PRODUCTIVITY, CARBON AND NUTRIENT STOCKS IN MULBERRY (*Morus indica* L.) AND SUBABUL (*Leucaena leucocephala* Lam.) BASED HIGH DENSITY FODDER PRODUCTION SYSTEM IN COCONUT

by

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THESIS

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DECLARATION

I, hereby declare that thesis entitled **"PRODUCTIVITY, CARBON AND NUTRIENT STOCKS IN MULBERRY (*Morus indica* L.) AND SUBABUL (*Leucaena leucocephala* Lam.) BASED HIGH DENSITY FODDER PRODUCTION SYSTEM IN COCONUT"** 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.

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

Introduction

INTRODUCTION

Dairy farming is an important source of subsidiary income to the rural population in the humid tropics of Kerala. It plays multifaceted role in providing livelihood support to the smallholder farmers. However, a major constraint to dairy farming in Kerala is the insufficient quality and quantity nutrition (Ajith *et al.*, 2012). It is estimated that the state produces only 60 per cent of the fodder requirement for livestock. This results in the dependence of farmers on high priced concentrate feeds, which accounts to around 70 per cent of the total cost of milk production, there by offsetting farmer's profit to a considerable extent. Thus, cultivation of quality fodder is of prime importance for maintaining animal health and productivity and for ensuring sustainable and profitable milk production.

Fodder trees, with their nutrient rich leaves, constitute a potential source of quality green fodder to livestock especially during lean periods. The majority grass vegetation available in the dry season is poor in digestibility, protein as well as overall nutrient content. Introducing fodder trees in the existing cropping systems is one of the promising ways for increasing production of protein rich fodder, which can save farmer's expenses on costly concentrate feeds. During dry periods, fodder trees remain green for a longer duration than grasses because of their deeper rooting pattern and can provide the required energy and protein. In addition, integration of trees in agricultural farm offers multiple ecological services that help to improve soil properties and overall productivity of the land use.

The suitability of *Morus indica* (mulberry) and *Leucaena leucocephala* (subabul) as promising fodder trees by virtue of their nutritive foliage and ability to withstand severe pruning has already been reported (Pye-Smith, 2010). These trees grow well in the agro climatic conditions of Kerala (KAU, 2016). However, in a land crunch state like Kerala, it is best to integrate fodder trees into the existing farming system like coconut gardens rather than planting the tree as pure stand fodder banks. Mature tall coconut gardens (> 25 years) usually have better spatial advantage in crown spread and hence can allocate more light to the understorey giving ample scope for intercropping. Hence, realizing their potential as ideal fodder trees suitable for integrating with coconut gardens, an intercropping trial has been initiated at Kerala Agricultural University (KAU) to optimize the tree density and pruning interval of hedgerow-grown mulberry and subabul for maximizing forage yields and quality. Observations after one year revealed higher yield and nutritive value for both the trees in high-density stands (49,382 plants ha^{-1}) and at the shortest pruning interval of 8 weeks (Raj *et al.*, 2016).

However, both the tree species are fast growing in nature with vigorous and extensive rooting pattern. Hence, when age advances, the above and below ground interaction within the species as well as with the component crop coconut may increase, leading to either complementary or competitive effects ultimately influencing the productivity of both the trees. Moreover, adoption of frequent harvesting over years may have a detrimental effect on tree health and longevity. Hence, a proper understanding of the long term effects of management regimes like tree density and harvest interval on growth, yield and longevity of fodder trees, as well as its effect on coconut productivity is important in standardizing sustainable production strategies for the system.

In addition to fodder production, fodder trees helps in soil fertility improvement through litter recycling and root exudation. Leguminous trees like subabul can fix nitrogen and supply it to the component crops. Moreover, adoption of trees in agricultural farms offers multiple ecosystem services like carbon storage and associated climate change mitigation. Agroforestry practices have gained considerable attention as a carbon sequestration strategy because of carbon storage potential in the various plant species as well as in the soil (Nair and Nair, 2003). However, this aspect is one of the promising, but least studied ecological service of agroforestry systems.

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

- To assess the effect of tree density and harvest interval on forage yield and carbon storage potential of three-year old mulberry and subabul fodder banks underneath coconut garden.

- The study also explores the variation in coconut productivity and the soil fertility changes associated with intercropping mulberry and subabul as hedgerows with coconut.

Review of literature

REVIEW OF LITERATURE

Integration of protein rich fodder trees in the inter spaces of existing farming systems like coconut garden is an excellent option for enhancing the production of quality fodder so as to minimize the crude protein deficit in livestock farms. However, inadequate knowledge on the standard management practices may be a limiting factor for farmers for cultivating fodder trees in the coconut garden to maximize production from the system. In a land crunch state like Kerala, by cultivating fodder trees in the inter spaces of existing coconut plantation can ensure higher forage productivity per unit area. Field trials on various fodder tree species established and managed as high density fodder banks indicated that, the management regimes like tree density and pruning interval influences fodder productivity, yield of the component crops, soil fertility condition of the system and also the carbon sequestration potential of the system.

The present study aims to evaluate the influence of stand management regimes like tree density and pruning interval of mulberry and subabul on fodder and coconut yield; and carbon dynamics and soil fertility status of coconut-fodder tree intercropping systems. The relevant literature supporting the above aspects is reviewed hereunder.

2.1 SCENARIO OF LIVESTOCK SECTOR IN INDIA AND KERALA

Livestock sector is an essential part of India's agricultural economy and plays multifarious role in providing livelihood support to the rural population. Livestock sector contributes 4.1 per cent to the national economy in terms of Gross Domestic Product (GDP) at current prices during 2012-13. There is a demand of 182 MT in the production of milk by the year 2021-22 whereas the current milk production in India is only 156 MT (GOI, 2014).

In 2015-16, milk production in Kerala was 26.50 lakh MT which contributed only 1.70 per cent of the annual milk production of the country. The dairy sector in Kerala produces only 60 per cent of the roughage requirement for cattle. The production potential of cattle is 8-10 litres per day. But the average production is only 5-6 litres per day due to poor nutrition (Kerala State Planning Board, 2016).

2.2 MAJOR CONSTRAINTS IN LIVESTOCK REARING

Low quality and quantity of feed and fodder are the major constraints for realizing the production potential of the livestock. Feed costs are around 70 per cent of total operating costs, the largest being expenditure on concentrates (65-80%), resulting in increasing cost of production (Wanapat *et al.,* 2013). With the tremendous rise in feedstuff prices and global inflation, livestock production is increasingly affected by feed scarcity and the high cost of feeds (Mpofu *et al.,* 2005). India is facing a shortfall of 10 per cent dry fodder, 35 per cent green fodder and 37 per cent concentrate feed (ICAR, 2013). Ogunbosoye and Babayemi (2010) reported the poor performance of the livestock due to the inadequate feed supply to the ruminants during the dry season in the tropics.

In India, there is a deficit of green fodder particularly during summer season and only 4.4 per cent of the cultivated area is under fodder crops with annual total forage production of 846 MT (Mathukia *et al.,* 2016). There is a demand of 1012 and 631 million tonnes of green and dry fodder by the year 2020. The supply of edible forage has to grow at 1.69 per cent annually for meeting the deficit (IGFRI, 2015). Ajith *et al. (*2012) reported that insufficient quantity and quality nutrition is one of the major hindrances in livestock production in Kerala.

2.3 SCOPE OF FODDER TREES IN LIVESTOCK NUTRITION

The fodder trees play a vital role as dietary supplements in dry seasons by providing appreciable amount of nutrients that are poor in other feed resources such as fodder grasses and other crop residues. The fodder tree leaves are an alternative source of livestock feeding during lean period, especially in prolonged dry season. The leaves of fodder trees are harvested several times during summer and fed to livestock and also stored as hay (Javed *et al*., 2008). They can meet production shortages in times of extreme climatic conditions such as droughts (Franzel *et al*., 2014). They have deep and vigorous root systems enabling the extraction of water and nutrients from deeper layers in the soil profile (Teferi *et al*., 2008).

According to Aganga and Tshwenyane (2003), feed may include tree components like leaves, tender shoots or twigs, fruits, pods and seeds. In general, leaves contain almost double amount of crude protein than twigs. Fodder tree leaves are commonly richer in calcium and phosphorus than fodder grass pastures at comparable stages of growth, and deficiencies of these minerals are often reflected in reproductive problems of ruminant animals. In addition, many fodder trees are rich in essential elements such as calcium, sodium and sulphur as well as critical micronutrients such as iron and zinc which have been shown to be deficient or minimum for productive purposes in grasses (Paterson *et al*., 1998).

Fodder based feeding strategies are required to reduce the cost of quality livestock product as the feed alone comprises 60-70 per cent of the milk production cost (IGFRI, 2015). Fodder trees with protein rich nutritive foliage have the potential to replace the heavy priced concentrates, thereby ensuring sustainable and profitable milk production (Raju, 2013). Most of the fodder trees have high crude protein content, ranging from 10 to more than 25 per cent on a dry matter basis (Moleele, 1998). This reliable protein resource can be used to create a sustainable feeding system and increase livestock productivity. Emmanuel and Tsado (2011) noticed that in all fodder development works, legumes play the major role by enriching the soil with nitrogen and producing highly digestible and protein rich fodder. Raghavan (1989) noticed that fodder tree foliage makes a substantial contribution to meet the nutritional requirements during the winter.

Moreover, fodder trees have various uses in the form of shade, wind shelter, live fence, improved fallow and pasture, mulch, bee forage, human food, fuel wood, timber, fibre, resins, dyes, tannins, medicine, food, fertility improvement, soil stabilization, oxygen, wildlife and bird habitat, increased self-sufficiency, nutrient cycling and farm diversity (Elevitch and Wilkinson, 2000).

2.4 MULBERRY (*Morus indica*)

Mulberry was originated from temperate zones in Asia and extended throughout the world (Benavides *et al.*, 1994). It is a perennial tree or shrub easily propagated, with fast growth and with vigorous shooting. Mulberry can easily be established in the field (Rodriguez *et al.*, 1994; Ezenwa *et al*., 1999), and has good coppicing ability (Singh and Makkar, 2002). It was reported that mulberry has good potential for forage production by giving a yield of fresh leaves in the range of 16-40 tons/ha/year (Mehla *et al*., 1987; Rodriguez *et al*., 1994). It develops a strong vertical and profuse horizontal root system (Paolieri, 1970). These features improve physical conditions of soil and permit better water conservation.

As forage, mulberry has shown exceptional organoleptic qualities and intake for livestock (Ortiz, 1992; Benavides *et al.*, 1994). Protein content varies from 14 to 22 per cent on dry matter basis (Piccioni, 1970). The high levels of crude protein and high levels of digestible energy in mulberry makes the biomass yield from the tree extremely differential from other fodder trees. In addition to that, mulberry high mineral content and low fibre as well as tannin content (Patra *et al*., 2002). This makes the tree an attractive fodder resource for ruminants particularly as a feed supplement to low quality basal diets and could be nutritionally superior to subabul due to the absence of anti- nutritional factors. Akbulut *et al*. (2009) studied the mineral composition in mulberry and reported that mulberry contain the highest amount of calcium, potassium, magnesium, sodium, phosphorous and sulphur. In a similar study by Liang *et al*. (2012), mulberry was reported as a better source of minerals and could be recognized as a valuable horticultural product based on their rich and beneficial nutrient composition.

Goats fed with mulberry foliage reported the highest milk yield of 4.0 kg/day when compared to those fed with concentrate feeds. With mulberry foliage, increasing weight gains have been observed with increasing proportion in the diet (Benavides *et al.,* 1994). The value of mulberry is multidimensional and the potential for increasing and expanding its uses is enormous (Singh and Makkar, 2002). The studies conducted on mulberry in different areas focussed mostly on the utilization of the leaves as silk worm feed. The whole plant when harvested during the early growth stages can be a potentially valuable feed supplement to low quality ruminant diets. However, systematic and thorough knowledge on the yield and nutritional composition of mulberry in early growth stages is either not available or poorly defined.

2.5 SUBABUL (*Leucaena leucocephala* Lam.)

Leucaena leucocephala is a multipurpose sustainable leguminous tree well grown in the tropics (Garcia *et al*., 1996). Subabul is known as the 'miracle tree' because it is long-lived and produce highly nutritious forage along with several other uses. It is a promising fodder tree with its leaves, pods, and seeds as rich source of protein, minerals and essential fatty acids. Several efforts have been made to use the tree as a feed supplement because of large amount of protein of high biological value and of other nutrients such as carotene and various minerals (NAS, 1977; Akbar and Gupta, 1985 ; Sunaria and Sagar, 1989). It can be grown in all kinds of soils and can withstand drought well, once established. The plant's drought tolerance and hardiness make it a promising species for increasing meat and milk supplies throughout the dry tropics.

Subabul helps to enrich soil and assist companion crops because its foliage rivals manure in nitrogen content, and natural leaf fall returns this to the soil underneath the shrubs. In addition, leucaena's aggressive root system breaks up impervious subsoil layers, improving moisture penetration and decreasing surface runoff. Neutral to slightly alkaline soils are considered better for its growth (NAS, 1977). Light textured soil is better than clayey soil for root development and growth (Singh, 1985). Subabul is less tolerant to acidic soils and in soil with high aluminium content or which are waterlogged for any period of time (Bapat, 1995).

In a study, Hill (1971) reported the improvement in the performance of grazing animals by the addition of protein rich subabul foliage in the diet of ruminants. Dry matter production of subabul varies with soil fertility and rainfall. It has a digestibility of 55-70 %, 8 % crude protein, 6 % ether extract, 6-10 % ash and 30-50 % N free extract. Leucaena is highly palatable than other forage tree legumes such as calliandra and gliricidia. It reported a yield up to 50 tonnes per hectare per year under a variety of climatic conditions (Felker and Bandurski, 1979; Duke, 1981). It recovers quickly from complete defoliation or heavy grazing and has good coppicing ability.

2.6 FORAGE YIELD OF FODDER TREES

Fodder tree species of the genera *Calliandra* and *Leucaena* under a wide range of conditions in block-planting arrangements, have given annual yields of 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* grown as hedges at a height of 0.5 m. The fresh yields for the three fodder trees during the initial year of establishment were 11.2, 17.2 and 20.3 Mg ha^{-1}, respectively. However, in the next 8 months, the highest yield of 36.7 Mg ha^{-1} was reported in calliandra, whereas leucaena (24.3 Mg ha^{-1}) and sesbania (10.8 Mg ha^{-1}) followed the lower positions.

2.6.1 Effect of tree density on forage yield of fodder trees

Several studies indicate the profound influence of density management on forage yield of fodder trees. Castillo *et al.* (1979) made a comparison of four tree densities (3000, 5000, 6000 and 10,000 plants per ha^{-1}) in subabul and reported higher forage yield from the two highest densities. Ella *et al.* (1989) observed that in high density planting of fodder trees, forage yield per unit area increases when compared to lower densities. In a similar study, higher dry matter yields were reported from higher fodder tree density of 40,000 plants ha^{-1} compared to lower density of 15,000 plants ha^{-1} (Pathak *et al.,* 1980).

Density trials of mulberry and subabul fodder banks in coconut gardens of Kerala revealed the significant enhancement 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). In calliandra, similar study reported an increase in fodder yield from lower tree density of 17,777 to higher tree density of 27,777 plants ha^{-1} (Joy, 2017).

2.6.2 Effect of harvest interval on forage yield of fodder trees

The most suitable pruning interval to promote high yields in fodder trees vary with environmental factors. In general, longer intervals between harvesting reported higher yields. However, the quantity of woody stem portion may also increase leading to a decline in forage quality (Ella *et al.*, 1989). Harvest interval may be 6-8 weeks at very productive sites where as up to 12 weeks at less productive locations (Brewbaker *et al.*, 1985). In Malaysia, the optimum stage to harvest mulberry for fodder is 5 weeks, which is a compromise between yield, nutrient composition and the annual number of harvests, with good crop persistence to recurrent harvests. In mulberry, increasing harvest interval up to 12 weeks increased dry matter, foliage and nutrient yields significantly and declined at 16 weeks, in humid tropical conditions of Kerala (Raj *et al.,* 2016).

In addition, similar experiments with different fodder trees reported that longer harvest intervals increase fodder biomass production. In density trials of fodder blocks, maximum production was observed for 12 weeks harvest interval (Guevara *et al.*, 1978; Ella *et al.*, 1989). Similar studies suggested that 8-12 weeks pruning interval is most desirable for maximising fodder yield (Paterson *et al.*, 1996; Shelton *et al.*, 1996). In the humid tropics of Kerala, mulberry and subabul fodder banks underneath coconut garden produced maximum edible forage under shorter harvest interval of 8 weeks when compared to the longer interval of 12 and 16 weeks (Raj *et al*., 2016).

2.7 INTERCROPPING FODDER TREE BANKS IN COCONUT PLANTATION

In a land crunch state like Kerala, per capita land holding is low and hence, the possibility of growing fodder tree banks in the open conditions is limited. The best alternative is to integrate fodder trees in the existing farming systems. In Kerala, coconut is the major land-use system with an area of 7.9 lakh hectare (Kerala State Planning Board, 2015). In Kerala, coconut based farming systems provide the scope for integrating fodder trees in the interspaces of coconut garden, thereby increasing production and productivity per unit area with the optimum utilization of resources (Nelliat, 1973). Kushwah *et al.* (1973) reported that about 74 per cent of coconut root did not go outside 2 m lateral distance and 82 per cent of the roots were limited to the 31 to 120 cm depth of soil. Thus, the active root zone of coconut is confined to 25 per cent of the available land area and the remaining area could be profitably utilized for raising intercrops. A high efficiency in the use of available soil moisture and nutrients can be achieved by growing intercrops 2 m radius away from the base of palms. Studies confirmed the possibility of cultivating fodder trees like subabul, mulberry, gliricidia and calliandra under coconut plantation (Raj *et al*., 2016).

Several studies were conducted in fodder trees intercropped in various plantations. ICRAF (1992) reported that the growth of subabul and calliandra is not inhibited by taller, timber and fuel wood species like *Casuarina equisetifolia* or *Grevillea robusta*, 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) evaluated yield performance of different fodder trees under various shade treatments and expressed it as a percentage of yields 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%).

Gliricidia and subabul, planted at 2.0 × 0.9 m spacing in double rows in mature coconut plantations and lopped at a cutting frequency of three-months, yielded 7-10 Mg ha^{-1} and 12-16 Mg ha^{-1} green fodder and 8-15 and 14-20 fresh fuel wood in the first and second year of establishment at the four sites of the Coconut Triangle in Srilanka (Liyanage and Jayasundera, 1987). In a study conducted in Bali, Oka Nurjaya *et al.* (1990) reported that calliandra 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 8 weeks interval for six harvests after planting.

2.8 CARBON SEQUESTRATION POTENTIAL OF COCONUT-FODDER TREE INTERCROPPING SYSTEMS

Trees play an essential role in sequestering carbon and enhancing the carbon storage potential of various land management systems. Several studies reported that trees could act as carbon sinks by holding large amount of carbon per unit area, thereby mitigating climate change (Lasco *et al.*, 2002). All the fast growing species like poplar, eucalyptus, leucaena, acacia etc. can be incorporated in the agroforestry system for sequestering carbon in the system. Fodder trees have the capacity to increase soil carbon, which greatly benefits agricultural productivity and sustainability (Singh *et al.,* 2015). Dabas and Bhatia (1996) also suggested great potential of tree based intercropping systems in lowering the atmospheric CO_2 levels compared to sole cropping systems.

Several studies reported that the perennial crop, coconut with a life span of 50- 60 years, possess the potential to act as a carbon reservoir (Jayasekara and Jayasekara, 1995; Ranasinghe and Silva, 2007). In a study, Navarro *et al*. (2008) reported that 19-22 year old Vanuatu Red Dwarf Vanuatu Tall, a high yielding hybrid of coconut accumulated a total carbon stock of 34.13 Mg ha^{-1} and a part of it, i.e., 5.0 Mg ha^{-1} was imparted by coarse and fine roots. Moreover, he also reported that the grass cover stored 1.8 Mg ha^{-1}. The study also shows that 25-year old Tall × Tall coconut plantations of Sri Lanka can sequester 17-25 Mg carbon per ha. In a study, Roupsard *et al*. (2008) reported that more carbon stocks were observed in the soil of coconut plantations on comparison with the biomass of coconut. The study conducted in Kerala by Varsha (2015) in mulberry and Joy (2017) in calliandra reported that planting high-density fodder banks in the interspaces of coconut plantation captured more carbon than lower densities.

2.9 SOIL CARBON STOCKS IN COCONUT-FODDER TREE INTERCROPPING SYSTEM

The soil organic carbon (SOC) pool is one of the largest near-surface carbon reservoirs on earth (Schlesinger, 1995). It comprise an estimated 1500 Gt of carbon, or 80 per cent of the total terrestrial carbon store (Amundson, 2001; Richards, 2007). Several studies suggest pastures containing legumes have a greater potential to increase SOC (Robles and Burke, 1997). Radrizzani *et al.* (2011) reported that leucaena pastures captured an extra 3.0 to 5.3 t ha^{-1} of SOC in the upper 0.15 m soil, compared with adjacent buffel grass pasture over 20 to 38 years. By extrapolating the data, Shelton and Dalzell (2007) estimated an additional 1.98 Mt of CO_2 sequestered by the 1.5 lakh ha of leucaena plantings across Queensland in the topsoil (0.15 m) alone.

In a study conducted on popular planted in homegardens of Bangladesh, Jaman *et al*. (2016) reported higher soil carbon sequestration than in monoculture plantations. Moreover, they can also serve as a crucial ecological tool in terms of species composition and soil organic carbon capture. In addition, tree density is reported to be an important factor that determines SOC content in many of tropical agroforestry systems. In a study on calliandra intercropped with coconut, Joy (2017) reported that the overall carbon storage potential of the system was obtained maximum (163.90 Mg ha^{-1}) for the highest tree density when compared with the lower densities.

