12^{ABb}	3.12^{Aa}	2.49^{Ba}	1.08^{Bc}	2.14^{Bb}	3.60^{Aa}	3.58^{Aa}	3.76^{Ba}	3.66^{Aa}
D2	1.83^{Ab}	3.32^{Aa}	2.77^{Ba}	2.14^{Ab}	3.20^{Aa}	3.36^{Aa}	3.86^{Ab}	4.67^{Aa}	3.62^{Ab}
D3	0.72^{Bc}	1.75^{Bb}	3.60^{Aa}	1.00^{Bc}	2.10^{Bb}	2.95^{Aa}	3.86^{Aa}	3.05^{Bb}	4.11^{Aa}
F value	67.37^{**}			3.53^{*}			40.85^{**}		
p value	<0.001			<0.05			<0.001		
Control	1.04 (±0.08)			0.49 (±0.04)			2.49 (±0.09)		
F value	215.35^{**}			93.18^{**}			199.13^{**}		
p value	<0.01			<0.01			<0.01		

** significant at $p<0.01$, * significant at $p<0.05$, ns= not significant at $p>0.05$, values with the same small letters as superscripts indicates that they are on par row wise and values with the same capital letters as superscripts indicates that they are on par column wise, values in parenthesis are standard error of means, D1 – 27,777 plants ha^{-1}, D2 – 22,222 plants ha^{-1}, D3 – 17,777 plants ha^{-1}, I1 – 8 weeks, I2 – 12 weeks, I3 – 16 weeks pruning interval

Table 35. Effect of tree density and pruning interval on total potassium concentration in soil at various depths at Vellanikkara, Thrissur, Kerala

Factors	Total potassium in soil (g kg^{-1})					
	0-20 cm	21-40 cm	41-60 cm	61-80 cm	81-100 cm	Mean
Tree density						
27,777 plants ha^{-1} (D1)	2.84^a (±0.11)	3.23^a (±0.08)	3.18^a (±0.10)	3.18^a (±0.18)	3.09^c (±0.16)	3.10^a (±0.10)
22,222 plants ha^{-1} (D2)	2.71^b (±0.14)	2.64^c (±0.14)	2.85^b (±0.19)	2.87^b (±0.14)	3.39^b (±0.13)	2.89^b (±0.12)
17,777 plants ha^{-1} (D3)	2.49^c (±0.15)	2.85^b (±0.07)	2.85^b (±0.07)	2.78^c (±0.14)	3.56^a (±0.07)	2.91^b (±0.07)
F value	43.98^{**}	180.82^{**}	218.42^{**}	77.06^{**}	250.70^{**}	81.96^{**}
p value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Pruning interval						
8 weeks (I1)	2.99^a (±0.06)	3.10^a (±0.11)	3.20^a (±0.14)	3.23^a (±0.16)	3.57^a (±0.06)	3.22^a (±0.09)
12 weeks (I2)	2.73^b (±0.16)	2.89^b (±0.12)	2.96^b (±0.06)	2.55^c (±0.08)	3.18^c (±0.09)	2.86^b (±0.07)
16 weeks (I3)	2.32^c (±0.08)	2.73^c (±0.14)	2.72^c (±0.15)	3.06^b (±0.15)	3.29^b (±0.20)	2.82^c (±0.09)
F value	159.38^{**}	71.68^{**}	344.86^{**}	214.85^{**}	170.47^{**}	273.32^{**}
p value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

** significant at $p<0.01$, * significant at $p<0.05$, ns= not significant at $p>0.05$, values with the same superscripts in a column do not differ significantly, values in parenthesis are standard error of means

Table 36. Interaction effect of tree density and pruning interval on total potassium concentration in soil at various depths at Vellanikkara, Thrissur, Kerala

Tree density	Total potassium in soil (g kg^{-1})								
	0-20 cm			21-40 cm			41-60 cm		
	Pruning interval			Pruning interval			Pruning interval		
	I1	I2	I3	I1	I2	I3	I1	I2	I3
D1	2.87^{Aa}	3.14^{Aa}	2.51^{Ab}	3.34^{Aa}	3.21^{Aa}	3.15^{Aa}	3.54^{Aa}	3.04^{Ab}	2.96^{Ab}
D2	3.04^{Aa}	2.92^{Aa}	2.18^{Ab}	3.13^{ABa}	2.51^{Bb}	2.28^{Cb}	3.36^{Aa}	3.04^{Ab}	2.13^{Bc}
D3	3.05^{Aa}	2.15^{Bb}	2.27^{Ab}	2.85^{Ba}	2.96^{Aa}	2.75^{Ba}	2.69^{Bb}	2.80^{Aab}	3.06^{Aa}
F value	50.35^{**}			35.36^{**}			365.50^{**}		
p value	<0.001			<0.001			<0.001		
Control	2.45 (±0.14)			2.94 (±0.14)			3.39 (±0.11)		
F value	10.65^{**}			0.27^{ns}			85.50^{**}		
p value	<0.01			>0.05			<0.01		
Tree density	61-80 cm			81-100 cm			Mean		
	I1	I2	I3	I1	I2	I3	I1	I2	I3
D1	3.64^{Aa}	2.53^{Ab}	3.38^{Aa}	3.55^{Aa}	3.20^{ABb}	2.51^{Bc}	3.39^{Aa}	3.03^{Ab}	2.90^{Ab}
D2	3.37^{Aa}	2.73^{Ab}	2.52^{Bb}	3.61^{Aa}	2.91^{Bb}	3.65^{Aa}	3.30^{Aa}	2.82^{Ab}	2.55^{Bb}
D3	2.67^{Bb}	2.38^{Ab}	3.28^{Aa}	3.54^{Aa}	3.44^{Aa}	3.71^{Aa}	2.96^{Ba}	2.75^{Aa}	3.01^{Aa}
F value	105.42^{**}			255.62^{**}			85.85^{**}		
p value	<0.001			<0.001			<0.001		
Control	2.59 (±0.08)			3.37 (±0.08)			2.95 (±0.10)		
F value	45.21^{**}			0.33^{ns}			0.15^{ns}		
p value	<0.01			>0.05			>0.05		

** significant at p<0.01, * significant at p<0.05, ns= not significant at p>0.05, values with the same small letters as superscripts indicates that they are on par row wise and values with the same capital letters as superscripts indicates that they are on par column wise, values in parenthesis are standard error of means, D1 – 27,777 plants ha^{-1}, D2 – 22,222 plants ha^{-1}, D3 – 17,777 plants ha^{-1}, I1 – 8 weeks, I2 – 12 weeks, I3 – 16 weeks pruning interval

Table 37. Effect of tree density and pruning interval on available potassium concentration in soil at various depths at Vellanikkara, Thrissur, Kerala

Factors	Available potassium in soil (g kg^{-1})					
	0-20 cm	21-40 cm	41-60 cm	61-80 cm	81-100 cm	Mean
Tree density						
27,777 plants ha^{-1} (D1)	0.21^{b} (±0.01)	0.11^{a} (±0.01)	0.06 (±0.00)	0.05^{b} (±0.00)	0.05^{b} (±0.00)	0.10^{b} (±0.01)
22,222 plants ha^{-1} (D2)	0.21^{b} (±0.01)	0.08^{b} (±0.02)	0.06 (±0.01)	0.05^{b} (±0.00)	0.05^{b} (±0.00)	0.09^{b} (±0.00)
17,777 plants ha^{-1} (D3)	0.23^{a} (±0.01)	0.11^{a} (±0.02)	0.06 (±0.00)	0.07^{a} (±0.01)	0.07^{a} (±0.00)	0.11^{a} (±0.01)
F value	103.95^{**}	27.45^{**}	3.15^{ns}	22.49^{**}	24.35^{**}	43.45^{**}
p value	<0.001	<0.001	>0.05	<0.001	<0.001	<0.001
Pruning interval						
8 weeks (I1)	0.22^{a} (±0.01)	0.11^{b} (±0.02)	0.055^{b} (±0.01)	0.06 (±0.01)	0.05^{b} (±0.00)	0.10 (±0.01)
12 weeks (I2)	0.21^{b} (±0.01)	0.12^{a} (±0.01)	0.062^{a} (±0.02)	0.05 (±0.00)	0.05^{b} (±0.00)	0.10 (±0.00)
16 weeks (I3)	0.22^{a} (±0.01)	0.08^{c} (±0.01)	0.058^{ab} (±0.01)	0.06 (±0.01)	0.06^{a} (±0.00)	0.10 (±0.00)
F value	66.40^{**}	48.47^{**}	4.19^{*}	3.16^{ns}	5.51^{*}	1.96^{ns}
p value	<0.001	<0.001	<0.05	>0.05	<0.05	>0.05

** significant at $p<0.01$, * significant at $p<0.05$, ns= not significant at $p>0.05$, values with the same superscripts in a column do not differ significantly, values in parenthesis are standard error of means

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Table 38. Interaction effect of tree density and pruning interval on available potassium concentration in soil at various depths at Vellanikkara, Thrissur, Kerala

Tree density	Available potassium in soil (g kg^{-1})								
	0-20 cm			21-40 cm			41-60 cm		
	Pruning interval			Pruning interval			Pruning interval		
	I1	I2	I3	I1	I2	I3	I1	I2	I3
D1	0.25^{Aa}	0.16^{Cb}	0.21^{Ac}	0.10^{Bb}	0.09^{Bb}	0.14^{Aa}	0.05^{Ab}	0.05^{Bb}	0.07^{Aa}
D2	0.20^{Bb}	0.19^{Bb}	0.24^{Aa}	0.05^{Cb}	0.15^{Aa}	0.06^{Bb}	0.05^{Ab}	0.08^{Aa}	0.05^{Ab}
D3	0.21^{Bb}	0.26^{Aa}	0.22^{Ab}	0.17^{Aa}	0.10^{Bb}	0.05^{Bc}	0.06^{Aa}	0.06^{Ba}	0.06^{Aa}
F value	284.33**			176.04**			17.36**		
p value	<0.001			<0.001			<0.001		
Control	0.12 (±0.07)			0.05 (±0.00)			0.05 (±0.00)		
F value	52.00**			25.26**			1.17^{ns}		
p value	<0.01			<0.01			>0.05		
Tree density	61-80 cm			81-100 cm			Mean		
	I1	I2	I3	I1	I2	I3	I1	I2	I3
D1	0.05	0.05	0.05	0.05	0.05	0.06	0.10^{Ba}	0.08^{Bb}	0.10^{Aa}
D2	0.05	0.05	0.05	0.05	0.05	0.05	0.08^{Cb}	0.10^{Aa}	0.09^{Aab}
D3	0.08	0.06	0.08	0.06	0.06	0.07	0.12^{Aa}	0.11^{Aab}	0.10^{Ab}
F value	1.58^{ns}			1.40^{ns}			50.36**		
p value	>0.05			<0.001			<0.001		
Control	0.04 (±0.00)			0.05 (±0.00)			0.06 (±0.00)		
F value	6.80*			0.93^{ns}			22.50**		
p value	<0.05			>0.05			<0.01		

** significant at $p<0.01$, * significant at $p<0.05$, ns= not significant at $p>0.05$, values with the same small letters as superscripts indicates that they are on par row wise and values with the same capital letters as superscripts indicates that they are on par column wise, values in parenthesis are standard error of means, D1 – 27,777 plants ha^{-1}, D2 – 22,222 plants ha^{-1}, D3 – 17,777 plants ha^{-1}, I1 – 8 weeks, I2 – 12 weeks, I3 – 16 weeks pruning interval

Table 39. Economics of fodder production as influenced by tree density and pruning interval under coconut plantation at Vellanikkara, Thrissur, Kerala

Factors	Fodder yield of three years (Mg ha^{-1})	B:C ratio of fodder production	B:C ratio of coconut-fodder integrated system
Tree density			
27,777 plants ha-1 (D1)	122.14^{a}	2.25^{a}	2.65^{a}
22,222 plants ha-1 (D2)	97.84^{b}	1.91^{ab}	2.37^{ab}
17,777 plants ha-1 (D3)	85.49^{b}	1.75^{b}	2.27^{b}
F value	8.94^{**}	4.71^{*}	4.07^{*}
p value	<0.01	0.03	0.04
Pruning interval			
8 weeks (I1)	98.33	1.81	2.28
12 weeks (I2)	106.93	2.09	2.52
16 weeks (I3)	100.20	2.02	2.48
F value	0.53^{ns}	1.54^{ns}	1.81^{ns}
p value	0.60	0.24	0.20

** significant at p<0.01, * significant at p<0.05, ns= not significant at p>0.05, values with the same superscripts in a column do not differ significantly

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Table 40. Economics of fodder production as influenced by various treatment combinations under coconut plantation at Vellanikkara, Thrissur, Kerala

Treatments	Total cost of fodder production (₹ ha^{-1} yr^{-1})	Fodder yield over three years (Mg ha^{-1} yr^{-1})	Returns from fodder (₹ yr^{-1})	B:C ratio of fodder production	Cost of harvesting coconuts (₹ yr^{-1})	Returns from coconuts (₹ yr^{-1})	Total returns from coconut-fodder production system (₹ yr^{-1})	Net returns from coconut-fodder integrated system (₹ yr^{-1})	B:C ratio of coconut-fodder integrated system
D1 X I1	398150.00	122.55	857855.38	2.15	77850.00	358456.00	1216311.38	740311.38	2.56
D1 X I2	378131.25	125.53	650471.24	2.33	77850.00	357072.00	1007543.24	551561.99	2.71
D1 X I3	360281.25	118.36	556663.72	2.27	77850.00	351536.00	908199.72	470068.47	2.67
D2 X I1	376550.00	92.92	878684.94	1.72	77850.00	354304.00	1232988.94	778588.94	2.21
D2 X I2	356531.25	104.20	729397.51	2.05	77850.00	351536.00	1080933.51	646552.26	2.49
D2 X I3	338681.25	96.39	637469.61	1.95	77850.00	350152.00	987621.61	571090.36	2.42
D3 X I1	365750.00	79.52	828492.87	1.55	77850.00	354304.00	1182796.87	739196.87	2.07
D3 X I2	345731.25	91.07	674697.62	1.88	77850.00	351536.00	1026233.62	602652.37	2.37
D3 X I3	327881.25	85.87	601066.94	1.83	77850.00	352920.00	953986.94	548255.69	2.35
F value		0.08^{ns}		0.07^{ns}					0.08^{ns}
p value		0.99		0.99					0.99

DISCUSSION

DISCUSSION

Forage yield, soil fertility and carbon dynamics of calliandra (*Calliandra calothyrsus* Meissn.) in coconut plantation under varying management regimes of tree densities and pruning intervals were studied and observations are discussed hereunder.

5.1 EFFECT OF TREE DENSITY AND PRUNING INTERVAL ON FODDER YIELD OF CALLIANDRA UNDER COCONUT PLANTATION

5.1.1 Tree density

The management of fodder trees for optimum fodder production depends on several factors like tree density, pruning interval, etc.

As depicted in fig 3 and fig 4, tree density had significant influence on fodder yield of calliandra. Higher densities recorded maximum fodder yield per unit area. Total fodder yield increased from 43.44 to 55.40 Mg ha^{-1} yr^{-1} from lower to higher density classes. There was also an increment of 30 percent in fresh edible fodder yield (leaf + edible stem) with increasing density from 17,777 to 27,777 plants ha^{-1}. Total dry fodder yield increased from 13.87 to 16.97 Mg ha^{-1} yr^{-1} from the lowest to the highest density, thereby indicating the necessity of closer planting of fodder trees for maximising forage production along with the optimum utilisation of available resources Similar reports were given by Ella *et al.* (1989), who observed that, in *Calliandra spp., Leucaena spp., Gliricidia spp.* and *Sesbania spp.,* when tree spacing was reduced, yield from each plant decreased due to competition, but total fodder yield per unit area increased.

In a previous study conducted in Kerala, Raj *et al.* (2016) reported maximum yields from mulberry and subabul at still higher density of 49,382 plant ha^{-1}, when planted as an intercrop in coconut garden. Turgut *et al.* (2005) explained the increase in yield in the case of narrow spacing due to greater solar energy interception. Moreover, higher yields under closer spacing could be due to thick canopy cover that prevents weed growth and reduces evaporation from the soil surface, there by promoting better growth of plants (Erkan and Aydin, 2016).

Tree density also had prominent effect on production of foliage and different stem fractions and it increased with increasing density. Highest tree density produced maximum dry leaf yield (9.04 Mg ha^{-1} yr^{-1}) compared to the lowest tree density (7.28 Mg ha^{-1} yr^{-1}). The highest dry edible fodder yield (12.64 Mg ha^{-1} yr^{-1}), which constitutes the leaf and edible stem, was also obtained for the highest density, that was 21 and 26 per cent higher than medium and lowest tree density This calls for the need of closer planting for the maximum production of palatable and nutritive fodder per unit area.

According to Pathak *et al.* (1980) highest tree density (40,000 plants ha-1) reported higher leaf dry matter yields (5.40 t ha^{-1} yr^{-1}) compared to that of lower plant density (15,000 plants ha-1). Ella *et al.* (1989) observed that in the case of *Calliandra, Leucaena, Gliricidia* and *Sesbania,* foliage production per unit area increased as the tree density increased. Raj *et al.*, (2016) reported higher dry foliage yields (7.14 Mg ha-1 yr-1) from mulberry and subabul trees at highest plant density (49,382 plants ha-1) than lower densities. Various fractions of stem also presented similar trends. As the tree density increased, leaf-stem ratio also increased but the differences were statistically non-significant.

5.1.2 Pruning interval

Pruning interval is a crucial management factor that influences sustainable fodder production as well as the palatability and quality of the forage. Our study also indicated that cutting interval had a more profound influence on stem and leaf fractions, which decides the palatability of forage, rather than the total forage yield. Even though maximum total fresh fodder yield (52.12 Mg ha^{-1} yr^{-1}) was recorded for longest interval of 16 weeks, a major portion, 17.22 Mg ha^{-1} yr^{-1} (33%) was inedible woody fraction, which is not palatable to animals.

Highest edible forage yield (40.16 Mg ha^{-1} yr^{-1}) which constitutes the leaf and edible stem fraction, was obtained for the medium pruning frequency of 12 weeks, followed by 8weeks interval. The edible dry fodder yield (leaf + edible stem) was highest for the medium pruning interval of 12 weeks (12.02 Mg ha^{-1} yr^{-1}), followed by 16 weeks (11.44 Mg ha^{-1} yr^{-1}). Fresh edible forage yield from 8 weeks cutting interval (37.81 Mg ha^{-1} yr^{-1}) was higher than that of 16 weeks cutting interval (34.90 Mg ha^{-1} yr^{-1}). But, on the other hand, dry edible fodder yield from 8 weeks pruning interval (9.60 Mg ha^{-1} yr^{-1}) was far lower than that of 16 weeks pruning interval (11.44 Mg ha^{-1} yr^{-1}). This might be due to high moisture and low dry matter content in the tender shoots, pruned at shorter intervals.