2.10 NUTRIENT STOCKS IN COCONUT-FODDER TREE INTERCROPPING SYSTEM

Utilization and stocking of nutrient is a part of the all over physiology of the plant and its genetic inheritance. In a study in *Populus deltoids* under high density plantations, Bhardwaj *et al.* (2001) observed that both accumulation of nutrients and its uptake showed increasing trends for macronutrients (N, P and K) with increase in plant population. Total amount of nitrogen retained (branch+ bole) was highest (1005 kg ha^{-1}) at 60 x 60 cm and least (765 kg ha^{-1}) at 120 x 120 cm plantation spacing, where P and K had values of 18.47 kg ha^{-1} and 895.7 kg ha^{-1} at closest spacing and 13.54 and 611.9 kg ha^{-1} at wider spacing respectively. In a study in plantation of 8 forest tree species, Singh and Singh (1998) reported that maximum N was found in leaves (1.18- 2.02 %) of all the species, followed by branches and twigs (0.54- 0.8 %), roots (0.28- 0.57 %) and stems (0.32- 0.5 %).

Kumar *et al.* (1998) studied the nutrient efficiency of multipurpose tree species and reported that nutrient accumulation was higher for *Acacia auriculiformis* and least for *Leucaena leucocephala*. The nutrient concentration decreased in the order to foliage> branches > roots > bole. *A. auriculiformis* had the highest N (1539 kg ha^{-1}), P (113 kg ha^{-1}) and K (478 kg ha^{-1}) accumulation at the 7-years of age, when grown in silvo-pastoral system.

2.11 SOIL FERTILITY DYNAMICS IN COCONUT-FODDER TREE INTERCROPPING SYSTEM

Studies on *Leucaena leucocephala* and *Calliandra calothyrsus* by Roose and Ndayizigiye (1997) and Syers (1994) reported a considerable reduction of soil loss in cultivated hill slopes. Evidential reduction in nitrogen and magnesium losses from the soil through hedgerow cultivation has also been reported (Schroth *et al.,* 1995). By tapping water and nutrients leached from the surface into the subsurface, perennial trees act as surface mulch that replenishes nutrients, conserves soil moisture and improves soil organic matter content (Carson, 1992; Young, 1997; Sharma *et al.*, 1998). Studies also pointed that agroforestry has potential for accelerating soil N through biological N fixation and nutrient retrieval from the lower soil layers (Fernandes and Matos, 1995; Shepherd *et al.*, 1996; Buresh and Tian, 1998).

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 soil also increased at various depths (Varsha, 2015) in mulberry plots when compared to treeless control. The study also indicated that the tree-based systems favourably influenced the nitrogen and potassium content in soil.

Materials and methods

MATERIALS AND METHODS

The present study entitled "Productivity, carbon and nutrient stocks in mulberry (*Morus indica* L.) and subabul (*Leucaena leucocephala* Lam.) based high density fodder production system in coconut" was carried out at Instructional Farm, College of Horticulture, Vellanikkara during the year 2017-2018. The major objective of the study was to evaluate the influence of tree density and harvest interval on forage yield and carbon storage potential of three-year old mulberry and subabul fodder banks underneath coconut garden. The study also explores the variation in coconut productivity and soil fertility changes associated with intercropping these fodder trees with coconut.

3.1 LOCATION

The proposed study forms part of a pre-existing field trial involving intercropping of mulberry and subabul hedgerows in mature coconut plantation (7.6 × 7.6 m spacing), located at Instructional Farm, College of Horticulture, Vellanikkara. The performance of the two fodder trees were evaluated under varying management regimes of tree densities and harvest intervals.

3.2 CLIMATE AND SOIL

Vellanikkara experiences a warm humid tropical climate. The area receives both southwest and northeast monsoons, with a major share from southwest monsoon. The mean maximum temperature ranged from 30.1 to 36.7^{0} C in the months of August and March respectively. While the mean minimum temperature varied from 20.9 to 26.0^{0} C in the months of January and April respectively. The soil of the experimental site was deep well drained sandy clay loam of Ultisol order. Initial soil tests indicated acidic soil reaction (pH: 5.76) with 0.79 per cent organic carbon; and available nitrogen, phosphorus and potassium @ 559, 3 and 454 kg ha^{-1} respectively (Raj, 2016).

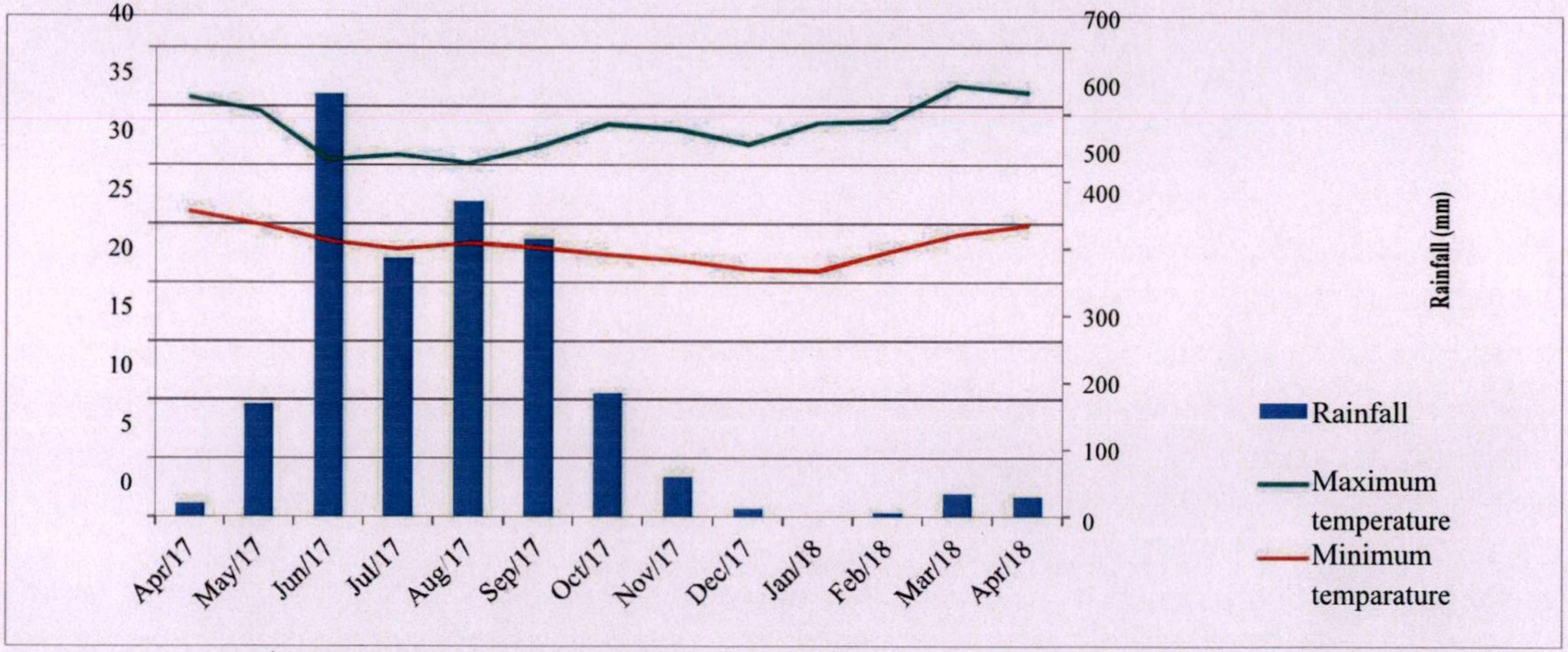


Fig.1. Mean monthly rainfall and temperature data from April 2017- April 2018 at Vellanikkara, Kerala.

3.3 MATERIALS

3.3.1. Crop

The fodder trees viz. mulberry (*Morus indica* L.) and subabul (*Leucaena leucocephala* Lam.) were intercropped in the interspaces of coconut variety, West Coast Tall, aged 37 years.

3.3.1.1 *Mulberry*

The leaves of mulberry, traditionally used for silkworm rearing, is known for its high protein and mineral content, high digestibility, low fibre content and very good palatability (Sanchez, 2001). The high forage yields of the plant coupled with its low tannin content make it an attractive fodder resource for ruminants. Being an ideal fodder tree suited to the agro climatic conditions of humid tropical Kerala, mulberry variety V1 (Victory-1, a cross of S-30 and Berc 776 mulberry cultivars), released from Central Sericulture Research and Training Institute, Mysore, Karnataka was the fodder tree species selected for this study.

3.3.1.2. *Subabul*

Subabul (*Leucaena leucocephala)*, a multipurpose fast growing leguminous tree with nutrient rich foliage, is promoted extensively in different regions as a fodder resource to enhance ruminant production. High crude protein content and digestibility and low fibre content are the major factors which make subabul a good supplement for ruminants in the tropics (Islam *et al*., 1991). The suitability of subabul (*Leucaena leucocephala* Lam.) as promising fodder tree by virtue of its nutritive foliage and ability to withstand severe pruning has already been reported (Pye-Smith, 2010). This is the most widely used leguminous fodder tree in various agroforestry models due to its high nitrogen fixing capacity. Subabul is also recommended as an ideal fodder tree for humid tropical conditions of Kerala (KAU, 2016).

Mulberry and subabul intercropped in coconut garden

Harvested biomass

Plate 1. Harvested biomass of mulberry and subabul fodder banks intercropped in coconut plantation, Vellanikkara, Kerala.

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 southwest monsoon. Fertilizers were applied through N: P: K mixture (18: 18: 18) in two split doses before onset of southwest and northeast monsoons.

3.4 METHODS

The present field experiment was superimposed on an existing field trial established during 2015, involving mulberry and subabul intercropped with coconut (7.6 × 7.6 m spacing), at varying tree densities and harvest intervals. The experimental details of the initial trial were as follows:

3.4.1 Design and Layout of the Experiment

Experimental design	: Factorial RBD (Randomized Block Design)
Number of treatments	: 18
Number of replications	: 3
Size of each plot	: 4 m × 3 m

3.4.2 Details of Treatments

The treatments consisted of two fodder tree species; mulberry and subabul under three levels of tree density and three levels of harvest interval in all possible combinations, the details of which are given below.

1. **Fodder Trees**

   P_1-Mulberry

   P_2-Subabul

2. **Tree Density (3 levels)**

   D_1 – 49,382 plants ha^{-1} (45 × 45 cm spacing)

   D_2 –37,037 plants ha^{-1} (60 × 45 cm spacing)

D_3 – 27,777 plants ha^{-1} (60 × 60 cm spacing)

3. Harvest Interval (3 levels)

F_1 – 8 weeks interval

F_2 – 12 weeks interval

F_3 – 16 weeks interval

The layout plan of the trial is shown in Fig.2.

3.4.3 Field culture

The intercropping trial of mulberry and subabul in coconut was established during April 2015. The field area (excluding coconut basin of 2m radius) was ploughed twice and the layout was done allocating a plot size of 4 m × 3 m (12 sq. m) for each treatment. Pits were taken at prescribed spacing for each treatment and 3-month-old mulberry saplings (variety, V1) and subabul seedling (variety, Cunningham) was transplanted to the main field with the onset of pre-monsoon showers. Manures and fertilizers were applied each year as detailed in section 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 1m, an initial uniform cut was given to all plants in 2016, 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 mulberry and subabul were recorded during 2017-18. Data on the fodder yield during the first and second year of growth was collected from the previous harvest observations during 2015-17.

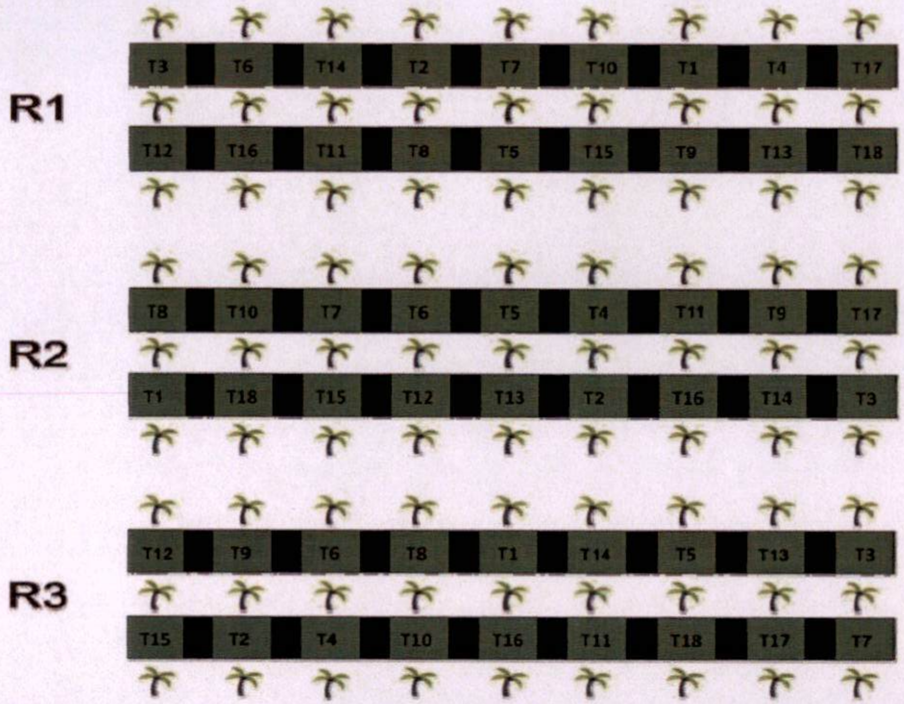


Fig. 2. Layout of the field trial

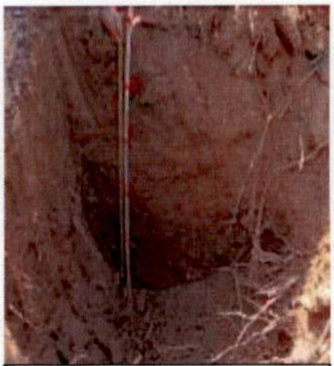
Treatment Combinations

T1- $P_1D_1F_1$	T10- $P_2D_1F_1$
T2- $P_1D_2F_1$	T11- $P_2D_2F_1$
T3- $P_1D_3F_1$	T12- $P_2D_3F_1$
T4-$P_1D_1F_2$	T13- $P_2D_1F_2$
T5- $P_1D_2F_2$	T14- $P_2D_2F_2$
T6- $P_1D_3F_2$	T15- $P_2D_3F_2$
T7- $P_1D_1F_3$	T16- $P_2D_1F_3$
T8- $P_1D_2F_3$	T17- $P_2D_2F_3$
T9-$P_1D_3F_3$	T18- $P_2D_3F_3$

P_1 and P_2	- Fodder tree species mulberry and subabul
D_1, D_2 and D_3	- Tree densities of 49,383; 37,077and 27,777 plants ha^{-1}
F_1, F_2 and F_3	- Harvest intervals of 8, 12 and 16 weeks
R	- Replication

Quadrant sampling

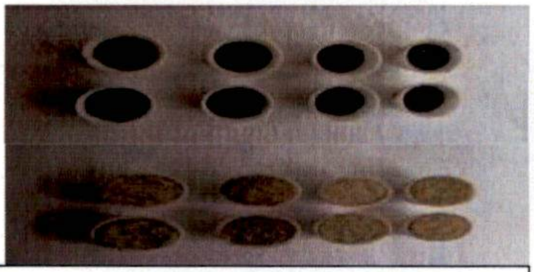
Stump biomass



Soil profile

Root biomass

Core sampling



Powdered plant samples for carbon estimation in muffle furnace

Plate 2. Estimation of carbon stocs in mulberry and subabul fodder bans at Vellanikkara, Kerala.

3.5.1 Annual green fodder yield

Fodder biomass from 5 trees/ plot avoiding border plants was assessed directly at each harvest. Biomass was separated into leaf, edible green stem and inedible brown stem and their individual fresh weights and total biomass determined. Thereafter, yield from all harvests in a year was pooled to get annual yields and using the net harvested area, fresh weight and annual green fodder yield was scaled to the area under fodder trees in one hectare coconut garden. The area under fodder trees in one-hectare coconut garden is 7827 m^2, 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 2015 to 2018.

3.5.2 Annual dry fodder yield

Triplicate sub-samples taken from the leaf, green and brown stem fractions of mulberry and subabul 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.

3.5.3 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.

3.5.4 Incidence of pest and diseases

No serious pest and disease incidence was noticed in mulberry and subabul during the experimental period. However, a minor attack of stem borer was noticed in subabul which resulted in toppling of the plants.

3.5.5 Annual coconut yield

Bimonthly records of nut yield were taken from palms with and without mulberry and subabul and summed up to get annual yield and expressed on hectare basis.

3.5.6 Assessment of carbon storage potential of coconut-fodder tree intercropping system

3.5.6.1 Harvested dry fodder biomass during three year period

The harvested dry fodder biomass from various treatments of mulberry and subabul 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.

3.5.6.2 Aboveground fresh and dry standing biomass of fodder trees

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

3.5.6.3 Belowground fresh and dry root biomass of fodder trees

The soil below the quadrats used for taking aboveground observation was excavated to 1 m depth to record the root biomass from 1cu.m volume of the soil. The roots of mulberry and subabul 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 were expressed on hectare basis (Joy, 2017).

3.5.6.4 Carbon stocks in the whole plant biomass of mulberry and subabul

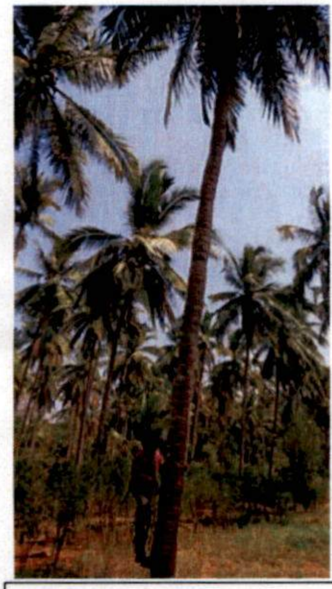
The oven dried leaves, stem and root fractions of fodder trees were ground thoroughly to pass through 2 mm sieve and used for analysing the carbon concentrations in the various tissue types, by igniting in muffle furnace at 550^0 C for 6 hours (Gaur, 1975). Carbon content in different plant fractions 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.

3.5.6.5 Carbon stocks in coconut palms

Carbon stocks in the intercropped and sole coconut palms were estimated by compiling carbon stocks in the coconut bole, leaves, harvested nuts and existing nuts of various size classes. Due to practical difficulties in estimating root biomass, carbon stocks in roots were not assessed.

At the end of the experiment, the intercropped and the sole coconut palms were climbed to count the number of nuts in each developing bunch (8-11 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 (Joy, 2017). C stocks of nuts were calculated based on the fact that 50% of dry biomass constituted carbon content (Ranasinghe and Thimothias, 2012). Carbon stocks of the harvested nuts in the 3rd year were also estimated in this manner.

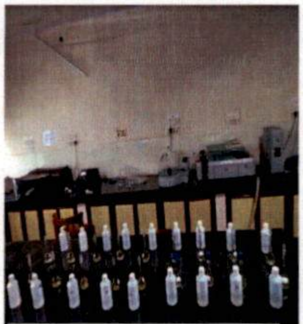
The dry weight of coconut bole was calculated by estimating the density of the bole. The average oven dry density of the bole of coconut palms of West Coast Tall variety aged 35-37 years in Ollukkara block and Malayoram agroclimatic zone of Thrissur district of Kerala is 509.60 kg m^{-3} (George, 2017).



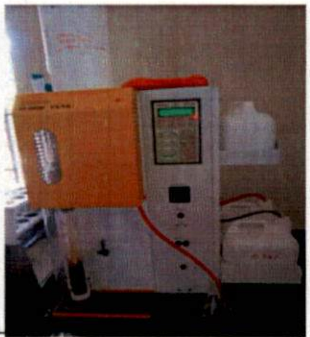
Different size classes of existing nuts on coconut palms

Taking observations from coconut palms

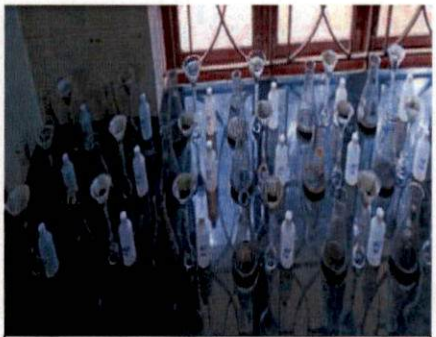
Taking biomass readings of leaves of coconut palms



Plant samples for nitrogen



Analysis of nitrogen in soil



Soil nutrient analysis

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

The bole dry weight of palm was estimated by multiplying the volume of the bole with the density (the shape of the coconut stem was assumed to be cylindrical). 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 standard mathematical formula ($\pi r^2 h$).

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 of coconut bole and fronds was assumed 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.

3.5.6.6 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 40 cm depth, and soil samples were collected from two soil depths (0-20 cm and 21-40 cm) from each plot. 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 sole coconut plantation and contiguous treeless plots to get the composite sample and subsamples were used for analysis (Joy, 2017).

Soil samples were collected separately from all the soil depths using a core sampler for estimation of bulk density (Gupta and Dakshinamurthy, 1980). 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-concentration (%) (Anderson and Ingram, 1989). Soil carbon stocks in individual soil depths were summed up to get the overall soil carbon sequestration under various treatments.

3.5.7 Nutrient stocks in fodder trees

3.5.7.1 Nitrogen Uptake

The total nitrogen content in different fractions of fodder trees were determined by digesting 1g of plant sample in 10 ml of sulphuric acid in the presence of digestion mixture (K_2SO_4: $CuSO_4$: Selenium in 10: 4: 1 ratio) and the N content in the digest was determined by Microkjeldhal method (Jackson, 1973). Total nitrogen uptake was calculated by multiplying the percentage so obtained with the corresponding dry matter and expressed in kg ha^{-1}.

3.5.7.2 Phosphorous Uptake

Total phosphorus was extracted by di-acid digestion and then estimated colorimetrically by vanadomolybdate (blue colour) method. The extracted P was estimated using spectrophotometry. Total phosphorous uptake was calculated by multiplying the percentage so obtained with the corresponding dry matter in various plant fractions and expressed in kg ha^{-1}.

3.5.7.3 Potassium Uptake

Total potassium was extracted by di-acid digestion (9:4 mixture HNO_3: $HClO_4$) and potassium in plant extract was estimated by flame photometer method. Total potassium uptake was calculated by multiplying the percentage so obtained with the corresponding dry matter in various plant fractions and expressed in kg ha^{-1}.

3.5.8 Soil Analysis

To study the comparative changes in soil physico-chemical 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.

3.5.8.1 Soil Physical Properties

3.5.8.1.1 Bulk Density

Bulk density was estimated by taking out a core of undisturbed soil by using a core sampler (Gupta and Dakshinamurthy, 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.

3.5.8.1.2 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, 1973).

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

3.5.8.1.3 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).

3.5.8.2 Soil Nutrient Analysis

3.5.8.2.1 Total Nitrogen

The total nitrogen content in the soil was determined by digesting 1g of soil in 5ml of sulphuric acid in presence of digestion mixture (K_2SO_4: $CuSO_4$: Selenium in 10: 4: 1 ratio) and the N content in the digest was determined by Microkjeldhal method (Jackson, 1973).

3.5.8.2.2 Available nitrogen

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

3.5.8.2.3 Available phosphorus

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

3.5.8.2.4 Available potassium

Available potassium was determined by flame photometry using 1N 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 (Joy, 2017).

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 field study on "Productivity, carbon and nutrient stocks in mulberry (*Morus indica* L.) and subabul (*Leucaena leucocephala* Lam.) based high density fodder production system in coconut", carried out at Vellanikkara reported valuable information on the influence of tree density and harvest interval on forage yield and carbon storage potential of three year old mulberry and subabul intercropped in coconut garden. The study also examined the variation in coconut productivity and soil fertility changes associated with intercropping these fodder trees in coconut plantations. The prominent results are presented hereunder.

4.1 SURVIVAL AND PRODUCTIVITY OF MULBERRY AND SUBABUL UNDER VARIABLE DENSITIES AND HARVEST INTERVAL IN COCONUT PLANTATIONS

4.1.1 Survival percentage of fodder trees

The data given in table 1 and 2 showed the influence of tree density and harvest interval on the survival percentage of mulberry and subabul. In general, mulberry had significantly higher survival percentage (86.82%) as compared to subabul (72.37%). However, management factors like tree density and harvest interval had no significant influence on the survival percentage of these fodder trees. Comparing treatment combinations, mulberry stands with the highest density and 16 weeks harvest interval (T_7) had more survival percentage (90.67%) as compared to all other treatments.

4.1.2 Annual fresh fodder yield of fodder trees

The main effect of tree densities and harvest interval on annual fresh fodder yield of mulberry and subabul are given in the table 1. Comparing both the trees, the total fodder yield of mulberry was higher (33.93 Mg ha^{-1} yr^{-1}) than subabul (20.14 Mg ha^{-1} yr^{-1}). Edible forage yield also followed the similar trend. Tree density had significant effect on edible fodder and total fodder yield. Edible fodder yield was higher (26.74 Mg ha^{-1} yr^{-1}) for trees at the closest spacing (45 cm × 45 cm) than the wider spacing. Total fodder yield of trees increased from 18.97 Mg ha^{-1} yr^{-1} at low tree density (27,777 plants ha^{-1}) to 35.04 Mg ha^{-1} yr^{-1} at the highest tree density (49,382 plants ha^{-1}). Harvest interval also showed significant effect on forage yield. The edible (24.17 Mg ha^{-1} yr^{-1}) as well as total (33.98 Mg ha^{-1} yr^{-1}) forage yield was higher for trees at medium harvest interval of 12 weeks than longer or shorter intervals.

The combined effect of tree densities and harvest interval showed significant effect on annual fresh fodder yield of mulberry and subabul (Table 2) under coconut plantation. Edible fodder, stem and total fodder yields of 45.04, 18.35 and 63.38 Mg ha^{-1} yr^{-1} respectively was highest for mulberry at high tree density (49,382 plants ha^{-1}) and 12 weeks harvest interval (T_4). Similar management practices also produced the maximum fresh fodder yield (30.96 Mg ha^{-1} yr^{-1}) in subabul.

4.1.3 Annual dry fodder yield

Table 3 shows the main effect of tree densities and harvest interval on annual dry fodder yield of fodder trees. The dry edible fodder (6.10 Mg ha^{-1} yr^{-1}), total stem (2.10 Mg ha^{-1} yr^{-1}) and total dry fodder biomass (8.21 Mg ha^{-1} yr^{-1}) was significantly higher for mulberry than subabul. Tree density had significant effect on dry fodder biomass of these fodder trees. The edible as well as total dry fodder biomass increased from the lowest tree density (27,777 plants ha^{-1}) to the highest tree density (49,382 plants ha^{-1}). Highest edible dry fodder was obtained at 8 weeks harvest interval (5.97 Mg ha^{-1} yr^{-1}), and was on par with those obtained at 12 weeks harvest interval (5.74 Mg ha^{-1} yr^{-1}). Total dry stem and total dry fodder biomass was comparatively higher (2.16 and 7.91 Mg ha^{-1} yr^{-1} respectively) for 12 weeks harvest interval.

Treatment combinations showed significant effect on dry fodder biomass of mulberry and subabul (Table 4). Higher dry fodder yield (14.85 Mg ha^{-1} yr^{-1}) was obtained from mulberry at higher tree density (49,382 plants ha^{-1}) and 12 weeks harvest interval. Similar trend was also observed in case of subabul even though the yield was significantly lower than mulberry under the same management practices.

4.1.4 Fodder biomass over three year period

Table 5 depicts the main effect of tree densities and harvest intervals on harvested dry fodder biomass from mulberry and subabul over three- year period. Total dry fodder yield over three- year period was significantly higher for mulberry (26.89 Mg ha^{-1}) than that of subabul (23.85 Mg ha^{-1}). Tree density had significant effect on total dry fodder yield and found to have increased from 18.69 to 31.82 Mg ha^{-1} from low to high tree density. Harvest interval also had significant influence on harvested dry fodder biomass from these fodder trees. Total dry fodder yield was reported highest (27.58 Mg ha^{-1}) for 12 weeks harvest interval.

Combined effect of tree densities and harvest interval showed significant influence on pooled harvested dry fodder yield of mulberry and subabul (Table 6). Highest pooled harvested dry fodder biomass over three-year period (39.95 Mg ha^{-1}) was obtained for the combination of mulberry at tree density of 49,382 plants ha^{-1} and 12 weeks harvest interval (T_4). In the case of subabul, highest total harvested dry fodder yield (32.64 Mg ha^{-1}) was obtained from the highest tree density and 8 weeks harvest interval (T_{10}).

Table 1. Effect of tree density and harvest interval on survival percentage and fresh fodder yield of fodder trees under coconut plantation at Vellanikkara, Kerala

Factors	**Survival %**	**Fractional and total fresh forage yield in the third year of intercropping (Mg ha^{-1} yr^{-1})**		
		Edible fodder (Leaf + green stem)	**Stem**	**Total fodder**
Fodder trees				
Mulberry(P_1)	86.82^{a}	25.27^{a}	8.66^{a}	33.93^{a}
Subabul(P_2)	72.37^{b}	16.17^{b}	3.96^{b}	20.14^{b}
p value	0.000**	0.000**	0.000**	0.000**
Tree density				
49,382 plants ha^{-1}(D_1)	81.78	26.74^{a}	8.29^{a}	35.04^{a}
37,037 plants ha^{-1} (D_2)	77.89	20.96^{b}	6.13^{b}	27.08^{b}
27,777 plants ha^{-1} (D_3)	79.11	14.46^{c}	4.51^{c}	18.97^{c}
p value	0.61^{ns}	0.000**	0.001**	0.000**
Harvest interval				
8 weeks(F_1)	78.78	20.32^{ab}	5.05^{b}	25.37^{b}
12 weeks(F_2)	79	24.17^{a}	9.81^{a}	33.98^{a}
16 weeks(F_3)	81	17.67^{b}	4.07^{b}	21.75^{b}
p value	0.83^{ns}	0.04*	0.000**	0.001**
PxFxD (p value)	0.34^{ns}	0.81^{ns}	0.56^{ns}	0.72^{ns}

** 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 2. Combined effect of tree density and harvest interval on survival percentage and fresh fodder yield of fodder trees under coconut plantation at Vellanikkara, Kerala.

Treatments	**Survival %**	**Fractional and total fresh forage yield (Mg ha^{-1} yr^{-1})**		
		Edible fodder (Leaf +green stem)	**Stem**	**Total fodder**
T_1-$P_1D_1F_1$	81.33	24.17	7.60	31.80
T_2-$P_1D_2F_1$	87.67	24.13	7.03	31.16
T_3-$P_1D_3F_1$	82.33	20.99	5.01	26.00
T_4-$P_1D_1F_2$	87.67	45.04	18.35	63.38
T_5-$P_1D_2F_2$	88.67	32.38	14.69	47.07
T_6-$P_1D_3F_2$	85.67	21.51	8.99	30.51
T_7-$P_1D_1F_3$	90.67	29.84	7.72	37.56
T_8-$P_1D_2F_3$	88.67	17.67	3.83	21.51
T_9-$P_1D_3F_3$	88.67	11.68	4.72	16.40
T_{10}-$P_2D_1F_1$	69.33	18.01	3.22	21.23
T_{11}-$P_2D_2F_1$	69.67	20.43	4.13	24.56
T_{12}-$P_2D_3F_1$	82.33	14.19	3.29	17.48
T_{13}-$P_2D_1F_2$	88.67	22.22	8.74	30.96
T_{14}-$P_2D_2F_2$	62.67	13.57	4.30	17.87
T_{15}-$P_2D_3F_2$	60.67	10.30	3.80	14.11
T_{16}-$P_2D_1F_3$	73.00	21.20	4.14	25.33
T_{17}-$P_2D_2F_3$	70.00	17.58	2.78	20.36
T_{18}-$P_2D_3F_3$	75.00	8.07	1.27	9.33
Treatment mean	79.59	20.72	6.31	27.03
p value	0.000**	0.000**	0.000**	0.000**
LSD (0.05)	21.30	12.60	5.70	16.30

** significant at $p<0.01$

Table 3. Effect of tree density and harvest interval on dry fodder yield of fodder trees under coconut plantation at Vellanikkara, Kerala.

Factors	Fractional and total dry fodder biomass (Mg $ha^{-1}yr^{-1}$)		
	Edible fodder (Leaf +green stem)	Stem	Total fodder
Fodder trees			
Mulberry(P_1)	6.10^{a}	2.10^{a}	8.21^{a}
Subabul(P_2)	4.19^{b}	0.79^{b}	4.98^{b}
p value	0.002**	0.000**	0.000**
Tree density			
49,382 plants ha^{-1} (D_1)	6.45^{a}	1.89^{b}	8.35^{a}
37,037 plants ha^{-1} (D_2)	5.26^{a}	1.36^{ab}	6.63^{ab}
27,777 plants ha^{-1} (D_3)	3.74^{b}	1.07^{b}	4.81^{b}
p value	0.002**	0.03*	0.002**
Harvest interval			
8 weeks(F_1)	5.97^{a}	1.37^{b}	7.35^{a}
12 weeks(F_2)	5.74^{a}	2.16^{a}	7.91^{a}
16 weeks(F_3)	3.73^{b}	0.80^{b}	4.53^{b}
p value	0.004**	0.000**	0.002**
PxFxD (p value)	0.794^{ns}	0.769^{ns}	0.752^{ns}

** 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 4. Combined effect of tree density and harvest interval on dry fodder yield of fodder trees under coconut plantation at Vellanikkara, Kerala.

Treatments	Fractional and harvested dry fodder biomass (Mg ha^{-1} yr^{-1})		
	Edible fodder (Leaf + green stem)	**Stem**	**Total fodder**
T_1-$P_1D_1F_1$	6.84	1.89	8.73
T_2-$P_1D_2F_1$	7.06	2.02	9.08
T_3-$P_1D_3F_1$	6.11	1.86	7.97
T_4-$P_1D_1F_2$	10.39	4.46	14.85
T_5-$P_1D_2F_2$	7.50	3.20	10.70
T_6-$P_1D_3F_2$	4.67	2.17	6.84
T_7-$P_1D_1F_3$	5.74	1.98	7.71
T_8-$P_1D_2F_3$	4.01	0.53	4.54
T_9-$P_1D_3F_3$	2.62	0.83	3.44
T_{10}-$P_2D_1F_1$	5.25	0.69	5.94
T_{11}-$P_2D_2F_1$	6.34	1.15	7.49
T_{12}-$P_2D_3F_1$	4.26	0.66	4.92
T_{13}-$P_2D_1F_2$	5.71	1.52	7.23
T_{14}-$P_2D_2F_2$	3.20	0.85	4.04
T_{15}-$P_2D_3F_2$	3.00	0.78	3.78
T_{16}-$P_2D_1F_3$	4.80	0.85	5.65
T_{17}-$P_2D_2F_3$	3.47	0.46	3.93
T_{18}-$P_2D_3F_3$	1.76	0.17	1.93
Treatment mean	5.15	1.45	6.60
p value	0.000**	0.000**	0.000**
LSD (0.05)	3.5	1.7	5

**significant at $p<0.01$

Table 5. Effect of fodder trees and management regimes on forage biomass production over three-year period in coconut plantation at Vellanikkara, Kerala.

Factors	**Fractional and total harvested dry fodder yield over three years period (Mg ha^{-1})**		
	Leaf	**Stem**	**Total**
Fodder trees			
Mulberry(P_1)	15.358	11.531	26.89
Subabul(P_2)	14.556	9.296	23.85
p value	0.249^{ns}	0.002**	0.015*
Tree density			
49,382 plants ha^{-1}(D_1)	19.136	12.709	31.842
37,037 plants ha^{-1}(D_2)	14.988	10.593	25.579
27,777 plants ha^{-1}(D_3)	10.748	7.939	18.689
p value	0.000***	0.000***	0.000***
Harvest interval			
8 weeks(F_1)	15.809	10.043	25.852
12 weeks(F_2)	15.414	12.168	27.581
16 weeks(F_3)	13.648	9.029	22.677
p value	0.033*	0.001**	0.006**
PxFxD (p value)	0.452^{ns}	0.344^{ns}	0.332^{ns}

** 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 6. Combined effect of management regimes on forage biomass production of fodder trees over three-year period in coconut plantation at Vellanikkara, Kerala.

Treatments	Fractional and total harvested dry fodder yield over three years (Mg ha^{-1})		
	Leaf	**Stem**	**Total fodder**
T_1-$P_1D_1F_1$	18.13	10.89	29.02
T_2-$P_1D_2F_1$	15.58	10.26	25.84
T_3-$P_1D_3F_1$	12.32	8.34	20.66
T_4-$P_1D_1F_2$	22.66	17.29	39.95
T_5-$P_1D_2F_2$	17.57	15.78	33.35
T_6-$P_1D_3F_2$	12.13	12.24	24.38
T_7-$P_1D_1F_3$	18.04	14.22	32.25
T_8-$P_1D_2F_3$	12.24	7.62	19.86
T_9-$P_1D_3F_3$	9.55	7.14	16.70
T_{10}-$P_2D_1F_1$	20.37	12.26	32.64
T_{11}-$P_2D_2F_1$	16.61	10.96	27.56
T_{12}-$P_2D_3F_1$	11.84	7.55	19.39
T_{13}-$P_2D_1F_2$	17.84	11.62	29.45
T_{14}-$P_2D_2F_2$	12.51	9.34	21.85
T_{15}-$P_2D_3F_2$	9.77	6.74	16.51
T_{16}-$P_2D_1F_3$	17.77	9.97	27.74
T_{17}-$P_2D_2F_3$	15.42	9.60	25.02
T_{18}-$P_2D_3F_3$	8.87	5.62	14.48
Treatment mean	14.96	10.41	25.37
p value	0.000**	0.000**	0.000**
LSD (0.05)	4.80	4.62	8.34

** significant at $p < 0.01$

4.2 PRODUCTIVITY OF COCONUT UNDER INTERCROPPED AND MONOCULTURE SYSTEMS

4.2.1 Annual nut yield of coconut palms

Annual nut yield of coconut during the third year of intercropping fodder trees is given in table 7. In general, intercropping of both the tree fodder species viz, mulberry or subabul had no significant effect on annual nut yield of coconut palms. However, tree density showed significant effect on productivity of coconut palms. Maximum nut yield (11,245 nuts ha^{-1}) was obtained from the lowest fodder tree density of 27,777 plants ha^{-1} when compared to higher density levels. Harvest interval had no significant effect on the annual nut yield of coconut palms. The annual nut yield was slightly higher (11,267 nuts ha^{-1}) for 16 weeks harvest interval.

The table 8 depicts the combined effect of various treatments on the annual nut yield. The combined effect showed no significant difference in annual nut yield between sole coconut palms (11,236 nuts ha^{-1}) and the palms intercropped with mulberry and subabul (10,207-11,245 nuts ha^{-1}) under different management practices.

4.2.2 Existing nuts in coconut palms

The existing coconut bunches in the palm are formed during the previous three year period. The count of the existing nuts gives an indication regarding the effect of fodder tree intercropping on the productivity of palms. The results indicate that intercropping of both the fodder tree species had no significant effect on the productivity of nuts in coconut palms. Similarly, various management practices like tree density and harvest interval and their treatment combinations had no significant influence on coconut yield as indicated by the corresponding nut counts in different treatments (Table 8). The nut count on intercropped palms ranged from 11,418- 12,456 nuts ha^{-1} and was found to be on par with that of the sole coconut palms (12,448 nuts ha^{-1}).

Table 7. Effect of fodder tree intercropping and management regimes on productivity of coconut palms at Vellanikkara, Kerala.

Factors	**Coconut productivity (ha^{-1})**	
	Annual nut yield during the third year of intercropping	**No. of existing nuts in palms**
Fodder trees		
Mulberry(P_1)	10,841	10,867
Subabul(P_2)	10,893	10,898
p value	0.530^{ns}	0.584^{ns}
Tree density		
49,382 plants ha^{-1}(D_1)	$10{,}899^{b}$	11,918
37,037 plants ha^{-1} (D_2)	$11{,}072^{a}$	12,223
27,777 plants ha^{-1} (D_3)	$11{,}245^{a}$	12,456
p value	0.006**	0.634^{ns}
Harvest interval		
8 weeks(F_1)	10,899	11,922
12 weeks(F_2)	11,145	12,071
16 weeks(F_3)	11,267	12,448
p value	0.624^{ns}	0.621^{ns}
PxFxD (p value)	0.607^{ns}	0.541^{ns}

** significant at $p<0.01$, ns= not significant at $p>0.05$

Table 8. Combined effect of tree density and harvest interval of fodder trees on productivity of coconut palms at Vellanikkara, Kerala.

Treatments	Coconut productivity (ha^{-1})	
	Annual nut yield during the third year of intercropping	No. of existing nuts in palms
T_1-$P_1D_1F_1$	10,207	11,418
T_2-$P_1D_2F_1$	11,072	12,110
T_3-$P_1D_3F_1$	11,245	12,456
T_4-$P_1D_1F_2$	10,495	11,648
T_5-$P_1D_2F_2$	11,072	12,110
T_6-$P_1D_3F_2$	11,245	12,456
T_7-$P_1D_1F_3$	10,207	11,418
T_8-$P_1D_2F_3$	11,187	11,994
T_9-$P_1D_3F_3$	11,302	12,456
T_{10}-$P_2D_1F_1$	10,495	11,648
T_{11}-$P_2D_2F_1$	10,783	11,879
T_{12}-$P_2D_3F_1$	11,129	12,283
T_{13}-$P_2D_1F_2$	10,495	11,648
T_{14}-$P_2D_2F_2$	11,072	12,110
T_{15}-$P_2D_3F_2$	11,129	12,283
T_{16}-$P_2D_1F_3$	10,495	11,648
T_{17}-$P_2D_2F_3$	11,187	12,340
T_{18}-$P_2D_3F_3$	11,245	12,456
Treatment mean	10,892	12,020
Coconut monoculture	11,236	12,448
p value	0.056^{ns}	0.09^{ns}
LSD (0.05)	1130	1065

ns = not significant at p>0.05

4.3 CARBON STOCKS IN COCONUT-FODDER TREE INTERCROPPING SYSTEMS UNDER VARIABLE MANAGEMENT REGIMES.

4.3.1 Carbon stocks in fodder tree biomass

4.3.1.1 Carbon stocks in harvested fodder biomass

The main effect of tree density and harvest interval on carbon content in harvested dry fodder biomass over three year period is given in table 9. Total dry fodder yield over three- year period was significantly higher for mulberry (14.29 Mg ha^{-1}) than subabul (12.88 Mg ha^{-1}). Tree density and harvest interval had significant influence on carbon content in harvested dry fodder biomass over three-year period. Highest carbon content was observed in high tree density for leaf (10.33 Mg ha^{-1}), stem (6.72 Mg ha^{-1}) and total dry harvested fodder biomass (17.06 Mg ha^{-1}) over three years. Carbon content in leaf fractions of 8 weeks (8.47 Mg ha^{-1}) and 12 weeks (8.43 Mg ha^{-1}) harvest interval were found to be on par. Regarding stem and total harvested dry fodder biomass, highest carbon content (6.44 Mg ha^{-1} and 14.88 Mg ha^{-1} respectively) was reported in 12 weeks harvest interval.

Combined effect of various treatment combinations on carbon content in mulberry and subabul over three year period is given in table 10. Highest carbon content in leaf (12.36 Mg ha^{-1}), stem (9.17 Mg ha^{-1}) and total harvested dry fodder biomass (21.53 Mg ha^{-1}) over three year period was reported in mulberry at high tree density and 12 weeks harvest interval (T_4).

Table 13 depicts the main effect of tree densities and harvest interval on carbon in pooled harvested dry fodder biomass over three- year period. Carbon in pooled harvested dry fodder biomass was significantly higher in mulberry (14.30 Mg ha^{-1}) than subabul. Tree density and harvest interval shows significant effect on the carbon content in pooled harvested dry fodder biomass over three year period and obtained highest for closer spacing and 12 weeks harvest interval (17.06 Mg ha^{-1} and 14.88 Mg ha^{-1} respectively).

Table 14 represents the effect of different treatments on carbon content in pooled harvested dry fodder biomass over three year period. On comparing different treatments, highest carbon in pooled harvested dry fodder biomass (21.53 Mg ha^{-1}) was obtained in mulberry with combinations of high tree density and 12 weeks harvest interval (T_4).