Leaf-stem ratio was significantly higher at 8 weeks pruning interval (1.74), followed by 12 weeks interval (1.24), indicating the production of more foliage and less inedible stem portions when cut at shorter cutting intervals. Ella *et al.* (1989) and Saddul *et al.,* (2004) also claim that the total fodder biomass production increases with longer cutting intervals, but the additional total fodder yield after a certain period of time mainly consists of inedible woody fractions. Raj *et al.* (2016) also obtained higher foliage yield from mulberry and subabul by pruning at shorter interval of 8 weeks than at higher intervals. In Karnataka, Basavaraju and Rao (1995) obtained maximum herbage yields from calliandra at cutting interval of 60 days compared to higher intervals.

5.2 INTERACTION EFFECT OF TREE DENSITY AND PRUNING INTERVAL ON FODDER YIELD UNDER COCONUT PLANTATION

Interaction effect of tree densities and pruning intervals showed no significant effect on forage yield of calliandra (Table 2). On comparing various treatment combinations, the total fresh fodder yield was found to be highest for highest density stand, pruned at prolonged interval of 16 weeks (D1xI3), but the edible fodder yield (46.25 Mg ha^{-1} yr^{-1}) was greater for the combination of 27,777 plants ha^{-1} (D1) and 12 weeks pruning interval (I2) with a foliage production of 31.57 Mg ha^{-1} yr^{-1}. The treatment combination of 27,777 plants ha^{-1} (D1) and 8 weeks pruning interval (I1) also presented a comparable fresh edible fodder yield of 45.30 Mg ha^{-1} $yr^{-1}$with a leaf production of 30.08 Mg ha^{-1} yr^{-1}.

The annual dry edible fodder yield (13.84 Mg ha^{-1} yr^{-1}) was maximum for the combination of 27,777 plants ha^{-1} (D1) and 12 weeks pruning interval (I2) with a foliage production of 9.89 Mg ha^{-1} yr^{-1} and leaf-stem ratio of 1.36. The treatment combination of 27,777 plants ha^{-1} (D1) and 16 weeks pruning interval (I3) also presented a comparable dry edible fodder yield of 12.63 Mg ha^{-1} yr^{-1} with a leaf production of 9.07 Mg ha^{-1} yr^{-1}, but the leaf-stem ratio was very low (0.80).

In consistent with the fresh yield trends, total dry fodder yield was also higher for D1xI3, but the edible forage fraction (13.84 Mg ha^{-1} yr^{-1}) was greater for D1xI2 (27,777 plants ha^{-1} and 12 weeks pruning interval), which also had a higher leaf-stem ratio (1.36) as against the ratio of 0.80 in D1xI3. Various studies reinforce the fact that even though the total fodder yield continues to increase with longer pruning frequencies, the additional yield after a certain interval consists mainly of inedible woody portions (Ella *et al.*, 1989). Comparing fresh and dry forage yields, foliage production, edible fodder yield and leaf-stem ratio, the optimum strategy for maximum fodder production in calliandra is to plant trees at a density of 27,777 plants ha^{-1} and cut them at an interval of 12 weeks.

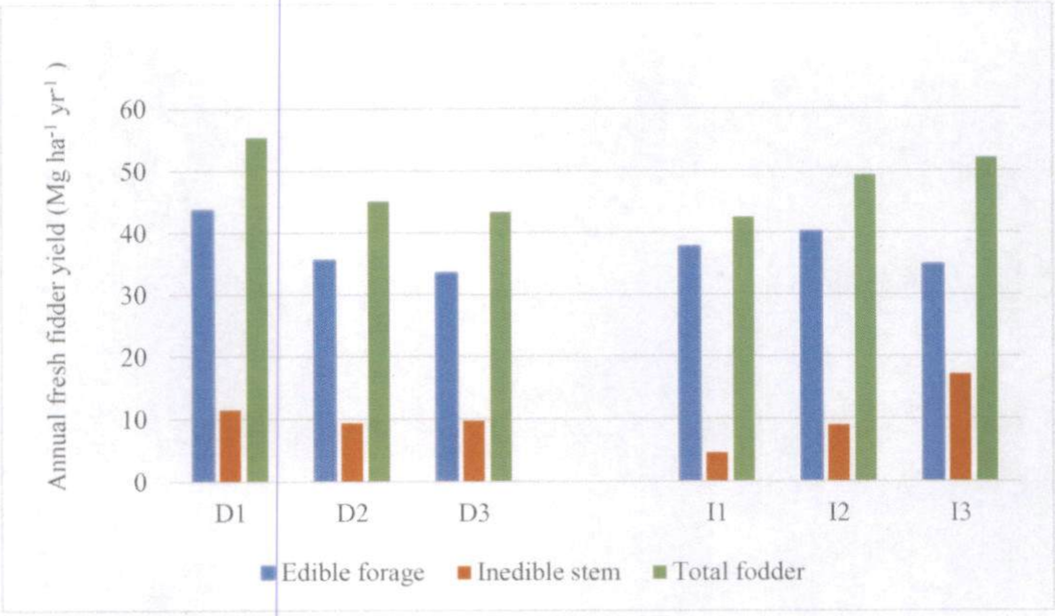

Fig. 3. Annual fresh fodder yield of calliandra as influenced by tree density and pruning interval under coconut plantation, Vellanikkara, Kerala

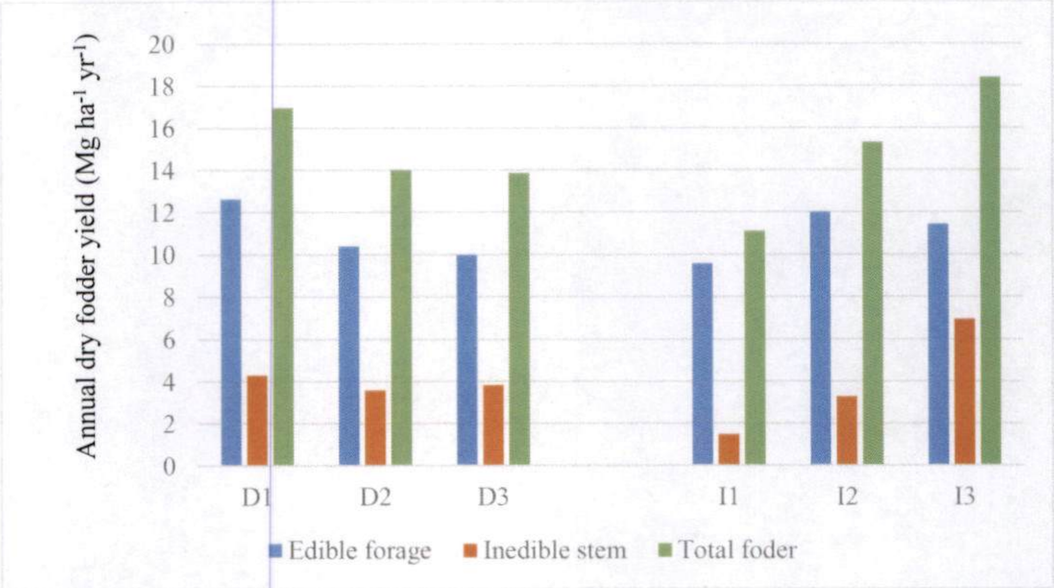

Fig. 4. Annual dry fodder yield of calliandra as influenced by tree density and pruning interval under coconut plantation, Vellanikkara, Kerala

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5.3 EFFECT OF TREE DENSITY AND PRUNING INTERVAL OF INTERCROPPED CALLIANDRA ON NUT YIELD OF COCONUT PALMS.

Annual nut yield from coconut during the third year as well as the number of nuts of various size classes now existing in the palm were estimated to study the influence of intercropping calliandra and various management regimes on coconut yield. The results indicated that management aspects like tree density and pruning interval of intercropped calliandra had no significant effect on annual nut yield of coconut palms on the third year. Similarly, there was no significant difference in annual nut yield between sole coconut palms (14,705 nuts ha^{-1}) and the palms intercropped with calliandra trees (14,590-14,936 nuts ha^{-1}).

However, the count on the existing nuts in coconut palms revealed that the yield from coconut monoculture was significantly lower (15,455 nuts ha^{-1}) when compared to that of the coconut plots intercropped with calliandra trees (16,608-16,781 nuts ha^{-1}). The nuts of various size classes now existing in the palms are formed during the previous 3 years, during which calliandra was intercropped in coconut. Hence, the number of nuts in the palms is actually the manifestation of effect of intercropping calliandra with coconut. This increment of coconut productivity in calliandra intercropped plots could be attributed to the nitrogen fixing nature of calliandra which could have provided a part of the nitrogen fixed to the component coconut. Similarly, the intercropped plots were manured, fertilized and irrigated which could have benefitted the coconut also, resulting in improving coconut productivity.

Several other authors also report that intercropping nitrogen fixing trees have no negative impact on the yield of coconut (Liyanage and Jayasundara 1987; Kumar, 2007). Moreover, since calliandra is regularly pruned, it remains as a lower layer and never interferes with the coconut canopy avoiding any vertical competition for above ground resources. It should also be assumed that the below ground competition has still not started due to the young age of the intercrops. It is also found that calliandra performed well under the partial shaded conditions of coconut.

Hence the results reiterate the scope for high density calliandra cultivation in coconut plantations and frequent harvesting of fodder with favourable effect on coconut yield, especially in the early years of cultivation.

5.4 CARBON SEQUESTRATION POTENTIAL OF THE FODDER-COCONUT INTEGRATED SYSTEM

5.4.1 Effect of tree density and pruning interval on biomass production and carbon stocks of calliandra over three-year period in coconut plantation

5.4.1.1 Tree density

Tree density had profound influence on fodder biomass production of calliandra per unit area. The highest density stand produced the maximum biomass during the three consecutive years, with a cumulative yield of 46.57 Mg ha^{-1} over three-year period. This yield was 24 and 35 % higher when compared to lower density classes of D2 and D3 respectively. Following the yield trends, the carbon storage in harvested biomass was also higher at closer spacing. Total carbon stored in harvested fodder biomass during first year for highest tree density was (6.55 Mg ha^{-1}) and there was an increment of 14% and 23% in next two consecutive years. The cumulative carbon capture in fodder biomass over three-year period was 25.81 Mg ha^{-1} in the highest density stand, which was 25 and 35.48 percent higher than the lower density stands, D2 and D3 respectively. The results indicate that tree density had a profound influence in carbon capture and accommodating more trees per unit area can be suggested as one of the strategies for efficient carbon capture and reduction of atmospheric CO_2 levels.

The total standing biomass includes the left-over stump biomass (1m height) after harvest and the below ground root biomass. Accumulation of standing biomass also varied significantly with tree density. Maximum quantity of dry biomass in stump

(10.77 Mg ha^{-1}) and root portions (1.25 Mg ha^{-1}) was accumulated in the highest density stand. Higher carbon stocks in the standing stem and root biomass (6.88 Mg ha^{-1}) was also recorded in the highest density stand, which was 36% higher than the lowest tree density.

Comparing the cumulative biomass production and carbon stocks of calliandra at varying densities over three-year period, the maximum biomass (58.53 Mg ha^{-1}) and carbon stocks (32.69 Mg ha^{-1}) was obtained from the highest density stand, and both the values were 36% more when compared to the lowest tree density. Similar results of enhanced C sequestration at closer spacing have been reported by Erkan and Aydin (2016) in *Pinus brutia*. In a study conducted in Kerala, carbon stocks in the harvested fodder biomass of mulberry under high density planting (40,000 plants ha-1) accounted to 10.30 and 30 Mg ha^{-1} respectively during 1st and 2nd year of its growth. Carbon sequestered in the standing tree stumps and roots of 2-year-old mulberry was 21 and 26 Mg ha^{-1} respectively (Varsha, 2015). The results indicated higher carbon capture and storage by high density stands of fodder trees.

5.4.1.2 Pruning interval

Pruning interval also had a marked effect on total biomass production and partitioning of calliandra. Total harvested biomass was found to be greater in stand pruned at longest interval of 16 weeks and was comparable to that of 12 weeks. Carbon stocks in harvested biomass was also higher in the longest pruning interval and significantly superior to lower levels. It was 7.95 Mg ha^{-1} in first year and showed an increase of 12% and 30% respectively in the next two years for 16 weeks cutting interval. Highest carbon stocks in longest pruning interval could be attributed to higher dry matter production with advancing age. Moreover, major portion of fodder harvest at prolonged interval constitutes the stem fraction, with more dry matter content, which enhances the overall dry biomass. Whereas in the case of shorter cutting intervals the harvested fodder mainly consists of tender shoots with more foliage and green stem, with more moisture and less dry matter, resulting in less dry biomass production.

Pruning frequency also had profound effect on standing biomass accumulation. It was noted that highest amount of fresh and dry stump biomass was observed in 12 weeks cutting interval, whereas that of root biomass was recorded in 16 weeks pruning interval, which was on par with that of 12 weeks. Total carbon stocks in the standing biomass (7.06 Mg ha^{-1}) was observed at its peak in the 12 weeks cutting interval, 55% more when compared to 8 weeks pruning interval. Hence, in the case of standing biomass it is observed that harvesting at medium interval of 12 weeks produced the maximum stem and root biomass that longer or shorter intervals suggesting the production of stronger shoot and root system at medium pruning interval, than longer or shorter intervals.

Cumulative biomass production over three-year period was highest (59.53 Mg ha^{-1}) from the stands subjected to the longest pruning interval of 16 weeks and was on par with that of 12 weeks interval (52.26 Mg ha^{-1}). Carbon stocks in plant biomass also showed similar pattern with respective values of 33.48 and 29.14 Mg ha^{-1} of carbon in 16 and 12 weeks pruning intervals. However, the biomass production as well as the carbon stocks was found to be significantly inferior in shorter interval of 8 weeks with more than 50 percent reduction when compared to higher levels. This could be attributed to the fact that frequent harvest and removal of foliage affects the photosynthesis and food production and allocation of food materials to stem and roots. This results in feeble stem and roots with less biomass.

Hence it can be seen that pruning at very short intervals of 8 weeks significantly reduces the overall plant biomass production and carbon capture whereas pruning at higher intervals of either 12 or 16 weeks enhances the carbon dynamics of trees.

5.4.2 Interaction effect of tree density and pruning interval on biomass production and carbon stocks of calliandra under coconut plantation

Interaction effect of tree densities and pruning intervals showed no significant effect on total plant biomass and various fractions as depicted in table 12. However, harvested biomass and carbon stocks in harvested fodder was found to be higher in D1xI3 (27,777 plants ha^{-1} and 16 weeks pruning interval), but standing biomass with respect to stem and root fractions and the carbon stocks in these fractions were comparatively higher in D1xI2 (27,777 plants ha^{-1} and 12 weeks pruning interval). Overall plant biomass (68.61 Mg ha^{-1}) and carbon stocks (38.56 Mg ha^{-1}) over three-year period was also highest for D1xI3, followed by that of D1xI2 (61.12 and 34.08 Mg ha^{-1} respectively).

However, a significant enhancement in carbon capture has been noticed due to calliandra intercropping in coconut (16.92 to 38.56 Mg ha^{-1} over three-year period, for various management regimes) than the sole coconut plots (0.77 Mg ha^{-1}). The interspaces of sole coconut plots were occupied by native grasses which had very less above and below ground biomass when compared to trees, hence the very low carbon stocks. On the contrary, calliandra, with its remarkable growth rate and fast regeneration after lopping, extensive and deep root system, woody stem and nitrogen fixing ability acts as a high potential carbon sink in coconut. In another study, Raveendra *et al.* (2017) reported 78.6 Mg ha^{-1} of carbon fixation by glyricidia over a period of six years when intercropped in coconut.

Moreover, the results also indicate that adoption of appropriate stand management strategies can still elevate the biomass production and carbon capture to higher levels. In our study, maintaining higher stand density (27,777 plants ha^{-1}) and pruning at the interval of either 12 or 16 weeks has doubled the biomass production and carbon stocks when compared to lower densities and pruning intervals. Hence the results indicated that in addition to fodder production, high density intercropping of fodder trees like calliandra in coconut garden and its proper management provide an ample scope for carbon capture, which has a positive role in mitigating climate change. Out of the total carbon captured in the plant biomass 75 percent is stored temporarily in fodder biomass, which gets recycled during harvest and 25 percent is stored in left over woody stump and roots, which accounts for permanent carbon.

5.4.3 Carbon stocks in coconut palms

The intercropping experiment was conducted in mature coconut plantation aged 37 years. Carbon stocks in the intercropped coconut palms and sole coconuts were estimated by compiling carbon content in the coconut bole, leaves, harvested nuts in the third year and existing nuts in the palms.

Tree density and pruning interval of intercropped of calliandra had no significant effect on carbon content of harvested nuts (Table 13, 14). Similarly, there was no significant difference between the carbon content of nuts in sole coconut palms (0.079 Mg ha^{-1}) and intercropped palms (0.079-0.080 Mg ha^{-1}). Management practises in callliandra also had no significant effect on carbon content in existing nuts of coconut palms (Table 13). However, the overall carbon stocks (1.85-2.02 Mg ha^{-1}) in the existing nuts of intercropped palms were significantly higher when compared to that of the coconut monoculture (1.70 Mg ha^{-1}). This could be attributed to more nut yield in intercropped trees when compared to that of coconut monoculture.

The carbon stocks in the existing coconut leaves of calliandra – coconut system ranged from of 3.03-3.15 Mg ha^{-1}, and was on par with that of sole coconut palms (2.99 Mg ha^{-1}) (Table 13, 14). Coconut bole accumulated 26.99-28.60 Mg ha^{-1} of carbon in coconut - calliandra intercropping systems under various management regimes and was on par with that of the sole coconut palms (27.62 Mg ha^{-1}). There was no statistically significant difference in carbon stored in bole of coconut palms among different treatment combinations (Table 14).

Tree density and pruning interval in intercropped calliandra had no significant effect on total carbon stocks in coconut palms. There was also no significant difference between the carbon stocks of sole coconut palms (32.39 Mg ha^{-1}) and that of the palms intercropped with calliandra (32.04 - 33.84 Mg ha^{-1}). This implies the possibility of introducing intercrops like calliandra with no negative effect on coconut growth and biomass production and the carbon storage potential. Similar findings were reported by Raveendra *et al.* (2017) where no significant differences were noticed in the carbon stocks of stem, nuts and leaves and overall biomass of coconut palms intercropped with either glyricidia or cocoa and coconut monoculture in Srilanka.