4.3.1.2 Standing biomass and carbon stocks

The total standing biomass of fodder trees constitute the left-over stump biomass after harvest and the belowground root biomass. Table 11 shows the main effect of tree density and harvest interval on standing biomass of mulberry and subabul. Total dry fodder yield over three- year period was slightly higher in mulberry (14.92 Mg ha^{-1}) than that of subabul (13.61Mg ha^{-1}). Tree density had significant influence on fresh stump, root and total standing biomass. Fresh stump biomass obtained highest (21.26 Mg ha^{-1}) for high tree density (49,382 plants ha^{-1}). Fresh root biomass of two higher densities, 49,382 plants ha^{-1}(12.44 Mg ha^{-1}) and 37,037 plants ha^{-1}(11.69 Mg ha^{-1}), were found to be on par. Even though the highest fresh stump, root and total standing biomass were observed in 16 weeks cutting interval, the differences are not statistically significant.

Table 12 represents the combined effect of various treatments on the standing biomass of mulberry and subabul intercropped in coconut plantation. On comparing the treatments, significant differences was observed on fresh standing biomass. Maximum fresh stump (38.82 Mg ha^{-1}) and total standing biomass (54.59 Mg ha^{-1}) was reported in mulberry at high tree density and 16 weeks cutting interval (T_7). Highest fresh root biomass was obtained from subabul of 37,037 plants ha^{-1} and 8 weeks harvest interval (T_{11}).

Combined effect of various treatment combinations on dry standing biomass was significant (Table 12). Highest dry stump (20.48 Mg ha^{-1}) and total dry standing biomass (28.80 Mg ha^{-1}) was obtained from mulberry at high tree density and 16 weeks harvest interval (T_7) whereas highest root biomass was obtained from subabul at 37,037 plants ha^{-1} and 8 weeks harvest interval (T_{11}).

The main effect of tree density and harvest interval on carbon content in standing biomass is given in table 11. Fodder trees had no significant effect on carbon content in standing biomass. Total carbon content in mulberry (8.26 Mg ha^{-1}) and subabul (7.61 Mg ha^{-1}) were found to be on par. Tree density had significant effect on carbon content in standing biomass. Carbon content in stump (6.36 Mg ha^{-1}), root (3.56 Mg ha^{-1}) and standing biomass (9.92 Mg ha^{-1}) was comparatively higher for closer spacing (49,382 plants ha^{-1}). Harvest interval showed no significant effect on carbon content in standing biomass. The carbon content in standing biomass was found to be on par for 8 and 12 weeks interval (7.62 Mg ha^{-1} and 6.93 Mg ha^{-1}respectively).

Table 12 depicts the combined effect of various treatments on carbon content in standing biomass. Total carbon content in standing biomass was found highest (15.94 Mg ha^{-1}) for mulberry at the highest tree density and 16 weeks harvest interval (T_7). In subabul, the carbon content was also found higher (12.03Mg ha^{-1}) for the highest tree density, but for 8 weeks harvest interval (T_{10}).

4.3.1.3 Total fodder tree biomass and carbon stocks over three-year period

Table 13 depicts the main effect of fodder tree species, tree density and harvest interval on total biomass production over three year period under coconut plantation. Total biomass was comparatively higher in mulberry (41.82 Mg ha^{-1}) than subabul, but was not statistically significant.

Tree density had significant effect on total plant dry biomass over three year period. Maximum plant dry fodder biomass (49.67 Mg ha^{-1}) was obtained for the highest tree density of 49,382 plants ha^{-1} when compared with the two lower densities. Harvest interval showed no profound significant effect on total plant dry fodder biomass over three year period. The total plant dry biomass over three year period for 8 weeks (39.55 Mg ha^{-1}), 12 weeks (40.05 Mg ha^{-1}) and 16 weeks (39.32 Mg ha^{-1}) harvest interval was found to be on par.

The combined effect of different treatments on total plant dry biomass over three year period under coconut plantation was found significant (Table 14). The highest total plant dry biomass (61.06 Mg ha^{-1}) over three-year period was observed in mulberry comprising tree density of 49,382 plants ha^{-1} and 16 weeks harvest interval (T_7).

The main effect of fodder tree species, tree density and harvest interval on total carbon stocks in plant dry biomass of mulberry and subabul over three-year period under coconut plantation is given in table 13. The total carbon stocks in plant biomass over three-year period were found to be higher for mulberry (22.56 Mg ha^{-1}) than subabul, but were not significantly different. Tree density had significant effect on total carbon stocks in plant dry biomass over three-year period. The carbon stocks in plant dry biomass increased from the lowest tree density of 27,777 plants ha^{-1} to the highest tree density of 49,382 plants ha^{-1} (15.44 Mg ha^{-1} to 26.97 Mg ha^{-1} respectively). The carbon stocks in plant dry biomass of 8 weeks, 12 weeks and 16 weeks were found to be on par (21.43 Mg ha^{-1}, 21.81 Mg ha^{-1} and 21.34 Mg ha^{-1} respectively).

The combined effect of treatments on total carbon stocks in plant dry biomass over three years period under coconut plantation was found significant (Table14). Maximum total carbon stocks (32.85 Mg ha^{-1}) in plant biomass over three-year period were observed in mulberry of 49,382 plants ha^{-1} and 16 weeks harvest interval (T_7).

Table 9. Effect of fodder tree density and harvest interval on carbon stocks in fodder biomass over three-year period in coconut plantation.

Factors	**Carbon stocks in fractional and total harvested fodder biomass over three years (Mg ha^{-1})**		
	Leaf	**Stem**	**Total**
Fodder trees			
Mulberry(P_1)	8.22^{a}	6.08^{a}	14.29^{a}
Subabul(P_2)	7.93^{b}	4.96^{b}	12.88^{b}
p value	0.441^{ns}	0.003**	0.034*
Tree density			
49,382 plants ha^{-1}(D_1)	10.33^{a}	6.72^{a}	17.06^{a}
37,037 plants ha^{-1} (D_2)	8.07^{b}	5.63^{b}	13.69^{b}
27,777 plants ha^{-1} (D_3)	5.82^{c}	4.21^{c}	10.03^{c}
p value	0.000**	0.000**	0.000**
Harvest interval			
8 weeks(F_1)	8.47^{a}	5.33^{ab}	13.81^{ab}
12 weeks(F_2)	8.43^{a}	6.44^{a}	14.88^{a}
16 weeks(F_3)	7.32^{b}	4.78^{b}	12.09^{b}
p value	0.023*	0.002**	0.004**
PxFxD (p value)	0.475^{ns}	0.367^{ns}	0.358^{ns}

** 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 10. Combined effect of fodder tree density and harvest interval on carbon stocks in fodder biomass over three-year period in coconut plantation.

Treatments	Carbon stocks in fractional and total harvested fodder biomass over three years (Mg ha^{-1})		
	Leaf	**Stem**	**Total fodder**
T_1-$P_1D_1F_1$	9.65	5.71	15.35
T_2-$P_1D_2F_1$	8.29	5.40	13.69
T_3-$P_1D_3F_1$	6.60	4.40	11.00
T_4-$P_1D_1F_2$	12.36	9.17	21.53
T_5-$P_1D_2F_2$	9.43	8.39	17.82
T_6-$P_1D_3F_2$	6.50	6.39	12.88
T_7-$P_1D_1F_3$	9.48	7.43	16.91
T_8-$P_1D_2F_3$	6.55	4.01	10.56
T_9-$P_1D_3F_3$	5.12	3.82	8.93
T_{10}-$P_2D_1F_1$	10.98	6.56	17.54
T_{11}-$P_2D_2F_1$	8.95	5.88	14.84
T_{12}-$P_2D_3F_1$	6.37	4.04	10.41
T_{13}-$P_2D_1F_2$	9.95	6.16	16.10
T_{14}-$P_2D_2F_2$	6.92	4.98	11.90
T_{15}-$P_2D_3F_2$	5.44	3.58	9.02
T_{16}-$P_2D_1F_3$	9.59	5.31	14.90
T_{17}-$P_2D_2F_3$	8.29	5.08	13.38
T_{18}-$P_2D_3F_3$	4.88	3.03	7.91
Treatment mean	8.08	5.52	13.60
p value	0.000**	0.000**	0.000**
LSD (0.05)	2	2.2	4.4

** significant at $p<0.01$

Table 11. Effect of tree density and harvest interval on standing biomass and carbon stocks of fodder trees over three-year period under coconut plantation.

Factors	Standing biomass and carbon stocks (Mg ha^{-1})								
	Fresh standing biomass			Dry standing biomass			Carbon stocks		
	Stump	Root	Total	Stump	Root	Total	Stump	Root	Total
Fodder trees									
Mulberry(P_1)	19.26	9.12	28.38	10.21	4.72	14.92	5.68	2.57	8.26
Subabul(P_2)	13.86	11.88	25.74	7.50	6.11	13.61	4.23	3.37	7.61
p value	0.056^{ns}	0.067^{ns}	0.504^{ns}	0.06^{ns}	0.071^{ns}	0.514^{ns}	0.071^{ns}	0.059^{ns}	0.56^{ns}
Tree density									
49,382 plants ha^{-1} (D_1)	21.26^{a}	12.44^{a}	33.70^{a}	11.34^{a}	6.48^{a}	17.82^{a}	6.36^{a}	3.56^{a}	9.92^{a}
37,037 plants ha^{-1} (D_2)	17.42^{ab}	11.69^{a}	29.11^{ab}	9.27^{ab}	5.96^{a}	15.23^{ab}	5.20^{ab}	3.27^{a}	8.46^{ab}
27,777 plants ha^{-1} (D_3)	11.00^{b}	7.38^{ab}	18.39^{b}	5.94^{b}	3.81^{b}	9.75^{c}	3.32^{b}	2.08^{ab}	5.41^{b}
p value	0.014*	0.016*	0.009**	0.011*	0.014**	0.007**	0.011*	0.014*	0.007**
Harvest interval									
8 weeks(F_1)	15.52	10.46	25.98	8.34	5.35	13.69	4.67	2.94	7.62
12 weeks(F_2)	14.31	9.05	23.37	7.77	4.69	12.47	4.35	2.57	6.93
16 weeks(F_3)	19.84	11.99	31.84	10.44	6.21	16.64	5.84	3.40	9.24
p value	0.235^{ns}	0.271^{ns}	0.208^{ns}	0.274^{ns}	0.266^{ns}	0.228^{ns}	0.277^{ns}	0.274^{ns}	0.234^{ns}
PxFxD (p value)	0.195^{ns}	0.105^{ns}	0.151^{ns}	0.185^{ns}	0.104^{ns}	0.145^{ns}	0.188^{ns}	0.107^{ns}	0.149^{ns}

** 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. Combined effect of management regimes on standing biomass and carbon stocks of fodder trees over three year period under coconut plantation at Vellanikkara, Kerala.

Treatments	Standing biomass and carbon stocks (Mg ha^{-1})								
	Fresh standing biomass			Dry standing biomass			Carbon stocks		
	Stump	Root	Total	Stump	Root	Total	Stump	Root	Total
T_1-$P_1D_1F_1$	20.73	7.03	27.75	10.78	3.65	14.44	6.01	1.99	8.00
T_2-$P_1D_2F_1$	15.64	3.30	18.94	8.26	1.71	9.98	4.60	0.93	5.54
T_3-$P_1D_3F_1$	14.08	7.45	21.53	7.38	3.76	11.14	4.11	2.05	6.16
T_4-$P_1D_1F_2$	7.94	3.95	11.89	4.63	2.18	6.80	2.58	1.19	3.77
T_5-$P_1D_2F_2$	25.35	12.85	38.20	13.56	6.64	20.20	7.55	3.62	11.17
T_6-$P_1D_3F_2$	12.30	6.66	18.97	6.52	3.41	9.92	3.63	1.86	5.48
T_7-$P_1D_1F_3$	38.82	15.78	54.59	20.48	8.33	28.80	11.40	4.54	15.94
T_8-$P_1D_2F_3$	21.63	12.50	34.12	11.21	6.33	17.55	6.24	3.45	9.70
T_9-$P_1D_3F_3$	16.87	12.58	29.45	9.03	6.50	15.53	5.03	3.54	8.57
T_{10}-$P_2D_1F_1$	22.15	18.36	40.51	12.10	9.43	21.52	6.82	5.21	12.03
T_{11}-$P_2D_2F_1$	12.76	19.76	32.52	6.97	9.99	16.95	3.93	5.52	9.44
T_{12}-$P_2D_3F_1$	7.78	6.83	14.61	4.60	3.55	8.15	2.59	1.96	4.55
T_{13}-$P_2D_1F_2$	19.82	16.30	36.12	10.64	8.43	19.07	6.00	4.65	10.66
T_{14}-$P_2D_2F_2$	12.77	9.63	22.40	7.21	4.89	12.10	4.06	2.70	6.77
T_{15}-$P_2D_3F_2$	7.71	4.94	12.64	4.09	2.64	6.73	2.31	1.46	3.76
T_{16}-$P_2D_1F_3$	18.09	13.23	31.32	9.45	6.87	16.31	5.33	3.79	9.12
T_{17}-$P_2D_2F_3$	16.39	12.07	28.46	8.41	6.22	14.62	4.74	3.43	8.17
T_{18}-$P_2D_3F_3$	7.29	5.83	13.11	4.05	3.00	7.05	2.28	1.66	3.94
Treatment mean	16.57	10.50	27.06	8.85	5.42	14.27	4.96	2.98	7.94
p value	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**
LSD (0.05)	18	10.4	28.6	9.5	5	14.4	5.2	2.8	8

**significant at $p<0.01$

66

Table 13. Effect of tree density and harvest interval on total biomass and carbon stocks of fodder trees under coconut plantation at Vellanikkara, 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**
Fodder trees						
Mulberry(P_1)	26.89^a	14.30^a	14.93	8.26	41.82	22.56
Subabul(P_2)	23.85^b	12.89^b	13.61	7.61	37.46	20.49
p value	0.034*	0.034*	0.514^{ns}	0.56^{ns}	0.111^{ns}	0.166^{ns}
Tree density (plants ha-1)						
49,382 (D_1)	31.84^a	17.06^a	17.83^a	9.92^a	49.67^a	26.97^a
37,037 (D_2)	25.58^b	13.70^b	15.23^b	8.46^b	40.81^b	22.16^b
27,777 (D_3)	18.69^c	10.03^c	9.75^c	5.41^c	28.44^c	15.44^c
p value	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**
Harvest interval						
8 weeks(F_1)	25.85^{ab}	13.81^{ab}	13.70	7.62	39.55	21.43
12 weeks(F_2)	27.58^a	14.88^a	12.47	6.93	40.05	21.81
16 weeks(F_3)	22.68^b	12.10^b	16.64	9.24	39.32	21.34
p value	0.004**	0.004**	0.228^{ns}	0.234^{ns}	0.974^{ns}	0.961^{ns}
PxFxD (p value)	0.358^{ns}	0.358^{ns}	0.145^{ns}	0.149^{ns}	0.144^{ns}	0.149^{ns}

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

Table 14. Combined effect of tree density and harvest interval on total biomass and carbon stocks of fodder trees under coconut plantation.

Treatments	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
T_1-$P_1D_1F_1$	29.02	15.35	14.44	8.00	43.45	23.35
T_2-$P_1D_2F_1$	25.84	13.69	9.98	5.54	35.81	19.23
T_3-$P_1D_3F_1$	20.66	11.00	11.14	6.16	31.80	17.16
T_4-$P_1D_1F_2$	39.95	21.53	6.80	3.77	46.75	25.29
T_5-$P_1D_2F_2$	33.35	17.82	20.20	11.17	53.55	29.00
T_6-$P_1D_3F_2$	24.38	12.88	9.92	5.48	34.30	18.37
T_7-$P_1D_1F_3$	32.25	16.91	28.80	15.94	61.06	32.85
T_8-$P_1D_2F_3$	19.86	10.56	17.55	9.70	37.41	20.26
T_9-$P_1D_3F_3$	16.70	8.93	15.53	8.57	32.23	17.50
T_{10}-$P_2D_1F_1$	32.64	17.54	21.52	12.03	54.16	29.57
T_{11}-$P_2D_2F_1$	27.56	14.84	16.95	9.44	44.52	24.28
T_{12}-$P_2D_3F_1$	19.39	10.41	8.15	4.55	27.54	14.97
T_{13}-$P_2D_1F_2$	29.45	16.10	19.07	10.66	48.52	26.76
T_{14}-$P_2D_2F_2$	21.85	11.90	12.10	6.77	33.95	18.66
T_{15}-$P_2D_3F_2$	16.51	9.02	6.73	3.76	23.24	12.79
T_{16}-$P_2D_1F_3$	27.74	14.90	16.31	9.12	44.06	24.02
T_{17}-$P_2D_2F_3$	25.02	13.38	14.62	8.17	39.64	21.55
T_{18}-$P_2D_3F_3$	14.49	7.91	7.05	3.94	21.54	11.84
Treatment mean	25.37	13.60	14.27	7.94	39.64	21.53
Coconut monoculture					1.38	0.76
p value	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**
LSD (0.05)	8.30	4.40	13.20	7.70	17.60	9.50

** significant at $p<0.01$

4.3.2 Carbon stocks in coconut palms

4.3.2.1 Carbon stocks in harvested nuts

Table 15 depicts the carbon content in harvested nuts of the third year as non-significant. The carbon content in harvested nuts of mulberry (0.06 Mg ha^{-1}) and subabul (0.07 Mg ha^{-1}) were found to be on par. Fodder tree density showed significant effect on carbon stocks in harvested nuts and was found to be higher (0.07 Mg ha^{-1}) for the lowest tree density of 27,777 plants ha^{-1} when compared to higher levels (0.06 Mg ha^{-1}). Comparing harvest interval higher carbon content in harvested nuts was observed for 16 weeks harvest interval than the lower levels.

4.3.2.2 Carbon stocks in the existing nuts on the palm

Carbon stocks in the existing nuts on the palm were found significant for fodder trees, tree density as well as harvest interval (Table 15). Higher carbon stocks in the existing nuts of coconut were observed in subabul (1.30 Mg ha^{-1}) intercropped palms than that of mulberry. Lower tree density of 27,777 plants ha^{-1} and longer harvest interval of 16 weeks showed higher carbon stocks of 1.56 and 1.40 Mg ha^{-1} respectively in the existing nuts on the palm when compared to other levels. The combined effect of various treatments (Table 16) depicts that the carbon stocks in the existing nuts on the palm was observed highest (1.8 Mg ha^{-1}) for subabul at tree density of 27,777 plants ha^{-1} and 16 weeks harvest interval (T_{18}).

4.3.2.3 Carbon stocks in coconut leaves

The carbon stocks in the existing coconut leaves showed no significant difference with the intercropping of either mulberry or subabul as well as for variable tree densities. However, among harvest intervals, 16 weeks reported significantly higher (3.49 Mg ha^{-1}) carbon stocks in coconut leaves when compared to lower levels. The combined effect of various treatments shows that the carbon stocks in the existing nuts on the palm was observed highest (3.63 Mg ha^{-1}) for subabul at tree density of 27,777 plants ha^{-1} and 16 weeks harvest interval (T_{18}).

4.3.2.4 Carbon stocks in coconut bole

Table 15 and 16 depicts the carbon stocks in coconut bole. Coconut bole accumulated 26.37-27.47 Mg ha^{-1} of carbon in coconut-mulberry and subabul intercropping systems under various management regimes and was on par with that of the sole coconut palms (27.41 Mg ha^{-1}). Tree density had significant effect on carbon stocks in coconut bole. Carbon stocks in coconut bole were observed highest (27.40 Mg ha^{-1}) for lower tree density (27,777 plants ha^{-1}), whereas harvest interval showed no significant influence on carbon stocks in coconut bole

4.3.2.5 Total aboveground carbon stocks in coconut palms

Fodder tree species as well as the management regimes like tree density and harvest interval showed significant effect on the total aboveground carbon stocks in coconut palms (Table 15). Subabul intercropped coconut palms (31.92 Mg ha^{-1}) had higher total aboveground carbon stocks than that of mulberry (31.60 Mg ha^{-1}). Highest total aboveground carbon stocks were obtained from tree density of 27,777 plants ha^{-1} and 16 weeks harvest interval (32.58 Mg ha^{-1} and 32.04 Mg ha^{-1}respectively). The combined effect of various treatments showed significant effect on the total aboveground carbon stocks in coconut palms (Table 16). Highest total aboveground carbon stocks were observed at the lowest tree density and longest harvest interval of 16 weeks for both mulberry (32.88 Mg ha^{-1}) and subabul (32.98 Mg ha^{-1}) and were found to be on par with that of sole coconut palms (32.78 Mg ha^{-1}).

4.4 SOIL CARBON STOCKS IN COCONUT- FODDER TREE INTERCROPPING SYSTEMS UNDER VARIABLE TREE DENSITIES AND HARVEST INTERVALS

4.4.1 Soil organic carbon content and stocks

Table 17 and 19 depicts the main effect of tree density and harvest interval on soil organic carbon content and carbon stocks. In general, the soil organic carbon content declined from the top 20 cm depth to the next lower depth, 20-40 cm. On comparing the fodder trees, soil organic carbon was slightly higher in subabul (0.80 %) than in mulberry (0.79 %) with no statistical significance. Similar trend was also observed in the case of carbon stocks with values of 44.76 Mg ha^{-1} for subabul and 43.53

Table 15. Effect of fodder tree intercropping and management regimes on carbon stocks of coconut palms at Vellanikkara, Kerala.

Factors	Fractional and total carbon content of coconut palms (Mg ha^{-1})				
	Harvested nuts	**Nuts in standing palms**	**Leaves**	**Bole**	**Total**
Fodder trees					
Mulberry(P_1)	0.06	1.28	3.42	26.81	31.60
Subabul(P_2)	0.07	1.30	3.42	27.13	31.92
p value	0.098^{ns}	0.021*	0.694^{ns}	0.029*	0.034*
Tree density					
49,382 plants ha^{-1}(D_1)	0.06	1.12	3.39	26.70	31.26
37,037 plants ha^{-1} (D_2)	0.06	1.18	3.33	26.82	31.44
27,777 plants ha^{-1} (D_3)	0.07	1.56	3.54	27.40	32.58
p value	0.000***	0.000***	0.000***	0.001**	0.000***
Harvest interval					
8 weeks(F_1)	0.06	1.18	3.36	26.87	31.47
12 weeks(F_2)	0.06	1.29	3.41	26.99	31.77
16 weeks(F_3)	0.07	1.40	3.49	27.05	32.04
p value	0.013*	0.000***	0.000***	0.587^{ns}	0.014*
PxFxD (p value)	0.963^{ns}	0.000***	0.542^{ns}	0.705^{ns}	0.647^{ns}

** 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 16. Carbon stocks in coconut palms under fodder tree intercropping and monoculture systems at Vellanikkara, Kerala.

Treatments	Fractional and total carbon content of coconut palms (Mg ha^{-1})				
	Harvested nuts	Nuts in standing palms	Leaves	Bole	Total
T_1-$P_1D_1F_1$	0.06	1.02	3.33	26.59	31.01
T_2-$P_1D_2F_1$	0.05	1.12	3.25	26.58	31.00
T_3-$P_1D_3F_1$	0.07	1.32	3.50	27.23	32.13
T_4-$P_1D_1F_2$	0.06	1.14	3.38	26.51	31.10
T_5-$P_1D_2F_2$	0.06	1.23	3.35	26.37	31.01
T_6-$P_1D_3F_2$	0.07	1.59	3.56	27.45	32.69
T_7-$P_1D_1F_3$	0.06	1.22	3.38	26.48	31.14
T_8-$P_1D_2F_3$	0.06	1.31	3.39	26.66	31.43
T_9-$P_1D_3F_3$	0.07	1.78	3.62	27.41	32.88
T_{10}-$P_2D_1F_1$	0.06	1.05	3.35	26.74	31.20
T_{11}-$P_2D_2F_1$	0.06	1.13	3.25	26.66	31.11
T_{12}-$P_2D_3F_1$	0.08	1.44	3.47	27.41	32.40
T_{13}-$P_2D_1F_2$	0.05	1.14	3.40	26.82	31.41
T_{14}-$P_2D_2F_2$	0.06	1.18	3.32	27.41	31.97
T_{15}-$P_2D_3F_2$	0.07	1.45	3.49	27.42	32.43
T_{16}-$P_2D_1F_3$	0.06	1.17	3.47	27.02	31.72
T_{17}-$P_2D_2F_3$	0.07	1.35	3.44	27.23	32.10
T_{18}-$P_2D_3F_3$	0.08	1.80	3.63	27.47	32.98
Treatment mean	0.06	1.30	3.42	26.97	31.77
Coconut monoculture	0.07	1.68	3.62	27.41	32.78
p value	0.000**	0.000**	0.000**	0.000**	0.000**
LSD (0.05)	0.01	0.02	0.03	0.10	1.01

** significant at $p<0.01$

72

Mg ha^{-1} for mulberry. Similarly, tree density and harvest interval also had no significant effect on SOC content and stocks.

However, the combined effect of various treatment combinations showed significant effect on the soil organic carbon content and stocks (Table 18, 20). But, no specific trend could be deciphered regarding the carbon dynamics of intercropped plots under different management regimes. The highest soil organic carbon content (1.00 %) was obtained from subabul at medium tree density (37,037 plants ha^{-1}) and 12 weeks harvest interval (T_{14}), which also recorded the highest carbon stocks of 54.80 Mg ha^{-1}. In mulberry, the maximum soil organic carbon percentage (0.98%) was obtained from the lowest tree density (27,777 plants ha^{-1}) and 12 weeks harvest interval (T_1) with carbon stocks of 54.65 Mg ha^{-1}.

The sole coconut plots (0.69%) and control open plots (0.61%) had comparatively lower carbon percentage than most of the intercropped plots. Similar trend was also observed in carbon stocks with respective values of 41.81 and 33.66 Mg ha^{-1}.

4.5 OVERALL CARBON STORAGE POTENTIAL OF COCONUT- FODDER TREE INTERCROPPING SYSTEMS UNDER VARIABLE TREE DENSITIES AND HARVEST INTERVALS

Table 21 represents the main effect of fodder tree species, tree density and harvest interval on total carbon storage potential of the system. On comparing fodder trees, slightly higher carbon storage was obtained from mulberry than subabul with no statistical significance. Tree density as well as harvest interval had significant effect on the carbon storage potential of the system. Total carbon storage potential of mulberry and subabul intercropping in coconut garden increased from the lowest tree density of 27,777 plants ha^{-1} to the highest tree density of 49,382 plants ha^{-1} (93.14 Mg ha^{-1} to 102.55 Mg ha^{-1} respectively). The highest carbon storage potential of the system (100.10 Mg ha^{-1}) was observed in the harvest interval of 12 weeks, followed by 16 weeks and 8 weeks interval.

74

On comparing the intercropped and coconut monoculture systems (Table 22), all fodder tree intercropping systems at different management levels (82.70-108.48 Mg ha^{-1}) had higher carbon capture than coconut monoculture system (75.35 Mg ha^{-1}). The carbon stocks in the contiguous open areas were substantially lower (34.43 Mg ha^{-1}) when compared to the coconut monoculture and intercropping systems. Comparing different intercropped plots, the highest amount of carbon capture (108.48 Mg ha^{-1}) was recorded in mulberry planted at the closest spacing (45 cm x 45 cm) and the shortest harvest interval of 8 weeks (T_1). In the case of subabul, the maximum total carbon storage potential (104.67 Mg ha^{-1}) was obtained at the closest spacing (45 cm x 45 cm) and the longest harvest interval of 16 weeks (T_{16}).

Table 17. Effect of fodder tree intercropping and management regimes on soil carbon content in coconut plantation at Vellanikkara, Kerala.

Factors	**Soil carbon content (%)**		
	0-20 cm	**21-40 cm**	**Mean**
Fodder trees			
Mulberry(P_1)	0.87	0.70	0.79
Subabul(P_2)	0.91	0.70	0.80
p value	0.287^{ns}	0.965^{ns}	0.575^{ns}
Tree density			
49,382 plants ha^{-1} (D_1)	0.92	0.69	0.80
37,037 plants ha^{-1} (D_2)	0.89	0.66	0.78
27,777 plants ha^{-1} (D_3)	0.87	0.75	0.81
p value	0.601^{ns}	0.099^{ns}	0.689^{ns}
Harvest interval			
8 weeks(F_1)	0.85	0.65	0.75
12 weeks(F_2)	0.95	0.73	0.84
16 weeks(F_3)	0.88	0.71	0.80
p value	0.073^{ns}	0.15^{ns}	0.11^{ns}
PxFxD (p value)	0.001**	0.032*	0.004**

** 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 18. Soil carbon content in coconut intercropping and monoculture systems at Vellanikkara, Kerala.

Treatments	Soil carbon content (%)		
	0-20 cm	21-40 cm	Mean
T_1-$P_1D_1F_1$	1.03	0.793	0.913
T_2-$P_1D_2F_1$	0.767	0.477	0.623
T_3-$P_1D_3F_1$	0.81	0.53	0.667
T_4-$P_1D_1F_2$	0.807	0.617	0.71
T_5-$P_1D_2F_2$	0.82	0.69	0.757
T_6-$P_1D_3F_2$	1.027	0.927	0.977
T_7-$P_1D_1F_3$	0.857	0.713	0.787
T_8-$P_1D_2F_3$	0.883	0.847	0.867
T_9-$P_1D_3F_3$	0.867	0.67	0.77
T_{10}-$P_2D_1F_1$	0.85	0.68	0.763
T_{11}-$P_2D_2F_1$	0.807	0.63	0.72
T_{12}-$P_2D_3F_1$	0.857	0.79	0.823
T_{13}-$P_2D_1F_2$	0.933	0.603	0.767
T_{14}-$P_2D_2F_2$	1.29	0.71	1.00
T_{15}-$P_2D_3F_2$	0.82	0.81	0.81
T_{16}-$P_2D_1F_3$	1.017	0.707	0.86
T_{17}-$P_2D_2F_3$	0.773	0.593	0.687
T_{18}-$P_2D_3F_3$	0.857	0.753	0.803
Treatment value	0.89	0.69	0.79
Sole coconut plots	0.82	0.56	0.69
Contiguous treeless plots	0.64	0.58	0.61
p value	0.000**	0.000**	0.000**
LSD (0.05)	4.5	7	12.2

** significant at $p<0.01$

Table 19. Effect of fodder tree density and harvest interval on carbon stocks in soil under coconut plantation at Vellanikkara, Kerala.

Factors	Soil carbon stocks (Mg ha^{-1})		
	0-20 cm	**21-40 cm**	**Total**
Fodder trees			
Mulberry(P_1)	22.57	20.96	43.53
Subabul(P_2)	24.71	20.05	44.76
p value	0.056^{ns}	0.422^{ns}	0.508^{ns}
Tree density			
49,382 plants ha^{-1} (D_1)	24.28	20.03	44.31
37,037 plants ha^{-1} (D_2)	23.17	19.82	42.99
27,777 plants ha^{-1} (D_3)	23.47	21.65	45.12
p value	0.693^{ns}	0.358^{ns}	0.639^{ns}
Harvest interval			
8 weeks(F_1)	22.15	19.09	41.24
12 weeks(F_2)	25.07	21.45	46.52
16 weeks(F_3)	23.70	20.97	44.67
p value	0.104^{ns}	0.205^{ns}	0.072^{ns}
PxFxD (p value)	0.001**	0.05^{ns}	0.001**

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

Table 20. Soil carbon stocks in coconut-fodder tree intercropping and monoculture systems at Vellanikkara, Kerala.

Treatments	Soil carbon stocks (Mg ha^{-1})		
	0-20 cm	21-40 cm	Total
T_1-$P_1D_1F_1$	27.15	24.11	54.65
T_2-$P_1D_2F_1$	18.79	14.09	32.88
T_3-$P_1D_3F_1$	21.12	14.95	36.07
T_4-$P_1D_1F_2$	22.01	18.61	40.63
T_5-$P_1D_2F_2$	21.24	21.70	42.94
T_6-$P_1D_3F_2$	25.51	28.73	54.24
T_7-$P_1D_1F_3$	21.66	20.98	42.64
T_8-$P_1D_2F_3$	23.87	25.71	49.57
T_9-$P_1D_3F_3$	21.75	19.75	41.50
T_{10}-$P_2D_1F_1$	21.42	20.22	41.64
T_{11}-$P_2D_2F_1$	20.50	18.91	39.41
T_{12}-$P_2D_3F_1$	23.92	22.23	46.15
T_{13}-$P_2D_1F_2$	23.71	16.96	40.67
T_{14}-$P_2D_2F_2$	34.25	20.54	54.80
T_{15}-$P_2D_3F_2$	23.67	22.17	45.84
T_{16}-$P_2D_1F_3$	29.70	19.32	49.03
T_{17}-$P_2D_2F_3$	20.36	17.99	38.35
T_{18}-$P_2D_3F_3$	24.85	22.07	46.92
Treatment mean	23.63	20.50	44.32
Sole coconut plots	24.55	17.26	41.81
Contiguous treeless plots	17.11	16.55	33.66
p value	0.000**	0.000**	0.000**
LSD (0.05)	4.5	7	12.2

**significant at $p<0.01$

Table 21. Effect of fodder tree density and harvest interval on carbon storage potential of coconut-fodder tree intercropping system at Vellanikkara, 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**
Fodder trees				
Mulberry(P_1)	22.56	31.60^{b}	43.53	97.68
Subabul(P_2)	20.49	31.93^{a}	44.76	97.18
p value	0.166^{ns}	0.034*	0.508^{ns}	0.06^{ns}
Tree density				
49,382 plants ha^{-1} (D_1)	26.97^{a}	31.26^{b}	44.31	102.55^{a}
37,037 plants ha^{-1} (D_2)	22.16^{b}	31.44^{b}	42.99	96.59^{b}
27,777 plants ha^{-1} (D_3)	15.44^{c}	32.58^{a}	45.12	93.14^{c}
p value	0.000**	0.000**	0.639^{ns}	0.000**
Harvest interval				
8 weeks(F_1)	21.43	31.47^{ab}	41.24	94.14^{b}
12 weeks(F_2)	21.81	31.77^{ab}	46.52	100.10^{a}
16 weeks(F_3)	21.34	32.04^{a}	44.67	98.05^{ab}
p value	0.961^{ns}	0.014*	0.072^{ns}	0.01*
PxFxD (p value)	0.149^{ns}	0.647^{ns}	0.003**	0.063^{ns}

** 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 22. Overall carbon storage potential of coconut monoculture and different intercropping systems at Vellanikkara, 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**
T_1-$P_1D_1F_1$	23.35	30.48	54.65	108.48
T_2-$P_1D_2F_1$	19.23	30.59	32.88	82.70
T_3-$P_1D_3F_1$	17.16	32.37	36.07	85.60
T_4-$P_1D_1F_2$	25.29	30.68	40.63	96.59
T_5-$P_1D_2F_2$	29.00	30.82	42.94	102.76
T_6-$P_1D_3F_2$	18.37	32.79	54.24	105.40
T_7-$P_1D_1F_3$	32.85	30.79	42.64	106.28
T_8-$P_1D_2F_3$	20.26	31.26	49.57	101.09
T_9-$P_1D_3F_3$	17.50	33.58	41.50	92.58
T_{10}-$P_2D_1F_1$	29.57	30.53	41.64	101.73
T_{11}-$P_2D_2F_1$	24.28	30.65	39.41	94.34
T_{12}-$P_2D_3F_1$	14.97	32.50	46.15	93.63
T_{13}-$P_2D_1F_2$	26.76	30.77	40.67	98.20
T_{14}-$P_2D_2F_2$	18.66	30.77	54.80	104.23
T_{15}-$P_2D_3F_2$	12.79	32.63	45.84	91.26
T_{16}-$P_2D_1F_3$	24.02	31.62	49.03	104.67
T_{17}-$P_2D_2F_3$	21.55	31.18	38.35	91.09
T_{18}-$P_2D_3F_3$	11.84	33.74	46.92	92.50
Treatment mean	21.52	31.54	44.32	97.39
Coconut monoculture	0.76	32.78	41.81	75.35
Contiguous treeless plots	0.77		33.66	34.43
p value	0.000**	0.000**	0.000**	0.000**
LSD (0.05)	9.50	1.01	12.2	18.5

** significant at $p<0.01$

4.6 NUTRIENT STOCKS IN MULBERRY AND SUBABUL FODDER BANKS UNDER COCONUT PLANTATION

4.6.1 Nitrogen stocks in fodder trees

Table 23 depicts the main effect of fodder tree species, tree density and harvest interval on nitrogen stocks in mulberry and subabul fodder biomass in the third year of intercropping in coconut plantation. Total nitrogen uptake was found to be significantly higher for mulberry (70.77 kg ha^{-1}) than that of subabul (51.62 kg ha^{-1}). Tree density had significant effect on the nitrogen uptake in fodder trees and followed an increasing trend from the lowest to the highest density (43.23 to 78.60 kg ha^{-1} respectively). In the case of harvest interval, slightly higher uptake was noticed in 12 weeks interval followed 8 weeks and 16 weeks with no statistical significance. In general, the nitrogen stocks in foliage fraction were substantially higher than that of the stem fraction.

·The combined effect of various treatments showed significant difference on the nitrogen uptake in fodder trees (Table 24). The highest nitrogen uptake (124.77 kg ha^{-1}) was observed in mulberry with the closest spacing (45x45 cm) and 12 weeks harvest interval (T_4) and was substantially higher than other treatments of mulberry. In the case of subabul, maximum nitrogen uptake (69.26 kg ha^{-1}) was obtained from the closest spacing and 16 weeks harvest interval (T_{16}) and was comparable with all other systems.

4.6.2 Phosphorous uptake in fodder trees

The significant influence of fodder tree species, tree density as well as harvest interval on phosphorous uptake in mulberry and subabul is depicted in table 23. Phosphorous uptake was found to be higher for mulberry (4.80 kg ha^{-1}) than that of subabul (2.97 kg ha^{-1}) and also observed an increasing trend from the lowest to the highest tree density (2.39 to 5.09 kg ha^{-1} respectively). Phosphorous stocks in edible and inedible stem as well as leaf portions (0.72, 1.09, and 3.13 kg ha^{-1} respectively) were obtained highest for 12 weeks harvest interval when compared to the other intervals.

The combined effect of various treatments on phosphorous uptake in fodder trees is given in table 24. The highest phosphorous uptake was obtained in mulberry at the closest spacing (45 x 45 cm) and 12 weeks harvest interval. In the case of subabul, the phosphorous stocks in most of the treatments were found to be on par.

4.6.3 Potassium uptake in fodder trees

The main effect of fodder tree species, tree density as well as harvest interval on potassium stocks in mulberry and subabul intercropped in coconut plantation is depicted in table 25. Potassium uptake was significantly higher for mulberry (38.22 kg ha^{-1}) than that of subabul (24.45 kg ha^{-1}). Potassium uptake in fodder trees significantly increased from the lowest to the highest tree density (21.71 to 42.63 kg ha^{-1} respectively). Harvest interval also showed a significant effect on potassium uptake in fodder trees with maximum uptake (40.86 kg ha^{-1}) in the interval of 12 weeks when compared to other intervals.

The combined effect of different treatments showed significant influence on potassium uptake in fodder trees (Table 26). The highest potassium uptake in fodder tree species (73.41 kg ha^{-1}) was obtained in mulberry with the closest spacing (45 x 45 cm) and 12 weeks harvest interval (T_4). Similarly in subabul, the same management practices reported the maximum potassium uptake (41.08 kg ha^{-1}) when compared to other treatment combinations.

Table 23. Effect of tree density and harvest interval on nitrogen and phosphorous uptake in fodder trees in coconut plantation at Vellanikkara, Kerala.

Factors	Nitrogen uptake (kg ha^{-1})				Phosphorous uptake (kg ha^{-1})			
	Edible stem	Inedible stem	Leaf	Total	Edible stem	Inedible stem	Leaf	Total
Fodder trees								
Mulberry(P_1)	4.70^{a}	7.07^{a}	58.99^{a}	70.77^{a}	0.72^{a}	1.01^{a}	3.07^{a}	4.80^{a}
Subabul(P_2)	3.11^{b}	3.89^{b}	44.62^{b}	51.62^{b}	0.47^{b}	0.37^{b}	2.13^{b}	2.97^{b}
p value	0.001**	0.000**	0.009**	0.002**	0.000**	0.000**	0.009**	0.000**
Tree density								
49,382 plants ha^{-1} (D_1)	4.84^{a}	7.47^{a}	66.27^{a}	78.60^{a}	0.70^{ab}	0.90^{ab}	3.49^{a}	5.09^{a}
37,037 plants ha^{-1} (D_2)	4.14^{ab}	5.29^{bc}	52.29^{b}	61.74^{b}	0.61^{ab}	0.68^{ab}	2.86^{b}	4.16^{b}
27,777 plants ha^{-1} (D_3)	2.71^{b}	3.67^{c}	36.84^{c}	43.23^{c}	0.46^{b}	0.47^{b}	1.44^{c}	2.39^{c}
p value	0.001**	0.001**	0.000**	0.000**	0.002**	0.036*	0.000**	0.000**
Harvest interval								
8 weeks(F_1)	4.77^{a}	4.08^{a}	50.46	59.32	0.66^{a}	0.64^{b}	2.01^{ab}	3.32^{b}
12 weeks(F_2)	4.62^{ab}	8.58^{b}	57.41	70.62	0.72^{a}	1.09^{a}	3.13^{a}	4.95^{a}
16 weeks(F_3)	2.30^{c}	3.78^{c}	47.54	53.62	0.39^{b}	0.33^{bc}	2.65^{ab}	3.37^{b}
p value	0.000**	0.000**	0.297^{ns}	$.063^{ns}$	0.000**	0.000**	0.037*	0.003**
PxFxD (p value)	0.199^{ns}	0.577^{ns}	0.70^{ns}	.647	0.513^{ns}	0.757^{ns}	0.277^{ns}	0.314^{ns}

** 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 24. Combined effect of tree density and harvest interval on nitrogen and phosphorous uptake in fodder trees in coconut plantation.

Treatments	Nitrogen uptake ($kg\ ha^{-1}$)				Phosphorous uptake ($kg\ ha^{-1}$)			
	Edible stem	Inedible stem	Leaf	Total	Edible stem	Inedible stem	Leaf	Total
T_1-$P_1D_1F_1$	5.77	6.01	54.53	66.31	0.74	0.934	2.64	4.32
T_2-$P_1D_2F_1$	5.12	4.47	57.46	67.05	0.72	1.13	3.21	5.06
T_3-$P_1D_3F_1$	4.25	3.36	51.24	58.85	0.65	0.69	1.12	2.45
T_4-$P_1D_1F_2$	9.80	15.50	99.47	124.77	1.21	2.45	6.55	10.22
T_5-$P_1D_2F_2$	6.63	12.78	70.25	89.66	0.92	1.48	4.45	6.85
T_6-$P_1D_3F_2$	4.00	6.76	50.55	61.32	0.85	0.88	2.57	4.31
T_7-$P_1D_1F_3$	2.98	7.12	71.84	81.94	0.54	0.69	3.82	5.05
T_8-$P_1D_2F_3$	2.20	3.51	43.98	49.69	0.48	0.35	1.82	2.64
T_9-$P_1D_3F_3$	1.52	4.14	31.68	37.33	0.38	0.47	1.46	2.31
T_{10}-$P_2D_1F_1$	4.09	3.30	50.71	58.10	0.60	0.23	2.17	2.99
T_{11}-$P_2D_2F_1$	5.88	4.10	55.04	65.03	0.77	0.54	1.77	3.09
T_{12}-$P_2D_3F_1$	3.56	3.24	33.83	40.63	0.51	0.34	1.16	2.01
T_{13}-$P_2D_1F_2$	2.73	8.74	59.78	71.26	0.63	0.90	2.16	3.70
T_{14}-$P_2D_2F_2$	2.90	4.22	33.17	40.30	0.49	0.47	2.13	3.09
T_{15}-$P_2D_3F_2$	1.70	3.47	31.28	36.46	0.24	0.37	0.93	1.54
T_{16}-$P_2D_1F_3$	3.71	4.19	61.35	69.26	0.50	0.20	3.60	4.30
T_{17}-$P_2D_2F_3$	2.17	2.66	53.89	58.72	0.31	0.17	3.77	4.25
T_{18}-$P_2D_3F_3$	1.24	1.10	24.84	24.83	0.18	0.10	1.43	1.71
Treatment mean	3.90	5.48	51.93	61.20	0.59	0.69	2.60	3.88
p value	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**
LSD (0.05)	2.92	4.04	29.22	40.04	0.32	0.80	2.33	2.60

** significant at $p<0.01$

Table 25. Effect of tree density and harvest interval on potassium uptake in fodder trees in coconut plantation at Vellanikkara, Kerala.