5.4.4 Soil carbon stocks in coconut- calliandra fodder production system

The data given in table 15 indicates the significant influence of planting density and pruning interval on soil organic carbon (SOC) content. Considering the individual effects, a medium planting density (22,222 plants ha^{-1}) and medium pruning interval (12 weeks) had a favourable impact on SOC content and carbon stocks rather than higher or lower levels. However, the interaction effects revealed that higher plant density (27,777 plants ha^{-1}) in combination with medium pruning interval (12 weeks) accumulated more carbon (131.84 Mg ha^{-1}) in the soil especially in the subsurface layers. Whereas, high planting density with shorter pruning intervals has seriously depleted the SOC levels, which implies that pruning interval has a more prominent impact on soil carbon than plant densities.

High planting densities contribute more carbon to soil through litter fall and root turnover than lower densities. Litter production is a major process in the transfer of organic matter and nutrients from above-ground tree parts to the soil (Szott *et al.*, 1991). Gunasena *et al.* (1991) have reported that *Gliricidia sepium* and *Leucaena leucocephala* increased soil fertility due to decomposition of leaf litter. Comparing SOC levels in different soil depths, the top 20 cm depth of the field were found to have comparatively higher C content than lower depths, irrespective of the treatments. This could be due to the recycling of organic matter and higher root concentration and activity in top soil.

Comparing the intercropped and monoculture coconut systems, soils under coconut monoculture accumulated very less carbon (75.57 Mg ha^{-1}), than the best calliandra treatment of D1xI2 (131.84 Mg ha^{-1}). In case of coconut monoculture system, the main crop coconut is not contributing much organic matter in terms of above ground dead biomass and below ground roots to the soil carbon pool especially in the interspaces of coconut rows. The interspaces of coconut sole plots are mainly occupied by local grasses which contributes carbon mainly in the surface whereas the subsurface contribution is quite less as evident from the table 16. Whereas, introduction of tree crops in the interspaces of coconut has a greater impact in enhancing carbon levels throughout the profile mainly through litter fall, deep rooting, root exudates and fine root dynamics.

It was observed that the root zone as well as root nodule activity is concentrated at a depth of 40-60 cm resulting in higher organic carbon content in that zone compared to deeper layers. Accumulation of SOC occurs primarily through the return of plant-fixed C to the soil mainly through leaves and roots (Lal and Kimble 2000; Oelbermann *et al.,* 2006). Litter fall, exerts a profound influence on belowground C sequestration (Jamaludheen and Kumar, 1999). Trees have the potential of producing larger quantities of aboveground and belowground biomass compared to shrubs or herbs. More biomass results in increased production of aboveground litter and belowground root activity and these make trees an important factor for SOC sequestration (Lemma *et al.,* 2007). Singh and Sharma (2012) studied the tree growth and accumulation of organic carbon and nutrients in soil under tree plantations, and reported that the concentration and accumulation of soil OC and available nutrients were higher under trees than control.

Hence it can be seen that intercropping fast growing tree like calliandra in coconut gardens and adoption of appropriate management practises can substantially elevate soil carbon sequestration of these systems.

5.4.5 Effect of intercropping calliandra and its various management regimes on overall carbon storage potential of calliandra – coconut system

The main effect of tree density and pruning interval on total carbon storage potential of the system is projected in table 19. The maximum total carbon storage was obtained for highest tree density (163.90 Mg ha^{-1}) and was on par with the medium tree density (163.10 Mg ha^{-1}). The largest amount of total carbon storage was recorded for 12 weeks pruning interval (176.71 Mg ha^{-1}), which was 12 and 25 percent higher than that of 16 weeks and 8 weeks interval.

On comparing the interaction effects, the highest amount of carbon capture (199.19 Mg ha^{-1}) was observed in the combination of 27,777 plants ha^{-1} tree density (row and plant spacing of 60 x60 cm) and 12 weeks cutting interval and the lowest value (118.84 Mg ha^{-1}) was recorded for 17,777 plants ha^{-1} and 8 weeks cutting interval. The carbon storage potential of control, sole coconut plantation (108.73 Mg ha^{-1}) was far behind when compared to the treatments.

In a study conducted in Srilanka, Raveendra *et al.* (2017) reported 138 Mg ha^{-1} total ecosystem carbon stock in coconut intercropped with glyricidia (1m x 1m spacing), when compared to 60 Mg ha^{-1} from coconut monoculture. Bhagya *et al.* (2017) reported carbon sequestration of 140.06 Mg ha^{-1} from coconut + jamun system when compared to 98.2 Mg ha^{-1} under coconut monocrop in Kerala. Our values were still higher for calliandra – coconut system which could due to closer spacing and accommodation of more trees thereby enhancing tree biomass and carbon stocks.

The results clearly indicate that, in addition to quality forage production, intercropping fodder tree calliandra has tremendous potential to enhance the carbon capture potential of the calliandra - coconut ecosystem (118.84 to 199.19 Mg ha^{-1}), when compared to coconut monoculture (108.73 Mg ha^{-1}). Rocha (2017) reported that fast growing trees are known for their higher biomass production and carbon sequestration especially through faster rates of elemental carbon accretion in their biomass and soil thereby contributing to climate change mitigation. These functions are further regulated by stand management strategies like planting density and harvesting frequencies as observed in our study.

The adoption of the highest density (27,777 plants ha^{-1}) and harvesting at the medium interval of 12 weeks accumulated more carbon in plant and soil (199.19 Mg ha^{-1}) than other treatments (118.84 to 182.9 8 Mg ha^{-1}). The above system has accumulated 90. 46 Mg ha^{-1} more carbon than the coconut monoculture system over three-year period, out of which 56.27 Mg ha^{-1} (63%) was sequestered in the soil and 8.10 Mg ha^{-1} in woody stump and root (9%) which accounts for the permanent carbon, and 25.98 Mg ha^{-1} in fodder biomass (28%) representing the labile fraction.

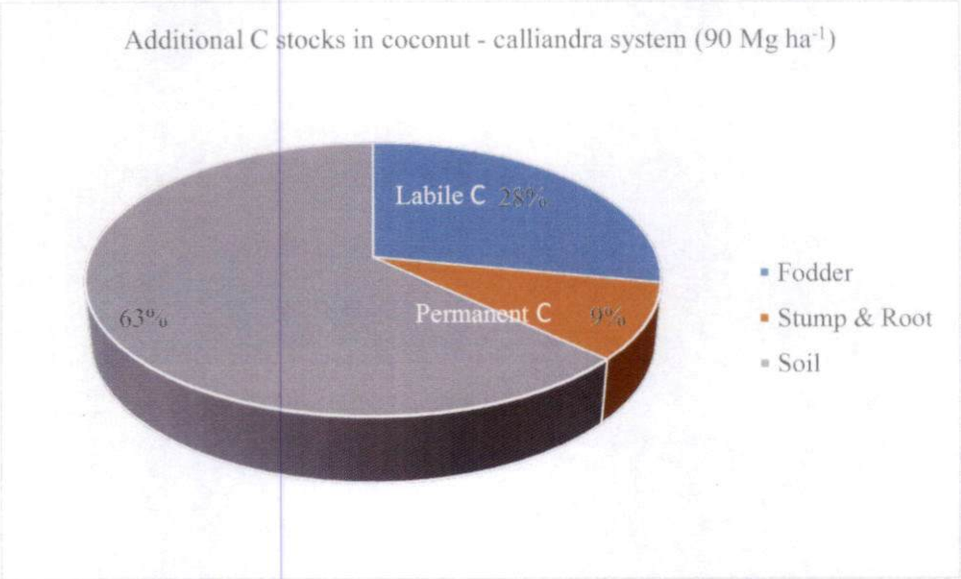

Fig. 5. Sequestration pattern of additional carbon in caliandra-coconut system, Vellanikkara, Kerala

Hence, it can be concluded that on account of fodder biomass production and carbon sequestration potential, intercropping calliandra at a density of 27,777 plants ha^{-1} and scheduling harvests at 12 weeks cutting interval can be recommended for farmers as a sustainable and environment friendly fodder production system in coconut.

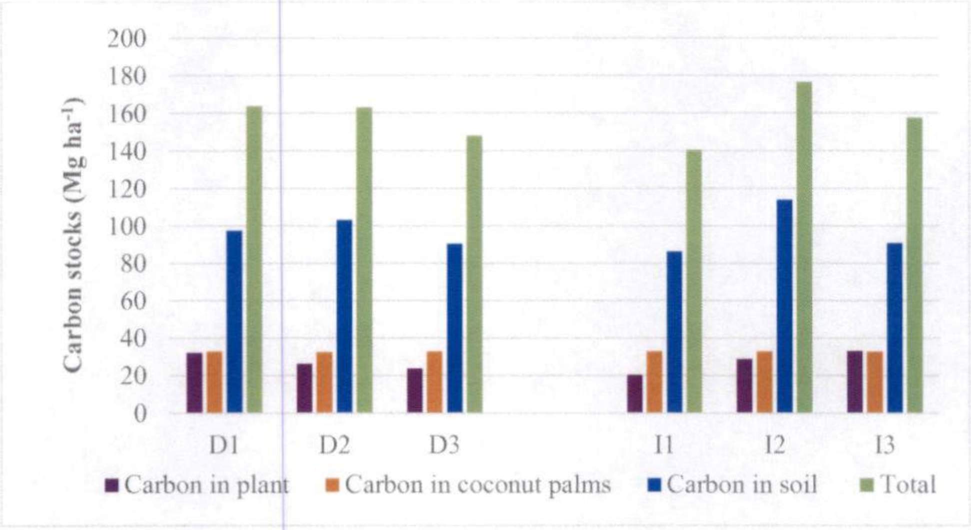

Fig. 6. Carbon stocks as influenced by tree density and pruning interval under coconut plantation, Vellanikkara, Kerala

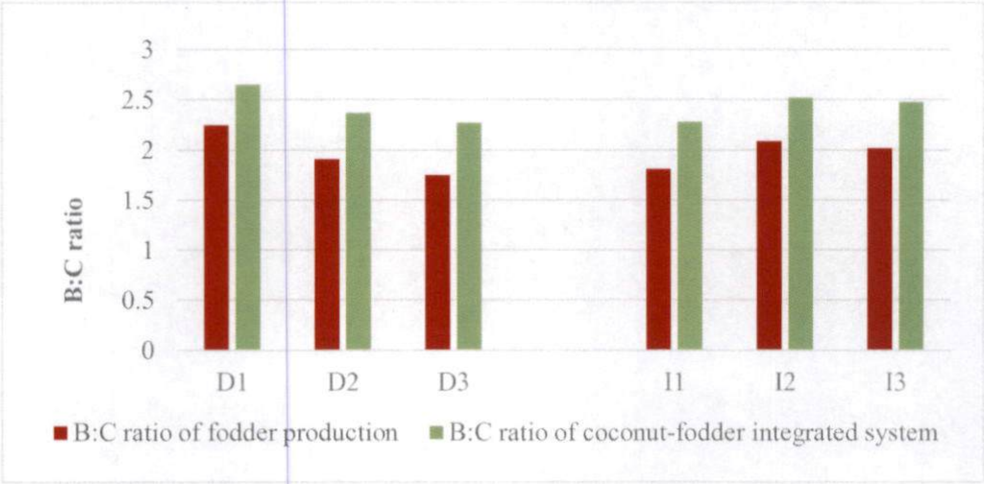

Fig. 7. B:C ratio as influenced by tree density and pruning interval under coconut plantation, Vellanikkara, Kerala

5.5 SOIL FERTILITY STATUS

5.6.1 Soil physical properties

5.6.1.1 Bulk density

The tree density, pruning interval and the various treatments significantly influenced the soil bulk density, but no specific trend has been observed across different soil depths as well as treatments. Many reports suggest increase in bulk density with soil depth (Lemma *et al.,* 2007; Jangra *et al.,* 2010; Singh *et al.*, 2010 and Tumwebaze *et al.,* 2012). But our study did not present such a clear trend, where in lower bulk density was observed in some of the deeper layers compared to surface. This might be due to the deep root activity of calliandra trees which loosens the soil and decrease soil bulk density. Varsha (2015) also reported lower bulk density in mulberry monoculture in 41-100 cm soil depth and was attributed to the deep rooting pattern of mulberry which improved the porosity and lowered BD at higher depths. Gunesena *et al*. (1991) also observed that by growing gliricidia and leucaena, soil bulk density was reduced and infiltration capacity was increased in clay soil compared to the control.

5.6.1.2 Soil pH

In humid tropical soils, the pH is usually slightly acidic in reaction and our values also showed similar trend. Both tree density and pruning interval of calliandra had significant effect on soil pH as depicted in table 23. On comparing the mean values of treatment combinations, highest soil pH (5.86) was observed for lowest tree density and the longest pruning interval. This was significantly higher than that of the coconut monoculture plots (5.50). Comparing the pH values of different soil layers, pH was comparatively higher at 20-40 cm depth than top and bottom layers, which could be attributed to higher root activity in this zone. Varsha (2015) also presented similar observations in mulberry monoculture.

5.6.1.3 Water holding capacity

The maximum water holding capacity was recorded for medium tree density and longest pruning interval, which could be due to the better porosity as indicated by the lower bulk density. The treatment combination of 22,222 plants ha^{-1} and 16 weeks pruning interval recorded highest water holding capacity (36.21 %) and the lowest water holding capacity was recorded in control plot (34.56 %). Research has demonstrated that inclusion of trees within agricultural systems can improve water quality (Lowrance, 1992). Water quality benefits of maintaining trees and other vegetation on farms and ranches are realized by reducing runoff, maintaining long-term water cycle, and recharging ground water aquifers (Wu *etal.,* 2001; Stednick, 1996).

5.6.2 Soil nutrient status

5.6.2.1 Total and available nitrogen concentration in soil

Management aspect like tree density significantly influenced the total nitrogen content in soil, whereas the pruning interval could not produce any significant changes. Medium tree density reported highest total nitrogen content and was statistically comparable to that of the highest tree density. This could be due to higher quantities of nitrogen fixed by more number of trees in dense plantations. Comparison of total N content in intercropped and coconut monoculture systems revealed significant difference only in the surface layer and the deepest layer of 81-100 cm depth. Coconut monoculture system had higher total N (1.73 g kg^{-1}) in the surface layer than intercropped systems (1.45 to 1.73 g kg^{-1}). This could be due to the nitrogen enrichment of soil by existing natural grass vegetation over long period time. On the other hand, the intensive cropping and harvest of calliandra would have depleted the surface nitrogen in the intercropped systems. Whereas in the lower most layer of 81-100 cm, all intercropped plots had higher N level (0.65 to 1.03 g kg^{-1}) than sole coconut plots (0.61 g kg^{-1}). This might be due to the nitrogen fixing nature of calliandra. Leguminous crops play a critical role in nitrogen enrichment of natural ecosystems, agriculture, and agro-forestry, by their nitrogen fixing nature (Rejili *et al.*, 2012).

Comparing the effect of management practices of calliandra on available nitrogen status of soil, it was found to be highest in lowest density and longest pruning interval treatments. This indicates that intensive management which includes higher densities and frequent harvest can cause depletion of soil nitrogen than less intensive management levels. However, all the treatment combinations of calliandra had higher available nitrogen content in soil compared to that of coconut monoculture system, which implies that there is a buildup of soil nitrogen in all intercropped systems irrespective of management levels, compared to coconut monoculture systems. This reinforces the role of nitrogen fixing tree, calliandra, in enhancing the available N status of intercropped systems.

5.6.2.2 Total and available phosphorus concentration in soil

Tree density and pruning interval had significant effect on total phosphorus content in soil. The highest density and the shortest pruning interval possessed maximum total phosphorous content, the reason for which is not clearly understood. No specific trend has been observed on the total P content between intercropped plots, their management levels, and coconut monoculture systems. Comparing various soil depths, P content was comparatively lower in 20-40cm depth than other areas, irrespective of treatments, which indicates that intense root activity and higher p uptake was concentrated in this zone.

Maximum available phosphorus content was observed in 0-20 cm soil depth and then presented gradual decrease with increasing soil depth with slight variations in 81-100 cm depth. Tree density significantly influenced available phosphorus and maximum value was obtained for medium density. Pruning interval had no significant effect on available phosphorus in soil. Maximum mean value (4.67 mg kg^{-1}) was recorded for the treatment D2xI2 (22,222 plants ha^{-1}+ 12 weeks pruning interval) and

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all the treatment means were comparatively higher than that of control value (2.49 mg kg^{-1}) in coconut monoculture system. One of the reasons could be due to the addition of P fertilizers to intercropped calliandra. This indicates that calliandra intercropping and appropriate cultural practices can appreciably improve the phosphorus status of soils.

5.6.2.3 Total and available potassium concentration in soil

Lowest values for total potassium were found in 0-20 cm soil depth and there was an increase with increasing soil depth, which can be due to the leaching of potassium to lower layers. Highest density and the shortest pruning interval possessed highest mean values for total potassium content. This could be due to the loss of potassium by leaching by heavy rainfall from widely spaced stands with less soil cover. Under heavy rain, tree hedgerows had significant effect in reducing total runoff and enrichment ratio of nutrients as well. Maximum mean value (3.39 g kg^{-1}) was recorded for the treatment D1xI1 (27,777 plants ha-1+ 8 weeks pruning interval) and that of control was 2.95 g kg^{-1}. Higher potassium values in intercropped plots can be attributed to nutrient enrichment from fertilizers and through potassium rich litter from calliandra, along with less leaching loss of potassium by high density planting of calliandra.

In contrast to the total potassium trends, highest available potassium content was observed in 0-20 cm soil depth and there was a decreasing trend with increasing soil depth. This could be due to the enrichment of potassium from fertilizers and also by the mineralization of leaf litter on the surface layer, whereas the potassium in lower layers was extracted by the plants which resulted in lower levels. Significantly higher values of available potassium were recorded for lowest tree density, indicating higher K depletion with increasing tree densities. Pruning interval was not significant in the case of available potassium content in soil. Maximum mean value (0.12 g kg^{-1}) was recorded for the treatment D3xI1 (17,777 plants ha^{-1}+ 8 weeks pruning interval) and all the treatment means were comparatively higher than that of control value (0.06 g kg^{-1}) in sole coconut plots.

Hence it can be concluded that, high density planting of calliandra in coconut garden and its frequent harvest had no adverse impact on soil fertility status of the system. On the other hand, there is an improvement in soil physico-chemical parameters like bulk density, WHC, soil pH and buildup of soil nutrients by addition of fertilizers, mineralization of litter, deep and intensive rooting by trees, avoiding leaching losses of nutrients by reducing surface runoff and through soil binding by the intensive root system of densely planted intercrops, when compared to coconut monoculture system.

5.6 ECONOMICS

Economics and B:C ratio of fodder production as influenced by tree density and pruning interval in coconut plantation are projected in table 39. On comparison of different tree densities, the B:C ratio was maximum for the highest tree density (2.25) and minimum for the lowest tree density (1.75). The B:C ratio for the medium tree density (1.91) was found to be on par with the other two densities. This could be due to higher biomass production from dense stands as compared to widely spaced stands. Pruning interval had no significant effect on B:C ratio, even though a slight increment was observed at longer intervals than the shorter intervals. The B:C ratio of the coconut-fodder integrated system also followed a similar trend.