Factors	Potassium uptake (%)			
	Edible stem	**Inedible Stem**	**Leaf**	**Total**
Fodder trees				
Mulberry(P_1)	4.79^a	10.04^a	23.40^a	38.22^a
Subabul(P_2)	3.62^b	4.87^b	15.97^b	24.45^b
p value	0.039*	0.000**	0.03*	0.005**
Tree density				
49,382 plants ha^{-1} (D_1)	5.14^a	10.17^a	27.32^a	42.63^a
37,037 plants ha^{-1} (D_2)	4.35^{ab}	6.70^b	18.59^b	29.65^b
27,777 plants ha^{-1} (D_3)	3.10^{ab}	5.48^{bc}	13.12^b	21.71^b
p value	0.015*	0.006**	0.004**	0.003**
Harvest interval				
8 weeks(F_1)	4.31^b	5.33^b	18.74	28.39^{ab}
12 weeks(F_2)	5.83^a	11.93^a	23.09	40.86^a
16 weeks(F_3)	2.45^b	5.09^c	17.20	24.75^b
p value	0.000**	0.000**	0.329^{ns}	0.018*
PxFxD (p value)	0.718^{ns}	0.956^{ns}	0.415^{ns}	0.677^{ns}

** 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 26. Combined effect of tree density and harvest interval on potassium uptake in fodder trees in coconut plantation at Vellanikkara, Kerala.

Treatments	Potassium uptake (%)			
	Edible stem	Inedible stem	Leaf	Total
T_1-$P_1D_1F_1$	4.79	7.28	19.75	31.82
T_2-$P_1D_2F_1$	5.06	7.72	25.67	38.45
T_3-$P_1D_3F_1$	4.26	5.31	15.40	24.97
T_4-$P_1D_1F_2$	10.03	22.39	40.99	73.41
T_5-$P_1D_2F_2$	5.45	13.94	24.94	44.33
T_6-$P_1D_3F_2$	5.77	12.35	22.28	40.40
T_7-$P_1D_1F_3$	3.05	11.74	40.01	54.81
T_8-$P_1D_2F_3$	2.41	4.15	10.20	16.77
T_9-$P_1D_3F_3$	2.25	5.47	11.33	19.04
T_{10}-$P_2D_1F_1$	3.27	3.50	22.64	29.41
T_{11}-$P_2D_2F_1$	5.45	4.90	18.51	28.86
T_{12}-$P_2D_3F_1$	3.07	3.27	10.52	16.85
T_{13}-$P_2D_1F_2$	6.29	11.64	23.14	41.08
T_{14}-$P_2D_2F_2$	5.57	6.35	16.13	28.05
T_{15}-$P_2D_3F_2$	1.88	4.95	11.06	17.88
T_{16}-$P_2D_1F_3$	3.40	4.48	17.43	25.30
T_{17}-$P_2D_2F_3$	2.22	3.14	16.14	21.51
T_{18}-$P_2D_3F_3$	1.39	1.56	8.14	11.10
Treatment mean	4.20	7.45	19.69	31.33
p value	0.000**	0.000**	0.000**	0.000**
LSD (0.05)	3.9	7.6	22.5	30

** significant at $p<0.01$

4.7 SOIL FERTILITY STATUS OF COCONUT-FODDER TREE INTERCROPPING SYSTEMS

4.7.1 Soil physical properties

4.7.1.1 Soil pH

Table 27 depicts the main effect of fodder tree species, tree density and harvest interval on the pH of soil at two depths (0-20 and 21-40 cm) in mulberry and subabul plots intercropped in coconut plantation. On comparing the fodder trees, the mean values of soil pH in the two depths (0-20 and 21-40 cm) was significantly higher in subabul than mulberry. Tree density had no significant influence on the pH of soil in the top 20 cm depth. However, tree density showed significant effect on the soil pH at the lower soil depth (21-40 cm) and the highest pH (5.04) was obtained from the lowest tree density (27,777 plants ha^{-1}). The mean value of soil pH (4.95) also showed the similar trend. Harvest interval had no significant effect on soil pH in both the soil depths.

The combined effect of different treatments on pH of soil in mulberry and subabul plots showed significant effect (Table 28). In mulberry, the highest mean value of soil pH (5.11) was observed in the combination of lowest tree density 27,777 plants ha^{-1} and 8 weeks harvest interval (T_3). Similarly, the maximum soil pH (5.27) obtained from subabul also followed the same management practices as that of mulberry. The mean soil pH of sole coconut plots and open plots were 4.64 and 5.75 respectively.

4.7.1.2 Soil bulk density

The data given in table 27 reveals that the fodder tree intercropping as well as various management regimes had no significant influence on bulk density of soil at two depths (0-20 and 21-40 cm). The different treatment combinations showed significant effect on soil bulk density as observed from table 28. Soil bulk density values ranged from 1.34-1.47 g cm^{-3} in various intercropping treatments with no specific trend. The soil bulk density in sole coconut plots and open plot was 1.52 and 1.38 g cm^{-3} respectively.

88

4.7.1.3 Water holding capacity

Table 27 depicts the main effect of tree density and harvest interval on water holding capacity of soil. On comparing the fodder trees, the maximum water holding capacity was observed in mulberry plots (53.96 %) than that of subabul (50.84%) and the difference was found to be significant. Tree density and harvest interval had no significant effect on the water holding capacity of soil at two depths.

The combined effect of various treatments showed significant effect on the water holding capacity of soil in mulberry and subabul plots (Table 28). An increasing trend in the water holding capacity was observed from the top soil depth to the lower soil depth and the highest water holding capacity (59.81%) was observed in mulberry at the lowest tree density 27,777 plants ha^{-1} and the shortest harvest interval of 8 weeks (T_3). In subabul, the maximum water holding capacity (54.33%) was obtained from the highest tree density (49,382 plants ha^{-1}) and the shortest harvest interval of 8 weeks (T_{10}). The water holding capacity in the sole coconut and contiguous treeless plots were found to be 60.92% and 56.98% respectively.

4.7.2 Soil nutrient stocks

4.7.2.1 Total nitrogen concentration in soil

The main effect of fodder trees, tree density as well as harvest interval showed no significant effect on the total nitrogen concentration in the soil (Table 29). Total nitrogen in soil was found to be on par for mulberry and subabul (0.127% and 0.128% respectively). The medium tree density showed comparatively highest total nitrogen in the soil (0.133%) when compared with the other two densities. Harvest interval of 8 and 12 weeks (0.131%) had slightly higher total soil nitrogen than 16 weeks interval (0.121%).

The combined effect of tree density and harvest interval on total nitrogen concentration in soil is depicted in table 30. Sole coconut plots (0.098%) and control areas (0.079%) had comparatively lower total nitrogen concentration in soil when compared to all treatment combinations.

4.7.2.2 Available nitrogen content in soil

Table 31 depicts the main effect of fodder tree species, tree density and harvest interval on the available nitrogen content in the soil. The available nitrogen content in the soil was found to be on par for the fodder tree species. Tree density had no significant effect on the available nitrogen content in the soil. In both the depths, the medium tree density had the highest available nitrogen content. On the contrary, harvest interval had significant effect on the available nitrogen content in soil and the highest available nitrogen content (203.76 kg ha^{-1}) was recorded in the 12 weeks harvest interval.

The combined effect of various treatments on the available nitrogen content in soil was given in table 32. Highest available soil nitrogen was recorded in mulberry (267.07 kg ha^{-1}) at medium tree density and 12 weeks harvest interval. In subabul, the maximum available nitrogen in soil was observed in the similar management practices. The available nitrogen in the sole coconut and control plot were obtained as 163.03 kg ha^{-1} and 152.57 kg ha^{-1} respectively, found to have comparatively lower content, when compared with most of the intercropped plots.

4.7.2.3 Available phosphorous in soil

The main effect of fodder trees, tree density and harvest interval on available phosphorous in the soil is given in table 31. All these factors had no significant influence in available phosphorus content in soil. On comparing different treatment combinations (Table 32) the P content in soil ranged from 5.3 to 30.75 kg ha^{-1} in various intercropped plots with no specific trend. However all the intercropped plots have higher P content in soils when compared to the coconut monoculture plots (4.32 kg ha^{-1}).

4.7.2.4 Available potassium content in soil

The data given in table 31 shows that, the fodder tree species, tree density and harvest interval had no significant effect on the available potassium content in soil. The combined effect of tree density and harvest interval showed significant effect on available potassium content in soil (Table 32) and values ranged from 61.75 to 220.79 kg ha^{-1} in the top layer. Whereas, the soil in the coconut sole plots had K content of 195.78 kg ha^{-1} in the respective layer.

4.8 ECONOMICS OF FODDER PRODUCTION IN COCONUT PLANTATION

Table 33 depicts the economics and B: C ratio of fodder production as influenced by tree density and harvest interval of fodder trees in coconut plantation over three year period. Comparing fodder tree species, significantly higher B: C ratio was obtained by intercropping mulberry (2.94) than subabul (2.54) in coconut garden. Management practices like tree density and harvest interval also showed significant effect on B: C ratio. B: C ratio showed an increasing trend (2.26 to 3.05) from lower to higher density classes. The highest B: C ratio (3.07) was obtained from 12 weeks harvest interval followed by 16 weeks and then 8 weeks.

The combined effect of various treatments show significant effect on the economics of mulberry and subabul intercropped in coconut plantation (Table 34). The highest fodder production over three year period (171.31 Mg ha^{-1}) and B: C ratio (3.99) was in mulberry at the highest tree density (49,382 plants ha^{-1}) and 12 weeks harvest interval. Whereas in subabul, the maximum fodder production (135.58 Mg ha^{-1}) and B: C ratio (3.6) was observed at medium tree density (37037 plants ha^{-1}) and 16 weeks harvest interval.

Table 27. Effect of management regimes on physico-chemical properties of soil under mulberry and subabul in coconut plantation at Vellanikkara, Kerala.

Factors	Soil pH			Soil bulk density (g cm $^{-3}$)			Water holding capacity of soil (%)		
	0-20 cm	21-40 cm	Mean	0-20 cm	21-40 cm	Mean	0-20 cm	21-40 cm	Mean
Fodder trees									
Mulberry(P_1)	4.71	4.45_b	4.58^b	1.29	1.50	1.39	50.11	57.81^a	53.96^a
Subabul(P_2)	4.77	4.91^a	4.84^a	1.36	1.44	1.40	47.75	53.93^b	50.84^b
p value	0.63^{ns}	0.000**	0.01**	0.08^{ns}	0.11^{ns}	0.77^{ns}	0.11^{ns}	0.000**	0.02**
Tree density									
49,382 plants ha^{-1} (D_1)	4.67	4.52^b	4.62^b	1.33	1.46	1.39	49.04	57.58	53.31
37,037 plants ha^{-1} (D_2)	4.62	4.50^b	4.52^b	1.30	1.50	1.40	48.77	54.16	51.47
27,777 plants ha^{-1} (D_3)	4.92	5.04^a	4.95^a	1.35	1.45	1.40	48.99	55.86	52.42
p value	0.12^{ns}	0.000**	0.000**	0.54^{ns}	0.52^{ns}	0.97^{ns}	0.99^{ns}	0.09^{ns}	0.48^{ns}
Harvest interval									
8 weeks(F_1)	4.80	4.69	4.75	1.30	1.47	1.39	50.27	55.18	52.72
12 weeks(F_2)	4.73	4.77	4.75	1.32	1.47	1.40	47.79	57.22	52.51
16 weeks(F_3)	4.68	4.59	4.64	1.36	1.47	1.41	48.74	55.20	51.97
p value	0.74^{ns}	0.37^{ns}	0.54^{ns}	0.45^{ns}	1.00^{ns}	0.64^{ns}	0.37^{ns}	0.31^{ns}	0.88^{ns}
PxFxD (p value)	0.16^{ns}	0.14^{ns}	0.07^{ns}	0.60^{ns}	0.93^{ns}	0.92^{ns}	0.27^{ns}	0.05^{ns}	0.44^{ns}

** 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 28. Combined effect of fodder tree density and harvest interval on physico-chemical properties of soil in coconut plantation at Vellanikkara, Kerala.

Treatments	Soil pH			Bulk density (g cm^{-3})			Water holding capacity (%)		
	0-20 cm	21-40 cm	Mean	0-20 cm	21-40 cm	Mean	0-20 cm	21-40 cm	Mean
T_1-$P_1D_1F_1$	4.85	4.66	4.76	1.31	1.52	1.42	52.05	56.78	54.42
T_2-$P_1D_2F_1$	4.19	3.87	4.03	1.21	1.47	1.35	47.94	49.14	48.54
T_3-$P_1D_3F_1$	5.19	5.04	5.11	1.31	1.42	1.37	53.81	65.80	59.81
T_4-$P_1D_1F_2$	4.50	4.16	4.33	1.35	1.51	1.44	49.14	69.88	59.51
T_5-$P_1D_2F_2$	4.70	4.40	4.55	1.29	1.53	1.41	49.86	58.90	54.38
T_6-$P_1D_3F_2$	5.12	5.05	5.09	1.23	1.55	1.39	49.30	52.64	50.97
T_7-$P_1D_1F_3$	4.58	4.23	4.41	1.27	1.47	1.37	48.50	56.31	52.40
T_8-$P_1D_2F_3$	4.53	4.29	4.41	1.34	1.52	1.43	53.85	57.85	55.85
T_9-$P_1D_3F_3$	4.73	4.38	4.56	1.26	1.48	1.37	46.54	52.96	49.75
T_{10}-$P_2D_1F_1$	4.93	4.66	4.80	1.28	1.49	1.39	52.95	55.70	54.33
T_{11}-$P_2D_2F_1$	4.62	4.40	4.51	1.26	1.50	1.38	48.53	54.01	51.27
T_{12}-$P_2D_3F_1$	5.01	5.52	5.27	1.39	1.41	1.40	46.32	49.63	47.98
T_{13}-$P_2D_1F_2$	4.98	5.00	4.99	1.28	1.40	1.34	43.28	53.77	48.53
T_{14}-$P_2D_2F_2$	4.65	4.94	4.80	1.32	1.44	1.38	45.00	51.32	48.16
T_{15}-$P_2D_3F_2$	4.46	5.06	4.76	1.44	1.37	1.41	50.16	56.83	53.50
T_{16}-$P_2D_1F_3$	4.18	4.40	4.29	1.47	1.35	1.41	48.32	53.06	50.69
T_{17}-$P_2D_2F_3$	5.06	5.06	5.07	1.33	1.52	1.43	47.44	53.76	50.60
T_{18}-$P_2D_3F_3$	5.01	5.19	5.10	1.45	1.47	1.47	47.78	57.27	52.53
Treatment mean	4.73	4.68	4.71	1.32	1.47	1.40	48.94	55.87	52.40
Sole coconut plots	4.90	4.38	4.64	1.50	1.54	1.52	59.62	62.22	60.92
Contiguous treeless plots	5.99	5.51	5.75	1.34	1.43	1.38	53.60	60.35	56.98
p value	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**
LSD (0.05)	0.80	0.57	0.51	0.27	0.2	0.18	10.6	7.6	9.7

** significant at $p<0.01$

Table 29. Effect of fodder tree density and harvest interval on total nitrogen concentration in soil at Vellanikkara, Kerala.

Factors	**Total nitrogen in soil (%)**		
	0-20 cm	**21-40 cm**	**Total**
Fodder trees			
Mulberry (P_1)	0.080	0.047	0.127
Subabul (P_2)	0.077	0.051	0.128
p value	0.45^{ns}	0.34^{ns}	0.95^{ns}
Tree density			
49,382 plants ha^{-1} (D_1)	0.079	0.047	0.126
37,037 plants ha^{-1} (D_2)	0.081	0.052	0.133
27,777 plants ha^{-1} (D_3)	0.076	0.047	0.123
p value	0.73^{ns}	0.53^{ns}	0.53^{ns}
Harvest interval			
8 weeks (F_1)	0.079	0.051	0.131
12 weeks (F_2)	0.080	0.05	0.13
16 weeks (F_3)	0.076	0.045	0.121
p value	0.78^{ns}	0.47^{ns}	0.53^{ns}
PxFxD (p value)	0.51^{ns}	0.55^{ns}	0.71^{ns}

ns= not significant at p>0.05

Table 30. Combined effect of fodder tree density and harvest interval on total nitrogen concentration in soil at Vellanikkara, Kerala.

Treatments	**Total nitrogen in soil (%)**		
	0-20 cm	**21-40 cm**	**Total**
T_1-$P_1D_1F_1$	0.075	0.037	0.112
T_2-$P_1D_2F_1$	0.075	0.047	0.121
T_3-$P_1D_3F_1$	0.089	0.056	0.145
T_4-$P_1D_1F_2$	0.079	0.037	0.117
T_5-$P_1D_2F_2$	0.093	0.051	0.145
T_6-$P_1D_3F_2$	0.075	0.051	0.126
T_7-$P_1D_1F_3$	0.056	0.047	0.103
T_8-$P_1D_2F_3$	0.093	0.047	0.140
T_9-$P_1D_3F_3$	0.089	0.047	0.135
T_{10}-$P_2D_1F_1$	0.093	0.056	0.149
T_{11}-$P_2D_2F_1$	0.075	0.070	0.145
T_{12}-$P_2D_3F_1$	0.070	0.042	0.112
T_{13}-$P_2D_1F_2$	0.084	0.061	0.145
T_{14}-$P_2D_2F_2$	0.079	0.056	0.135
T_{15}-$P_2D_3F_2$	0.070	0.042	0.112
T_{16}-$P_2D_1F_3$	0.084	0.047	0.131
T_{17}-$P_2D_2F_3$	0.070	0.042	0.112
T_{18}-$P_2D_3F_3$	0.065	0.042	0.107
Treatment mean	0.078	0.049	0.127
Sole coconut plots	0.056	0.042	0.098
Contiguous treeless plots	0.047	0.033	0.079
p value	0.000**	0.000**	0.000**
LSD (0.05)	0.031	0.03	0.05

** significant at $p<0.01$

Table 31. Effect of fodder tree density and harvest interval on available nitrogen, phosphorous and potassium content in soil at Vellanikkara, Kerala.

Factors	Available nitrogen in soil (kg ha^{-1})			Available phosphorous in soil (kg ha^{-1})			Available potassium in soil (kg ha^{-1})		
	0-20 cm	21-40 cm	Total	0-20 cm	21-40 cm	Total	0-20 cm	21-40 cm	Total
Fodder trees									
Mulberry(P_1)	103.67	78.32	181.99	9.48	4.06	13.54	139.03	174.26	313.29
Subabul(P_2)	95.02	77.71	172.73	12.01	4.54	16.55	160.65	158.58	319.23
p value	0.19^{ns}	0.91^{ns}	0.43^{ns}	0.42^{ns}	0.69^{ns}	0.46^{ns}	0.24^{ns}	0.20^{ns}	0.80^{ns}
Tree density									
49,382 plants ha^{-1} (D_1)	92.03	69.42	161.45	14.54	5.23^{a}	19.77	146.94	175.27	322.21
37,037 plants ha^{-1} (D_2)	109.60	86.13	195.73	11.44	5.85^{a}	17.29	145.54	157.92	303.46
27,777 plants ha^{-1} (D_3)	96.41	78.48	174.89	6.26	1.83^{b}	8.08	157.04	166.08	323.12
p value	0.08^{ns}	0.05^{ns}	0.07^{ns}	0.10^{ns}	0.02*	0.06^{ns}	0.85^{ns}	0.50^{ns}	0.75^{ns}
Harvest interval									
8 weeks(F_1)	88.62^{bc}	65.04^{c}	153.67^{b}	10.94	4.73	15.68	139.76	154.30	294.07
12 weeks(F_2)	112.77^{a}	90.99^{a}	203.76^{a}	9.05	3.70	12.75	158.44	180.74	339.18
16 weeks(F_3)	96.64^{b}	78.01^{b}	174.65^{b}	12.23	4.47	16.71	151.32	164.22	315.54
p value	0.01	0.00**	0.01**	0.70^{ns}	0.76^{ns}	0.71^{ns}	0.70^{ns}	0.21^{ns}	0.31^{ns}
PxFxD (p value)	0.66^{ns}	0.16^{ns}	0.42^{ns}	0.57^{ns}	0.50^{ns}	0.51^{ns}	0.01*	0.05^{ns}	0.06^{ns}

** 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.

95

Table 32. Combined effect of fodder tree density and harvest interval on available nitrogen, phosphorous and potassium content in soil at Vellanikkara,, Kerala.

Treatment	Available nitrogen in soil (kg ha^{-1})			Available phosphorous in soil (kg ha^{-1})			Available potassium in soil (kg ha^{-1})		
	0-20 cm	21-40 cm	Total	0-20 cm	21-40 cm	Total	0-20 cm	21-40 cm	Total
T_1-$P_1D_1F_1$	96.23	72.40	168.63	10.87	6.72	17.59	173.15	140.97	314.12
T_2-$P_1D_2F_1$	100.80	67.20	168.00	7.80	4.64	12.44	72.87	92.62	165.50
T_3-$P_1D_3F_1$	73.50	52.50	126.00	2.78	1.27	4.05	126.49	195.37	321.85
T_4-$P_1D_1F_2$	98.70	63.00	161.70	4.40	1.21	5.62	129.43	181.14	310.58
T_5-$P_1D_2F_2$	148.23	118.83	267.07	11.63	5.41	17.04	103.79	199.73	303.52
T_6-$P_1D_3F_2$	119.70	105.00	224.70	8.28	1.25	9.53	106.02	195.78	301.80
T_7-$P_1D_1F_3$	100.57	70.53	171.10	8.90	2.84	11.74	155.16	259.39	414.55
T_8-$P_1D_2F_3$	107.10	84.00	191.10	18.76	9.71	28.46	194.99	147.95	342.94
T_9-$P_1D_3F_3$	88.20	71.40	159.60	11.87	3.51	15.38	189.38	155.38	344.76
T_{10}-$P_2D_1F_1$	75.60	63.00	138.60	20.88	7.07	27.95	61.75	151.98	213.73
T_{11}-$P_2D_2F_1$	92.40	56.70	149.10	19.97	7.07	27.04	218.85	196.45	415.30
T_{12}-$P_2D_3F_1$	93.20	78.47	171.67	3.36	1.62	4.98	185.47	148.43	333.91
T_{13}-$P_2D_1F_2$	94.50	79.80	174.30	21.18	9.57	30.75	182.04	169.94	351.98
T_{14}-$P_2D_2F_2$	108.27	99.77	208.03	5.13	3.15	8.28	208.54	199.29	407.83
T_{15}-$P_2D_3F_2$	107.23	79.53	186.77	3.70	1.60	5.30	220.79	138.58	359.37
T_{16}-$P_2D_1F_3$	86.57	67.80	154.37	20.98	3.98	24.96	180.10	148.18	328.28
T_{17}-$P_2D_2F_3$	100.80	90.30	191.10	5.35	5.10	10.44	74.22	111.48	185.70
T_{18}-$P_2D_3F_3$	96.60	84.00	180.60	7.54	1.72	9.26	114.09	162.92	277.01
Treatment mean	99.34	78.01	177.35	10.43	4.30	15.04	149.84	166.42	316.27
Sole coconut plots	85.30	77.73	163.03	3.02	1.30	4.32	195.78	181.66	377.44
Contiguous treeless plots	83.93	68.63	152.57	2.81	1.30	4.11	179.42	194.99	374.41
p value	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**
LSD (0.05)	25.2	32.50	21.00		18.40		8.10		13.35

** significant at $p<0.01$

96

Table 33. Economics of fodder production as influenced by tree density and harvest interval of mulberry and subabul under coconut plantation at Vellanikkara, Kerala.

Factors	Fodder yield of three years (Mg ha^{-1})	B:C ratio of fodder production over three year period
Fodder trees		
Mulberry(P_1)	115.69	2.94
Subabul(P_2)	99.97	2.54
p value	0.000**	0.000**
Tree density		
49,382 plants ha^{-1} (D_1)	131.25	3.05
37,037 plants ha^{-1} (D_2)	112.28	2.90
27,777 plants ha^{-1} (D_3)	79.96	2.26
p value	0.000**	0.000**
Harvest interval		
8 weeks(F_1)	88.96	2.18
12 weeks(F_2)	120.58	3.07
16 weeks(F_3)	113.94	2.97
p value	0.000**	0.000**
PxFxD (p value)	0.16	0.11

** 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 34. Economics of fodder production as influenced by different treatment combinations under coconut plantation at Vellanikkara, Kerala.

Treatments	**Total cost of fodder production for three years(Rs. ha^{-1})**	**Fodder yield over three years (Mg ha^{-1})**	**Returns from fodder over three year period (Rs.)**	**B:C ratio of fodder production**
T_1-$P_1D_1F_1$	312882.95	107.15	750029	2.40
T_2-$P_1D_2F_1$	282236.90	94.55	661829	2.34
T_3-$P_1D_3F_1$	258296.85	68.85	481971	1.87
T_4-$P_1D_1F_2$	300536.75	171.31	1199170	3.99
T_5-$P_1D_2F_2$	269890.70	150.07	1050511	3.89
T_6-$P_1D_3F_2$	245950.65	109.54	766801	3.12
T_7-$P_1D_1F_3$	294363.65	150.52	1053640	3.58
T_8-$P_1D_2F_3$	263717.60	106.20	743379	2.82
T_9-$P_1D_3F_3$	239777.55	83.01	581091	2.42
T_{10}-$P_2D_1F_1$	312882.95	99.23	694589	2.22
T_{11}-$P_2D_2F_1$	282236.90	90.12	630861	2.24
T_{12}-$P_2D_3F_1$	258296.85	73.88	517181	2.00
T_{13}-$P_2D_1F_2$	300536.75	130.45	913171	3.04
T_{14}-$P_2D_2F_2$	269890.70	97.16	680099	2.52
T_{15}-$P_2D_3F_2$	245950.65	64.95	454650	1.85
T_{16}-$P_2D_1F_3$	294363.65	128.82	901719	3.06
T_{17}-$P_2D_2F_3$	263717.60	135.58	949039	3.60
T_{18}-$P_2D_3F_3$	239777.55	79.52	556619	2.32
Treatment mean	274183.70	107.82	754797	2.74
p value		0.000**		0.000**
LSD (0.05)		0.21		0.41

**significant at $p<0.01$

99

Discussion

DISCUSSION

The field study on "Productivity, carbon and nutrient stocks in mulberry (*Morus indica* L.) and subabul (*Leucaena leucocephala* Lam.) based high density fodder production system in coconut" was conducted and the results obtained are discussed hereunder.

5.1 SURVIVAL PERCENTAGE AND FORAGE YIELD OF MULBERRY AND SUBABUL UNDER VARIABLE DENSITIES AND HARVEST INTERVALS IN COCONUT PLANTATION

5.1.1 Fodder tree species

The study was conducted on the fodder tree species like mulberry and subabul intercropped in coconut plantation under variable density and harvest intervals. Both the trees showed significant variation with respect to their survival and forage productivity in the third year of intercropping in coconut.

In general, mulberry had significantly higher survival percentage (86.82%) as compared to subabul (72.37%). This could be due to the poor performance of subabul under acidic soil conditions of Kerala. Several other workers also reported poor survival and establishment of subabul under acidic soil conditions (NAS, 1977; Bapat, 1995). Moreover, the clayey nature of soils have also affected the growth of subabul, as light textured soil are better than clayey soil for root development and growth of subabul (Singh, 1985). In contrast, mulberry can easily be established in any type of field conditions (Ezenwa *et al*., 1999) and develops a strong vertical and profuse horizontal root system (Paolieri, 1970) which helps in better survival.

Annual fresh fodder yield from fodder trees per hectare of coconut garden in the third year of intercropping also showed significant variation among the tree species. Total forage yield from mulberry was significantly higher (33.93 Mg ha^{-1} yr^{-1}) than that of subabul (20.14 Mg ha^{-1} yr^{-1}). Similar trend was also observed in the case of edible forage (leaf + green stem) and dry forage yield. This could be due to the poor survival as well as the productivity of subabul under acidic conditions of Kerala. Raj

(2016) reported poor survival and establishment of subabul (92%) when compared to mulberry (100%) in the initial year of intercropping in coconut garden, which in turn resulted in low fodder productivity per unit area. This trend also followed during the subsequent years also. Moreover it is observed that mulberry is more amenable to pruning with rapid regrowth and proficient coppicing (Singh and Makkar, 2002) whereas regrowth from subabul was comparatively slow and poor. A minor attack of stem borer was also observed in subabul which resulted in toppling of the plants.

5.1.2 Tree density

The data given in fig 3 and 4 represents the significant variation in fresh and dry forage yield from fodder trees at variable tree densities. In general, edible fodder yield was higher (26.74 Mg ha^{-1} yr^{-1}) for trees at the closest spacing (45 cm x 45 cm) than the wider spacing. Total fodder yield of trees almost doubled from 18.97 Mg ha^{-1} yr^{-1} at the lowest tree density (27,777 plants ha^{-1}) to 35.04 Mg ha^{-1} yr^{-1} at the highest tree density (49,382 plants ha^{-1}). The dry fodder yield also followed the similar trend. The results imply that in humid tropical regions which receive ample rainfall, there is a need for closer planting of fodder trees for maximizing productivivty from limited land areas along with the proper utilisation of resources. Higher plant density also provides thick canopy cover and dense root growth that limits understorey weed growth and competition for resources. In addition, close canopy reduces soil erosion and subsequent soil and nutrient loss during rainy season and evaporation rate during dry season, all favouring the resource conservation and utilisation for enhancing the productivity of trees (Sagaran, 2017). Moreover, higher plant density also promotes greater solar energy interception per unit area resulting in higher productivity (Turgut *et al*., 2005). Similar results of higher forage production from high density stands has been reported in mulberry and subabul (Raj, 2016), Sagaran (2017) and Joy (2017) in Calliandra and Ella *et.al.* (1989) in *Leucaena, Gliricidia* and *Sesbania.*

5.1.3. Harvest interval

Harvest interval also showed significant effect on forage yield of mulberry and subabul. The edible (24.17 Mg ha^{-1} yr^{-1}) as well as total (33.98 Mg ha^{-1} yr^{-1}) forage yield was higher for trees at medium harvest interval of 12 weeks than longer or shorter intervals of 16 and 8 weeks. Highest edible dry fodder was obtained at 8 weeks harvest interval (5.97 Mg ha^{-1} yr^{-1}), and was on par with those obtained at 12 weeks harvest interval (5.74 Mg ha^{-1} yr^{-1}). Total dry stem and total dry fodder biomass was comparatively higher (2.16 and 7.91 Mg ha^{-1} yr^{-1} respectively) for 12 weeks harvest interval.

Frequent harvest at short intervals reduces the photosynthetic rate due to the removal of foliage fraction. This reduces nutrient assimilation and food reserve which influences the growth rate and productivity of plants in the long run (Latt *et al*., 2000). Where as in the case of longer harvest interval of 16 weeks, majority of the harvested biomass consist of stem fraction, which reduces the proportion of edible forage. Hence, it is observed that it is ideal to maintain a medium harvest interval of 12 weeks for getting more edible forage. Similar results are also reported by Joy (2017) in calliandra.

5.1.4 Cumulative effect of management regimes on productivity of fodder trees in coconut garden

Drastic variation in forage yield has been noticed in both mulberry and subabul due to varying tree densities and harvest intervals (Table 2). Forage yields of mulberry and subabul stands underneath coconut plantation ranged from 16.40 to 63.38 and 9.33 to 30.96 Mg ha^{-1} yr^{-1} respectively under various management levels. This indicates the critical role of management factors like density and harvesting schedule for maximizing productivity from fodder tree banks. Edible fodder, stem and total fodder yields of 45.04, 18.35 and 63.38 Mg ha^{-1} yr^{-1} respectively and the dry forage yields were highest for mulberry at high tree density (49,382 plants ha^{-1}) and 12 weeks harvest interval. Similar management practices also produced the maximum fresh fodder yield (30.96 Mg ha^{-1} yr^{-1}) in subabul even though the yield was significantly lower than that of mulberry. Similar results of yield enhancement in tree fodder banks underneath coconut plantation by adoption of high tree densities and 12 weeks harvesting schedule has been reported by Raj (2016), Joy (2017) and Sagaran (2017) in different fodder tree species.

5.2 EFFECT OF FODDER TREE INTERCROPPING AND MANAGEMENT PRACTICES ON PRODUCTIVITY OF COCONUT

The influence of intercropped fodder trees on the productivity of stabilized mature coconut was assessed based on the harvested nut yield in the third year and by estimating the number of existing nuts of various size classes in the palms (Table 7). The results indicated that in general, intercropping of both the tree fodder species viz, mulberry or subabul and different harvest intervals had no significant effect on annual nut yield of coconut palms in the third year of intercropping. However, density management of fodder trees showed significant effect on productivity of coconut palms. Maximum nut yield (11,245 nuts ha^{-1}) was obtained from the lowest fodder tree density of 27,777 plants ha^{-1} when compared to higher density levels (10,899 nuts ha^{-1}). This shows that enhancement of tree density beyond a particular level will result in competition with the main crop coconut for various resources which resulted in yield reduction. Nutrient supplementation for both the crops is a requisite strategy to avoid yield loss in high density fodder production systems in coconut.

However, no significant difference in annual nut yield was observed between sole coconut palms (11,236 nuts ha^{-1}) and the palms intercropped with mulberry and subabul (10,207-11,245 nuts ha^{-1}) under different management practices (Table 8). This shows that high-density fodder tree cultivation can be adopted in the interspaces of coconut garden without any adverse effect on coconut yield by proper nutrient management.

The existing coconut bunches in the palm are formed during the previous three year period. The count of the existing nuts gives an indication regarding the effect of fodder tree intercropping on the productivity of palms during this period. The results indicate that intercropping of both the fodder tree species had no significant effect on the productivity of nuts in coconut palms. Similarly, various management practices like tree density and harvest interval and their treatment combinations also had no significant influence on the nut count (11,418- 12,456 nuts ha^{-1}), when compared to that of the sole coconut palms (12,448 nuts ha^{-1}). In spite of intensive intercropping of fodder trees, no negative effect on the productivity of coconut was observed. This could be due to the proper application of manures, fertilizers and irrigation to the fodder trees which prevented the exploitation of resources for the main crop ie, coconut. Moreover, the fodder trees were regularly pruned and mainly occupied the lower strata thereby avoiding any vertical competition for aboveground resources. Since the active root zone of coconut is confined to 25 per cent of the available land area, the remaining area could be profitably exploited for raising intercrops with the optimum utilisation of resources (Maheswarappa *et al.,* 2000). It should also be assumed that the belowground root competition has not started due to the young age of the fodder trees. However, Joy (2017) reported higher nut count in calliandra intercropped coconut palms than that of sole palms. In her study, she has adopted a density of 27,777 calliandra trees ha^{-1}. Whereas in the current study it was tried even higher densities of 49,382 plants ha^{-1} and observed that higher tree densities can adversely affect coconut yield in the long run when compared to the lower levels. Several other workers also observed that intercropping fodder trees at low tree densities have no negative impact on the yield of coconut (Liyanage and Jayasundara, 1987; Kumar, 2007).

Hence, the study reiterate the scope for cultivation of high density mulberry and subabul fodder banks with proper resource management in interspaces of coconut gardens and recurrent harvesting of fodder with no detrimental effect on coconut productivity especially in the early years of cultivation.

5.3 CARBON STORAGE POTENTIAL OF HIGH DENSITY COCONUT- FODDER TREE INTERCROPPING SYSTEMS

5.3.1 Biomass production and carbon stocks in fodder trees under varying management regimes over three-year period

Carbon stocks in fodder trees were estimated by summing up the carbon stocks in harvested fodder biomass over three year period and carbon stocks in standing stem and root biomass at the end of the third year.

Comparing the fodder tree species, total dry fodder yield over three- year period was significantly higher (26.89 Mg ha^{-1}) from mulberry than that of subabul (23.85 Mg ha^{-1}). Similar trend was also observed in the case of carbon stocks. However, in the case of standing biomass with respect to left over stump and root, and the carbon stocks, both the tree species showed no significant difference. In general, mulberry fodder banks accumulated total biomass of 41.82 Mg with carbon stocks of 22.56 Mg per hectare of coconut garden and was comparable with that of subabul (37.46 and 20.49 Mg ha^{-1} respectively).

However, management practices like tree density and harvest interval had significant effect on biomass production and carbon capture of fodder tree banks in coconut garden. Comparing tree densities, total dry fodder yield as well as carbon stocks over three year period, were found to have increased by 72% from low tree density (27,777 plants ha^{-1}) to high tree density (49,382 plants ha^{-1}). Similar trend was also observed in the case of standing biomass. On over all basis, significant higher carbon capture (26.97 Mg ha^{-1}) was observed in the highest tree density when compared to the lowest one (15.44 Mg ha^{-1}). In a similar study in calliandra, Joy (2017) reported that the biomass production as well as carbon capture in biomass was higher in high density stands than the lower levels. These results indicate the profound influence of tree density on carbon capture per unit area. Hence, accommodating more trees per unit area can be recommended as one of the promising strategies for enhancing carbon capture and thereby reducing the atmospheric CO_2 levels. Carbon storage potential of trees is basically a function of the biomass production potential which is also observed in the present study.

Harvest interval significantly influenced fodder biomass production and carbon stocks in mulberry and subabul. In general, harvesting at a medium interval of 12 weeks yielded the maximum dry fodder over three year period with carbon stocks of 14.88 Mg ha^{-1} and was significantly higher than longer or shorter interval of 16 and 8 weeks. Lower biomass production in the shorter intervals could be due to the fact that recurrent harvest and removal of leaf affect the photosynthesis and food production and accumulation of biomass. Where as in the case of longer pruning intervals, the quantity of harvested biomass was much lower due to lower number of harvests in a year. There was also loss of foliage fraction through leaf fall. However, harvest interval had no significant influence on standing biomass production as well as the total biomass production in fodder trees. Irrespective of the intervals, carbon capture of around 21 Mg ha^{-1} was observed in the current study.

The cumulative effect of tree density and harvest interval had significant effect on biomass production and carbon stocks of mulberry and subabul. Comparing various management levels, adoption of the highest tree density (D1) and the longest pruning interval yielded the maximum biomass (61.06 Mg ha^{-1}) and carbon stocks (32.85 Mg ha^{-1}) in mulberry ($P_1D_1F_3$) and was comparable with that of $P_1D_2F_2$ and $P_1D_1F_2$. In case of subabul, highest density and shortest interval ($P_2D_1F_1$) yielded the maximum biomass

(54.16 Mg ha^{-1}) and carbon stocks (29.57 Mg ha^{-1}) and was on par with that of $P_2D_1F_2$. Joy (2017) reported higher carbon stocks of 34.08 Mg ha^{-1}from calliandra fodder banks with tree density of 27,777 plants ha^{-1}and maintained at harvest interval of 12 weeks.

Cultivation of fodder trees and the different management practices have significantly enhanced the carbon capture in coconut plantations (11.84- 32.85 Mg ha^{-1}) compared with that of the sole coconut palms (0.76 Mg ha^{-1}). The interspaces of coconut monoculture palms have local grasses as under storey vegetation which had very less above and below ground biomass when compared to trees which resulted in very low carbon stocks. As against grasses, fast growing fodder trees like mulberry and subabul with its remarkable growth rate and quick regeneration after pruning, dense and deep root system, and woody stem acts as a high potential carbon sink. In a study conducted in Srilanka, Raveendra *et al.* (2017) reported higher carbon fixation (78.6 Mg ha^{-1}) by gliricidia fodder banks in coconut garden over six year period.

In addition, the results also indicate that the adoption of proper stand management strategies can elevate biomass accretion and carbon fixation to higher levels. In this study, higher density and medium pruning interval have enhanced the carbon fixation rates when compared to other management levels. Hence, in addition to fodder production, high density intercropping of mulberry and subabul and its proper management can enhance the carbon capture in coconut garden, which has a significant role in mitigating climate change.

5.3.2 Carbon stocks in coconut palms

The fodder trees were intercropped in a 37-year-old stabilized mature coconut garden (variety, West Coast Tall). Carbon stocks in coconut palms were estimated by summing up the carbon stocks in the coconut bole, fronds, harvested nuts in the third year and existing nuts in the palms (Joy, 2017). Carbon stocks in the coconut root was not estimated due to practical difficulties.

The results indicate that intercropping fodder trees as well as the management regimes like tree density and harvest interval showed significant effect on the total aboveground carbon stocks in coconut palms (Table 15). Subabul intercropped coconut palms (31.92 Mg ha^{-1}) had higher total aboveground carbon stocks than that of mulberry (31.60 Mg ha^{-1}).

The higher carbon stocks in subabul intercropped palms are mainly attributed due to higher nut production. This could be due to the complementary effect of nitrogen fixation by subabul. In addition, subabul also had less vigorous growth and biomass production than mulberry which poses less competition to coconut thereby enhancing coconut growth and carbon accretion. Moreover, coconut palms intercropped with mulberry especially under higher densities were found to be under moisture stress during summer months as indicated by the drooping of leaves which might have adversely affected the growth rate. However, such moisture stress symptoms were absent in subabul intercropped palms.

Tree density and harvest interval also had significant influence on the carbon stocks of coconut palms. Palms recorded higher carbon stocks (32.58 Mg ha^{-1}) when intercropped with lower fodder tree densities (27,777 plants ha^{-1}) compared to higher levels (Table 16). Similarly, adoption of longer pruning intervals of 16 weeks (32.04 Mg ha^{-1}) produced higher carbon stocks than the shorter intervals. This indicates that adoption of extremely high densities and frequent pruning of fodder trees, which depletes the soil resources, can initiate competition with the coconut as indicated by the lower growth rate of coconut and carbon accretion in the long run.

Combined effect of management practices indicate that the carbon stocks in coconut were maximum at the lowest tree density and longest harvest interval of 16 weeks for both mulberry (32.88 Mg ha^{-1}) and subabul (32.98 Mg ha^{-1}) and were found to be on par with that of sole coconut palms (32.78 Mg ha^{-1}). This indicates that fodder trees can be integrated with coconut palms by following the above management practices with no detrimental effect on growth rate of coconut. Joy (2017) and Raveendra *et al.* (2017) also reported similar findings in calliandra and gliricidia in coconut plantation. However, higher tree densities and intensive harvesting can be practiced with appropriate nutrient and irrigation management to compensate the needs for both the component crops.

5.4 SOIL CARBON STOCKS OF COCONUT –FODDER TREE INTERCROPPING SYSTEMS

The soil organic carbon content of coconut-fodder tree intercropping systems was evaluated up to 40 cm depth (Table 17). In general, the carbon content and stocks declined from the top 20 cm depth to the next lower depth, 20-40 cm. Similar findings are also reported by Varsha (2015).The higher SOC content in the surface layer may be due to the recycling of organic matter through litter fall and higher root growth and activity in the surface layer.

Different fodder tree species and various management practices had no significant effect on the soil carbon content. In general, soils under subabul had slightly higher carbon content (0.80%) and stocks (44.76 Mg ha^{-1}) than that of mulberry (0.79%). However, the combined effect of various treatment combinations showed significant effect on the soil organic carbon content and stocks. But, no specific trend could be observed regarding the carbon dynamics of intercropped plots under different management regimes. Probably, intercropping over a three year period may be too short to make significant and visible changes in the carbon dynamics of the soil. Comparing various plots, higher soil carbon content (1.00%) was obtained from subabul at medium tree density (37,037 plants ha^{-1}) and 12 weeks harvest interval, which also recorded the highest carbon stocks of 54.80 Mg ha^{-1}. In mulberry, the maximum soil organic carbon percentage (0.98%) was obtained from the lowest tree density (27,777 plants ha^{-1}) and 12 weeks harvest interval. This indicates that very high densities and frequent pruning leads to depletion of carbon than the lower levels. Appropriate manuring should be adopted for maintaining the carbon levels under such intensive management practices.

However, the sole coconut plots (0.69%) and contiguous open areas (0.61%) had comparatively lower carbon percentage than most of the intercropped plots. Similar trend was also followed in the case of soil carbon stocks with respective values of 41.81 and 33.66 Mg ha^{-1}. This trend was also observed even in the initial year of intercropping as reported by Raj (2016). This implies that integration of fodder trees in the interspaces of coconut has a greater impact in elevating SOC levels mainly through litter fall and recycling, extensive and deep root systems, root exudates and fine root turn over (Lal and Kimble, 2000; Oelbermann *et al.*, 2006). Moreover, trees have greater potential for above and below ground biomass production when compared to shrubs and herbs thereby making substantial contribution to SOC content (Lemma *et al.*, 2007).