Comparing the economics of different treatments (table 40), the maximum B:C ratio for fodder production as well as coconut-fodder integrated system (2.33 and 2.71 respectively) was obtained for tree density of 27,777 plants ha^{-1} and 12 weeks pruning interval. Hence, it can be concluded that planting calliandra at highest density of 27,777 plants ha^{-1} and harvesting at an interval of 12 weeks under coconut plantation yielded maximum fodder with good nutritive value at the cheapest level.

SUMMARY

SUMMARY

A research programme entitled "Forage yield, soil fertility and carbon dynamics of calliandra (*Calliandra calothyrsus* Meissn.) in coconut plantation" was carried out at Instructional Farm, College of Horticulture, Vellanikkara during the year 2016-17, to evaluate the influence of stand management practices like tree density and pruning interval on forage yield and carbon storage potential of three-year old calliandra underneath coconut plantation. The study also explored the variation in coconut productivity and soil fertility status in coconut – calliandra intercropping system in comparison with coconut monoculture system.

Salient findings of the study are summarized as follows:

1. Tree density had significant effect on fodder yield of calliandra during the third year of growth. Annual fresh and dry fodder yield of intercropped calliandra per hectare of coconut garden increased from 43.44 to 55.40 and 13.87 to 16.97 Mg from lower to higher density classes, thereby indicating the necessity of closer planting of fodder trees for maximising forage production along with the optimum utilisation of available resources.

2. Tree density also had prominent effect on production of foliage and stem fractions, which increased with increasing density. The highest dry edible fodder yield (12.64 Mg ha^{-1} yr^{-1}), which constitutes the leaf and edible stem, was also obtained for the highest density, that was 21 and 26 per cent higher than medium and lowest density. Leaf-stem ratio also showed slight increment towards higher densities, but the differences were marginal.

3. Pruning interval had a more profound influence on edible forage yield, rather than the total yield. Even though maximum fresh fodder yield (52.12 Mg ha^{-1} yr^{-1}) was recorded for longest interval of 16 weeks, a major portion was inedible woody stem. Highest fresh and dry edible forage yield (40.16 and 12.02 Mg ha^{-1} yr^{-1}) which

constitutes the leaf and edible stem fraction was obtained for the medium pruning frequency of 12 weeks, followed by 8weeks interval.

4. Leaf-stem ratio was significantly higher at 8 weeks pruning interval (1.74), followed by 12 weeks interval (1.24), indicating the production of more foliage and less inedible stem portions when cut at shorter cutting intervals.

5. Interaction effect of tree densities and pruning intervals showed no significant effect on forage yield of calliandra. Total fresh and dry forage yields were highest for the highest density stand, with longest pruning interval (16 weeks). However, the edible forage yield was higher for the high density stand with medium pruning interval (12 weeks). Leaf-stem ratio was significantly higher for the densest stand with shorter pruning intervals, but overall forage yields were much lower. Hence, ccomparing fresh and dry forage yields, foliage production, edible fodder yield and leaf-stem ratio, the best stand management practises for maximising the production of quality fodder in calliandra is to adopt tree density of 27,777 plants ha^{-1} and scheduling harvests at interval of 12 weeks.

6. Management aspects like tree density and pruning interval of intercropped calliandra had no significant effect on annual harvested nut yield of coconut palms on the third year. Similarly, there was no significant difference in annual nut yield between sole coconut palms (14,705 nuts ha^{-1} yr^{-1}) and the palms intercropped with calliandra trees (14,590-14,936 nuts ha^{-1} yr^{-1}).

7. However, the count on the existing nuts of various size classes in palms, which were developed during the previous three years showed significant difference with intercropping. Existing nuts in coconut monoculture systems was significantly lower (15,455 nuts ha^{-1}) when compared to intercropped coconut plots (16,608-16,781 nuts ha^{-1}). This reiterates the scope for high density calliandra cultivation in coconut and frequent harvesting of fodder with favourable effect on coconut yield, especially in the early years of cultivation.

8. Various management practices significantly influenced the plant biomass production and carbon stocks of calliandra.

9. Comparing density regimes, the highest density stand produced the maximum fodder biomass (46.57 Mg ha$^{-1)}$, with carbon stocks of 25.81 Mg ha^{-1} over three-year period. Accumulation of standing biomass in stump (10.77 Mg ha^{-1}) and root portions (1.25 Mg ha^{-1}) also showed similar trend, with total carbon stocks of 6.88 Mg ha^{-}1. The overall plant biomass (58.53 Mg ha^{-1}) and carbon stocks (32.69 Mg ha^{-1}) were also higher in the highest density stand, and both the values were 36% more when compared to the lowest tree density.

10. Pruning interval also had a marked effect on total biomass production and partitioning, and carbon stocks of calliandra. Total harvested fodder biomass and carbon stocks was found to be higher in calliandra stands pruned at longest interval of 16 weeks and was comparable to that of 12 weeks. Standing biomass with respect to stump and root biomass and the corresponding carbon stocks (7.06 Mg ha^{-1}) were higher for 12 weeks interval, followed by 16 weeks interval. Cumulative biomass production (59.53 Mg ha^{-1}) and carbon stocks (33.48 Mg ha^{-1}) over three-year period was highest for the stands subjected to the longest pruning interval of 16 weeks and was on par with that of 12 weeks interval.

11. Comparing the treatment combinations, fodder biomass and carbon stocks in fodder was found to be higher in D1I3 (27,777 plants ha^{-1}, 16 weeks pruning interval), but standing biomass with respect to stem and root fractions and the carbon stocks in these fractions were comparatively higher in D1I2 (27,777 plants ha^{-1}, 12 weeks pruning interval). Overall plant biomass (68.61 Mg ha^{-1}) and carbon stocks (38.56 Mg ha^{-1}) over three-year period was also highest for D1I3, followed by that of D1I2 (61.12 and 34.08 Mg ha^{-1} respectively).

12. A significant enhancement in carbon capture has been noticed due to calliandra intercropping in coconut (16.92 to 38.56 Mg ha^{-1}) over three-year period, for

various management regimes) than the sole coconut plots (0.77 Mg ha^{-1}), with local grasses as understorey component. In addition, adoption of appropriate stand management strategies in calliandra can still elevate the biomass production and carbon capture to higher levels. In our study, maintaining higher stand density (27,777 plants ha^{-1}) and pruning at the interval of either 12 or 16 weeks has doubled the biomass production and carbon stocks when compared to lower densities and pruning intervals.

13. Tree density and pruning interval in intercropped calliandra had no significant effect on total carbon stocks in coconut palms. There was also no significant difference between the carbon stocks of sole coconut palms (32.39 Mg ha^{-1}) and that of the palms intercropped with calliandra (32.04-33.84 Mg ha^{-1}). This implies the possibility of introducing intercrops like calliandra with no negative effect on coconut growth and biomass production and the carbon storage potential.

14. Management practices in calliandra had significant impact on soil organic carbon content and stocks (68.80-131.84 Mg ha^{-1}) of coconut- calliandra intercropping system. Higher plant density (27,777 plants ha^{-1}) in combination with medium pruning interval (12 weeks) (D1I2) accumulated more carbon (131.84 Mg ha^{-1}) in the soil especially in the subsurface layers. Whereas, high planting density with shorter pruning intervals has seriously depleted the SOC levels, which implies that pruning interval has a more prominent impact on soil carbon than plant densities.

15. Comparing the intercropped and monoculture coconut systems, soils under coconut monoculture accumulated very less carbon (75.57 Mg ha^{-1}), than the best calliandra treatment of D1I2 (131.84 Mg ha^{-1}), which implies that intercropping fast growing trees like calliandra in coconut gardens and adoption of appropriate management practices can substantially elevate soil carbon sequestration of these systems.

16. Significant changes have been noticed in the overall carbon storage potential of coconut cropping system due to calliandra intercropping and its various

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management strategies. Comparing the individual impact of management factors, the maximum total carbon storage was obtained for highest tree density (163.90 Mg ha^{-1}) and was on par with the medium tree density (163.10 Mg ha^{-1}). The largest amount of total carbon storage was recorded for 12 weeks pruning interval (176.71 Mg ha^{-1}), which was 12 and 25 percent higher than that of 16 weeks and 8 weeks interval.

17. On comparing the interaction effects, the highest amount of carbon capture (199.19 Mg ha^{-1}) was observed in the combination of 27,777 plants ha^{-1} tree density and 12 weeks cutting interval and the lowest value (118.84 Mg ha^{-1}) was recorded for 17,777 plants ha^{-1} and 8 weeks cutting interval. The carbon storage potential of control, sole coconut plantation (108.73 Mg ha^{-1}) was far behind when compared to the treatments. The best calliandra system has accumulated 90. 46 Mg ha^{-1} more carbon than the coconut monoculture system over three-year period, out of which 56.27 Mg ha^{-1} (63%) was sequestered in the soil and 8.10 Mg ha^{-1} in woody stump and root (9%) which accounts for the permanent carbon, and 25.98 Mg ha^{-1} in fodder biomass (28%) representing the labile fraction.

18. Significant improvement in soil fertility parameters has been observed due to calliandra intercropping in coconut, as compared to monoculture systems. However, different stand management practices did not present a clear trend in soil fertility changes.

19. The tree density, pruning interval and the various treatments significantly influenced the soil bulk density. Bulk density of the subsurface layers of intercropped plots was lower when compared to that of sole coconut plots, indicating the influence of deep root activity of calliandra. The bulk density of various treatment combinations recorded in the range of 1.24 to 1.50 g cm^{-3} and that of control (sole coconut plantation) was 1.33 g cm^{-3}. The lowest mean bulk

density was observed for the treatment combination of 22,222 plants ha^{-1} and 16 weeks pruning interval (1.24 g cm^{-3}).

20. Highest soil pH was observed for lowest tree density (5.55) and the longest pruning interval (5.48). Comparing the mean values, the soil pH of various treatment combinations was recorded in the range of 4.93 to 5.86 and that of control (sole coconut plantation) was 5.50. The highest soil pH was observed for the treatment combination of 17,777 plants ha^{-1} and 16 weeks pruning interval (5.86).

21. Maximum soil water holding capacity was observed for medium tree density (33.04%) and the longest pruning interval (33.42%). Comparing the mean values, the soil water holding capacity of various treatment combinations was recorded in the range of 30.14 to 33.93% and that of control (sole coconut plantation) was 34.56%. The highest soil water holding capacity was observed for the treatment combination of 17,777 plants ha^{-1} and 16 weeks pruning interval (33.93%).

22. The soil total nitrogen content of various treatment combinations of calliandra was recorded in the range of 0.99 to 1.16 g kg^{-1} and that of sole coconut plantation was 1.11 g kg^{-1}. Available N content of soil was found to be highest in lowest density and longest pruning interval treatments. This indicates that intensive management which includes higher densities and frequent harvest can cause depletion of soil nitrogen than less intensive management levels. However, all the treatment combinations of calliandra had higher available nitrogen content (0.16 to 0.21 g kg^{-1}) in soil compared to that of coconut monoculture system (0.16 g kg^{-1}), which implies that there is a buildup of soil nitrogen in all intercropped systems irrespective of management levels, compared to coconut monoculture systems.

23. Highest soil total phosphorous content was observed for highest tree density (351.41mg kg^{-1}) and the shortest pruning interval (378.16 mg kg^{-1}). Comparing various soil depths, P content was comparatively lower in 20-40cm depth than other areas, irrespective of treatments. Total P content of various treatment combinations

ranged from 306.20 to 402.78 mg kg^{-1} and that of control (sole coconut plantation) was 351.53 mg kg^{-1}. The highest soil total phosphorous content was observed for the treatment combination of 27,777 plants ha^{-1} and 8 weeks pruning interval (402.78 mg kg^{-1}).

24. On comparing the mean values of main effects, highest soil available phosphorous content was observed for medium tree density (4.05 mg kg^{-1}) and the 12 weeks pruning interval (3.83 mg kg^{-1}). Comparing the mean values, the soil available phosphorous content of various treatment combinations was recorded in the range of 3.05 to 4.67 mg kg^{-1} and that of control (sole coconut plantation) was 2.49 mg kg^{-1}. The highest soil available phosphorous content was observed for the treatment combination of 22,222 plants ha^{-1} and 12 weeks pruning interval (4.67 mg kg^{-1}).

25. Highest soil total potassium content was observed for highest tree density (3.10 g kg^{-1}) and the shortest pruning interval (3.22 g kg^{-1}). Comparing the mean values, the soil total potassium content of various treatment combinations was recorded in the range of 2.55 to 3.39 g kg^{-1} and that of control (sole coconut plantation) was 2.95 g kg^{-1}. The highest soil total potassium content was observed for the treatment combination of 27,777 plants ha^{-1} and 8 weeks pruning interval (3.39 g kg^{-1}), but was not statistically significant.

26. Highest soil available potassium content was observed for lowest tree density (0.11 g kg^{-1}) and all the pruning intervals were comparable (0.10 g kg^{-1}). Comparing the mean values, the soil available potassium content of various treatment combinations was recorded in the range of 0.08 to 0.12 g kg^{-1} and that of control (sole coconut plantation) was 0.06 g kg^{-1}. The highest soil available potassium content was observed for the treatment combination of 17,777 plants ha^{-1} and 8 weeks pruning interval (0.12 g kg^{-1}).

27. On comparison of different tree densities, the B:C ratio was maximum for the highest tree density (2.25). Pruning interval had no significant effect on B:C ratio,

even though a slight increment was observed at longer intervals than the shorter intervals. The B:C ratio of the coconut-fodder integrated system also followed a similar trend. Comparing the economics of different treatments (table 40), the maximum B:C ratio for fodder production as well as coconut-fodder integrated system (2.33 and 2.71 respectively) was obtained for tree density of 27,777 plants ha^{-1} and 12 weeks pruning interval.

Hence it can be summarized that calliandra is a promising fodder tree suited to the agroclimatic conditions of Kerala and can be successfully grown as an understory component in coconut gardens to enhance quality forage production. Adoption of effective stand management techniques like tree density of 27,777 plants ha^{-1} and scheduling harvests at 12 weeks interval can substantially enhance the edible forage yields and coconut productivity at cheapest level, with favourable impact on soil fertility status, thereby providing direct benefit to the farmers. In addition, the intercropping practices can almost double the carbon fixation rates than in coconut monoculture systems, and provides environmental services via climate change mitigation.

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FORAGE YIELD, SOIL FERTILITY AND CARBON DYNAMICS OF CALLIANDRA (*Calliandra calothyrsus* Meissn.) IN COCONUT PLANTATION

by

JILNA JOY

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ABSTRACT OF THE THESIS

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DEPARTMENT OF SILVICULTURE AND AGROFORESTRY
COLLEGE OF FORESTRY
VELLANIKKARA, THRISSUR – 680 656
KERALA, INDIA

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ABSTRACT

The research programme entitled "Forage yield, soil fertility and carbon dynamics of calliandra (*Calliandra calothyrsus* Meissn.) in coconut plantation" was carried out at Instructional Farm, College of Horticulture, Vellanikkara during the year 2016-17, to evaluate the influence of stand management practices like tree density and pruning interval on forage yield and carbon storage potential of three-year old calliandra underneath coconut plantation. The study also explored the variation in coconut productivity and soil fertility status in coconut – calliandra intercropping system in comparison with coconut monoculture system. The treatments consisted of calliandra intercropped in coconut plantations under three levels of tree density (27,777; 22,222 and 17,777 plants ha^{-1}) and three levels of pruning interval (8, 12 and 16 weeks) in all possible combinations with factorial randomized block design replicated thrice.

The study indicated that the annual fresh and dry fodder yield of intercropped calliandra per hectare of coconut garden increased from 43.44 to 55.40 and 13.87 to 16.97 Mg from lower to higher density classes. The edible forage fraction (12.64 Mg ha^{-1} yr^{-1}), with leaf and green stem, was also higher for the highest density. Highest fresh and dry edible forage yield (40.16 and 12.02 Mg ha^{-1} yr^{-1}) was obtained for the medium pruning interval of 12 weeks. Comparing the interaction effects, total forage yields was highest for the highest density stand, with longest pruning interval (16 weeks), but the edible forage yield was higher for the high density stand with medium pruning interval (12 weeks). Leaf-stem ratio was significantly higher for the densest stand with shorter pruning intervals, but overall forage yields were much lower. Hence, productivity of edible forage from calliandra can be maximized by adopting tree density of 27,777 plants ha^{-1} and scheduling harvests at interval of 12 weeks.

Calliandra intercropping and various management levels had no significant effect on harvested nut yield of coconut palms during the third year. However, the count on

the existing nuts of various size classes in palms, which were developed during the previous three years showed significant improvement with intercropping at various management levels (16,608-16,781 nuts ha^{-1}) when compared to sole coconut plots (15,455 nuts ha^{-1}).

Significant enhancement in carbon capture has been noticed due to calliandra intercropping in coconut (16.92 to 38.56 Mg ha^{-1} over three-year period, for various management regimes) than the sole coconut plots (0.77 Mg ha^{-1}), with local grasses as understorey component. Maintaining higher stand density (27,777 plants ha^{-1}) and harvest interval of either 12 or 16 weeks has doubled the biomass production and carbon stocks when compared to lower densities and pruning intervals. There was no significant difference between the carbon stocks of sole coconut palms (32.39 Mg ha^{-1}) and that of the palms intercropped with calliandra (32.04-33.84 Mg ha^{-1}). Comparing soil carbon stocks, coconut monoculture systems accumulated very less carbon (75.57 Mg ha^{-1}), than the best calliandra treatment (131.84 Mg ha^{-1}). The overall carbon storage potential of sole coconut plantation (108.73 Mg ha^{-1}) was far lower than the best calliandra-coconut system (199.19 Mg ha^{-1}), which had additional carbon capture of 90.46 Mg ha^{-1} over three-year period.

Significant improvement in soil fertility parameters has been observed due to calliandra intercropping in coconut, as compared to monoculture systems. However, different stand management practices did not present a clear trend in soil fertility changes. Comparing the economics of different systems, the maximum B:C ratio for fodder production as well as coconut-fodder integrated system (2.33 and 2.71 respectively) was obtained for tree density of 27,777 plants ha^{-1} and 12 weeks pruning interval.

Hence it can be concluded that calliandra can be successfully grown as an understorey component in coconut gardens of Kerala to enhance quality forage production. Adoption of effective stand management techniques like tree density of

27,777 plants ha^{-1} and scheduling harvests at 12 weeks interval can substantially enhance the edible forage yields and coconut productivity at cheapest level, with favourable impact on soil fertility status, thereby providing direct benefit to the farmers. In addition, the intercropping practices can almost double the carbon fixation rates than in coconut monoculture systems, and provides environmental services via climate change mitigation.