5.5 OVERALL CARBON STOCKS IN COCONUT-FODDER TREE SYSTEMS

The main effect of fodder tree species, tree density and harvest interval on total carbon storage potential of the system is represented in table 21. On comparing fodder trees, slightly higher carbon storage was obtained from mulberry than subabul with no statistical significance. Tree density as well as harvest interval had significant effect on the carbon storage potential of the system. Total carbon storage potential of mulberry and subabul intercrops in coconut garden increased from the lowest tree density of 27,777 plants ha^{-1} to the highest tree density of 49,382 plants ha^{-1} (93.14 Mg ha^{-1} to 102.55 Mg ha^{-1} respectively). This could be due to the higher above and below ground biomass production in the high density stands when compared to the lower levels. Similar findings are reported by Varsha (2015) and Joy (2017).

The highest carbon storage potential of the system (100.10 Mg ha^{-1}) was observed in the medium harvest interval of 12 weeks, followed by 16 weeks and 8 weeks interval. This could be due to the fact that too short or too long intervals reduce the overall biomass production from the stands and the carbon accumulation in soil. Based on these results, adoption of proper harvest management can be recommended as a low cost technology to enhance carbon capture in plantations.

On comparing the intercropped and coconut monoculture systems (Table 22), all fodder tree intercropping systems at different management levels (82.70-108.48 Mg ha^{-1}) had higher carbon capture than coconut monoculture system (75.35 Mg ha^{-1}). The carbon stocks in the contiguous open areas were substantially lower (34.43 Mg ha^{-1}) when compared to the coconut monoculture and intercropping systems. In another study, Bhagya *et al*. (2017) reported carbon stocks of 140 Mg ha^{-1} from coconut- jamun systems when compared to 98 Mg ha^{-1} in sole coconut palms. Joy (2017) reported an additional carbon capture of 48 Mg ha^{-1}over three year period in high density coconut-calliandra fodder production systems up to 40 cm profile depth when compared to coconut monoculture. However, comparing the overall carbon stocks of different intercropped plots (82.70-108.48 Mg ha^{-1}) no specific trend could be observed between different treatment combinations. May be three year intercropping period is a short duration to arrive at a meaningful conclusion regarding the carbon dynamics of the system.

5.6 NUTRIENT STOCKS IN MULBERRY AND SUBABUL FODDER BANKS UNDER COCONUT PLANTATION

Nitrogen, phosphorous and potassium uptake by mulberry and subabul under varying densities and harvest intervals in coconut garden are discussed below. Significant difference was observed in nutrient uptake by the two fodder tree species, tree density and harvest schedule.

5.6.1 Fodder tree species

Table 23 and 25 depicts the main effect of fodder tree species on nutrient uptake in fodder biomass in the third year of intercropping in coconut plantation. N, P and K uptake was found to be significantly higher for mulberry (70.77, 4.80 and 38.22 kg ha^{-1}) than that of subabul (51.62, 2.97 and 24.45 kg ha^{-1}). In general, it was observed that establishment, survival, growth rate, faster regeneration after pruning and coppicing ability was much better in mulberry than that of subabul. This has resulted in vigorous growth and nutrient uptake by mulberry when compared to subabul. The higher fodder biomass production from mulberry also indicates the superior growth performance of mulberry than subabul. Several other workers also reported the fast and vigorous growth and proficient coppicing ability of mulberry (Paolieri, 1970; Ezenwa *et al*., 1999; Singh and Makkar, 2002).

5.6.2 Tree density

Tree density had significant effect on the nutrient uptake in fodder trees and followed an increasing trend from the lowest to the highest density. N, P and K uptake enhanced by 81, 113 and 96 per cent from lower to higher densities. Higher nutrient uptake by increasing tree density is already reported by several workers (Savory and Breen, 1979; Bhardwaj *et al.*, 2001). This implies that adoption of higher tree densities will lead to soil nutrient depletion of the whole system in the long run. Hence high density cultivation should be undertaken only with proper nutrient supplementation so as to maintain the sustainable production of the whole system.

5.6.3 Harvest interval

Nutrient uptake in fodder biomass showed significant variation across harvest intervals and the uptake was higher in the medium interval of 12 weeks when compared to shorter or longer intervals. This could be due to higher biomass production in 12 weeks harvest interval with more nutrient rich foliage fraction. At longer harvest intervals, majority of the biomass consist of stem fractions which has lower nutrient content than foliage where as in case of shorter intervals, the overall biomass production itself was lower. This was due to frequent pruning of trees during the previous three years at shorter interval of 2 months. Annually six harvests were taken in these trees with the removal of foliage thereby providing less space and time for photosynthesis and food production affecting the overall growth and vigour of the tree. This has also resulted in reduced nutrient uptake.

5.6.4 Combined effect

The combined effect of various treatments showed significant difference on the nutrient uptake in fodder trees (Table 24, 26). The highest N, P and K uptake (124.77, 4.80 and 38.22 kg ha^{-1}) was observed in mulberry with the closest spacing (45 cm x 45 cm) and 12 weeks harvest interval. In case of subabul, nutrient uptake was comparable with all other treatments of subabul. Thus results indicate that management practices have a significant impact on nutrient uptake of fodder trees, which should be considered while establishing fodder banks.

5.7 SOIL FERTILITY STATUS OF COCONUT-FODDER TREE INTERCROPPINGSYSTEMS

5.7.1 Soil physical properties

5.7.1.1 Soil pH

Table 27 depicts the main effect of fodder tree species, tree density and harvest interval on the pH of soil at two depths (0-20 and 21-40 cm) in mulberry and subabul plots intercropped in coconut plantation. On comparing the fodder trees, the mean values of soil pH were significantly higher in subabul (4.84) than mulberry (4.58). This could be due to the alkaline nature of leguminous tree subabul. Generally, legume materials have higher ash alkalinity due to the unbalanced uptake of cations and anions, and thus have greater amelioration effects on soil acidity than non-legume materials (Wang *et al*., 2009).

Tree density had no significant influence on the pH of soil in the top 20 cm depth. However, tree density showed significant effect on the soil pH at the lower soil depth (21-40 cm) and the highest pH (4.92) was obtained from the lowest tree density (27,777 plants ha^{-1}). The mean value of soil pH (4.95) also showed the similar trend. Joy (2017) also reported similar findings in calliandra. Harvest interval had no significant effect on soil pH in both the soil depths.

The combined effect of different treatments on pH of soil in mulberry and subabul plots showed significant effect (Table 28). In mulberry, the highest mean value of soil pH (5.11) was observed in the combination of lowest tree density 27,777 plants ha^{-1} and 8 weeks harvest interval. Similarly, the maximum soil pH (5.27) obtained from subabul also followed the same management practices as that of mulberry. The mean soil pH of sole coconut plots were comparatively lower (4.64) than most of intercropped plots. This could be due to addition of litter and fine roots by high density fodder trees in the intercropped plots as against the rudimentary grass vegetation in sole coconut plots. Similarly farm yard manure was also added to fodder tree plots which might have had an ameliorating effect in soil. Several workers report that direct application and incorporation of green manures, animal wastes, and crop residues can ameliorate soil acidity (Hue, 1992; Chen, 2006; Raj, 2016).

5.7.1.2 Soil bulk density

The data given in table 27 reveals that the fodder tree intercropping as well as various management regimes had no significant influence on bulk density of soil at two depths (0-20 and 21-40 cm). The different treatment combinations showed significant effect on soil bulk density as observed from table 28. Soil bulk density values ranged from 1.34-1.47 g cm^{-3} in various intercropping treatments with no specific trend. The soil bulk density in sole coconut plots (1.52 g cm^{-3}) was significantly higher than all the intercropped plots. This could be due to the dense root system of intercropped fodder trees which increased the porosity of the soil. Gunesena *et al*. (1991) also reported that by growing gliricidia and leucaena, soil bulk density was reduced in clay soil compared to the control. Varsha (2015) also reported lower bulk density in soils under high density mulberry fodder banks owing to the deep and dense rooting pattern of mulberry which improved the porosity and lowered bulk density in the soil.

5.7.1.3 Water holding capacity

Table 27 depicts the main effect of tree density and harvest interval on water holding capacity of soil. On comparing the fodder trees, significantly higher water holding capacity (WHC) was observed in mulberry plots (53.96 %) than that of subabul (50.84%), the reasons for which are not clear. However, tree density and harvest interval had no significant effect WHC of soil.

5.7.2 Soil nutrient status

5.7.2.1 Total nitrogen concentration in soil

The main effect of fodder trees, tree density as well as harvest interval showed no significant effect on the total nitrogen concentration in the soil (Table 29). However, the combined effect of these management practises on fodder trees had significant effect on N concentration (Table 30) which ranged from 0.103 to 0.149 per cent with no specific trend. However, sole coconut plots (0.098%) had comparatively lower total nitrogen concentration in soil when compared to all the intercropped plots. This could be due to the nitrogen fertilization in the intercropped plots.

5.7.2.2 Available nitrogen content in soil

As depicted in table 31, fodder tree species and tree density had no significant effect on the available nitrogen content in the soil. On the contrary, harvest interval had significant effect on the available nitrogen content in soil and the highest value (203.76 kg ha^{-1}) was recorded in the 12 weeks harvest interval.

The combined effect of various treatments on the available nitrogen content in soil is given in table 32. Highest available soil nitrogen was recorded in mulberry (267.07 kg ha^{-1}) at medium tree density and 12 weeks harvest interval. In subabul, the maximum available nitrogen content in soil was observed in the similar management practices. This implies that under very high tree densities the uptake of nitrogen is much higher due to higher plant population there by resulting in nitrogen depletion in soil, whereas under low densities the trees are widely spaced and nutrient losses from exposed soil is much higher. The available nitrogen in the sole coconut (163.03 kg ha^{-1}) plots was comparatively lower than most of the intercropped plots which might be due to the nitrogen fertilization in intercropped plots.

5.7.2.3 Available phosphorous content in soil

The main effect of fodder trees, tree density and harvest interval on available phosphorous in the soil is given in table 31. All these factors had no significant influence in available phosphorus content in soil. On comparing different treatment combinations (Table 32) the P content in soil ranged from 5.3 to 30.75 kg ha^{-1} in various intercropped plots in 40 cm depth of soil with no specific trend. However all the intercropped plots have higher P content in soils when compared to the coconut monoculture plots (4.32 kg ha^{-1}), which could be attributed to the phosphorus fertilization in intercropped plots.

5.7.2.4 Available potassium content in soil

The data given in table 31 shows that, the fodder tree species, tree density and harvest interval had no significant effect on the available potassium content in soil. The combined effect of tree density and harvest interval showed significant effect on available potassium content in soil (Table 32) and values ranged from 61.75 to 220.79 kg ha^{-1} in the top layer. Whereas, the soil in the coconut sole plots had K content of

195.78 kg ha^{-1} in the respective layer. In general, no noticeable trend could be observed in potassium content of soil due to intercropping practises.

In general, the results indicated that there is an enhancement in the soil nutrient status due to fodder tree intercropping in coconut plantation. This is mainly due to the nutrient supplementation through manures and fertilizers, mineralization of litter, deep and dense rooting by trees that reduces leaching and runoff losses of nutrients through soil binding. However, the soil phosphorus content in intercropped plot is found to be much higher indicating the accumulation of phosphorus over the period of time. Hence it is observed that annual application of phosphorus is not needed due to low uptake of P by plants in comparison to N and K.

Stand management practices like density and harvest interval also influenced the soil nutrient levels. In general plots with medium tree density and harvest interval of 12 weeks had higher soil nutrient content when compared to higher or lower levels. Hence, higher plant densities should be adopted only with additional nutrient supplementation to avoid competition with main crop coconut.

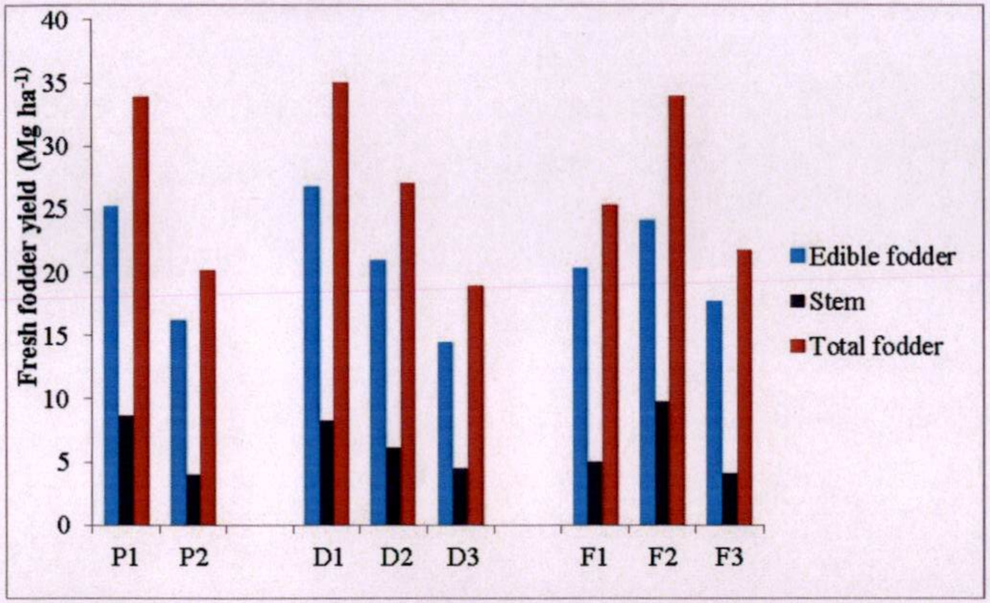
5.8 ECONOMICS OF FODDER PRODUCTION IN COCONUT PLANTATION

Table 33 depicts the economics and B:C ratio of fodder production as influenced by tree density and harvest interval of fodder trees in coconut plantation over three year period. Comparing fodder tree species, significantly higher B: C ratio was obtained by intercropping mulberry (2.94) than subabul (2.54) in coconut garden. This could be due to higher forage yields from mulberry than that of subabul under similar management practises. Management practices like tree density and harvest interval also showed

significant effect on B:C ratio. B:C ratio showed an increasing trend (2.26 to 3.05) from lower to higher density classes. The highest B:C ratio (3.07) was obtained from 12 weeks harvest interval followed by 16 weeks and then 8weeks. Similar findings were also reported by Joy (2017) and Sagaran (2017) with respects to calliandra intercropping in coconut garden.

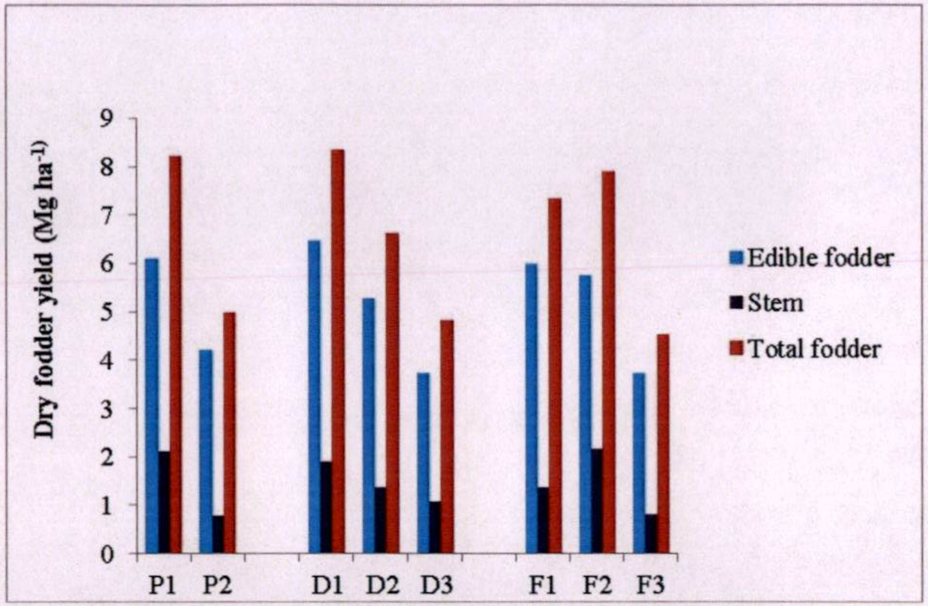
The combined effect of various treatments showed significant effect on the economics of mulberry and subabul intercropped in coconut plantation (Table 34). The highest fodder production over three year period (171.31 Mg ha^{-1}) and B:C ratio (3.99) was in mulberry at the highest tree density (49,382 plants ha^{-1}) and 12 weeks harvest interval. Whereas in subabul, the maximum fodder production (135.58 Mg ha^{-1}) and B: C ratio (3.60) was observed at medium tree density (37037 plants ha^{-1}) and 16 weeks harvest interval and was on par with that of the highest density stands with 12 weeks and 16 weeks interval. The results thus indicate that high density fodder tree integration underneath coconut plantation with proper harvest management is an economically viable option for boosting fodder production in Kerala.

Hence to conclude, the present field study clearly demonstrates that, in the wake of acute fodder and crude protein deficit in the livestock farms of Kerala, the cultivation of fodder trees like mulberry and subabul in the vacant interspaces of coconut gardens is a promising strategy for enhancing quality forage production, thereby providing more net returns to the farmer by saving huge expenses towards concentrate feeds purchase. In addition, adoption of ideal stand management practices can further elevate the forage productivity in land limited conditions of Kerala. Based on the present study, establishment of fodder tree banks with a higher density of 49,382 plants ha^{-1} and scheduling fodder harvests at an interval of 12 weeks generated higher edible fodder biomass than other management options. Most of the intercropping practices showed no detrimental effect on coconut productivity, except for a slight decline in the case of palms under high density mulberry stands. Nutrient uptake studies also point out the higher extraction of nutrients by the densely populated stands, especially that of mulberry, which can lead to soil nutrient depletion in the long run. This reiterates the need for the adoption of proper crop specific nutrient and irrigation management to prevent any possible competition with the main crop coconut, which warrants further research. The study also revealed that, apart from fodder production, the intercropped fodder trees have fixed more carbon to a maximum of 33 Mg ha^{-1} in the plant biomass and in soil up to 40 cm depth, when compared to coconut monoculture systems, thereby making considerable contribution for reducing atmospheric carbon dioxide levels to minimize global warming. Moreover, intercropping practices in coconut have overall improved the fertility status of the soil when compared to coconut monoculture systems.



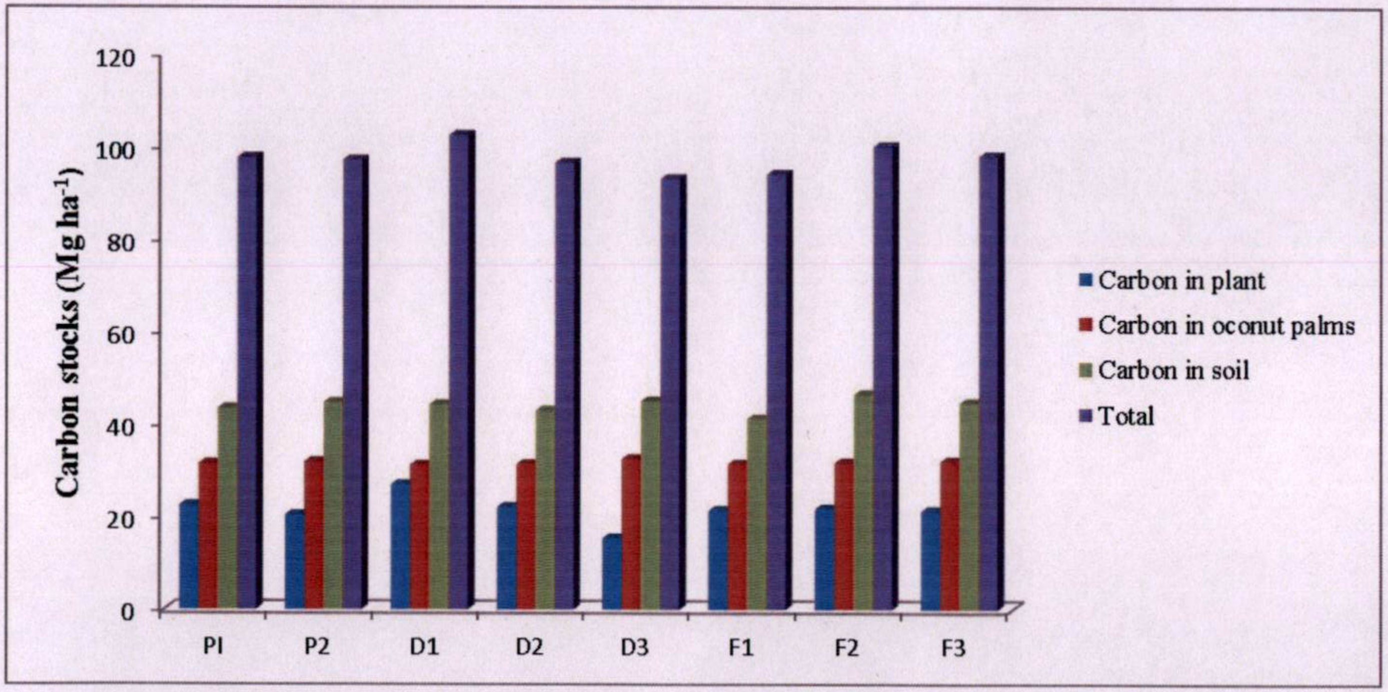
P1- Mulberry D1, D2 & D3- 49,383; 37,077 & 27,777 plants ha^{-1}
P2- Subabul F1, F2 & F3 - 8,12 & 16 weeks harvest interval

Fig 3. Annual fresh fodder yield from three-year-old mulberry and subabul under coconut plantation



P1- Mulberry D1, D2 & D3- 49,383; 37,077 & 27,777 plants ha^{-1}
P2- Subabul F1, F2 & F3 - 8,12 & 16 weeks harvest interval

Fig 4. Annual dry fodder yield from three-year-old mulberry and subabul under coconut plantation



P1- Mulberry, P2- Subabul | D1, D2 & D3- 49,383; 37,077 & 27,777 plants ha^{-1}
F1, F2 & F3 - 8,12 & 16 weeks harvest interval

Fig 5. Carbon stocks in various components of coconut-fodder tree integrated system, Vellanikkara, Kerala.

Summary

SUMMARY

The present investigation on "Productivity, carbon and nutrient stocks in mulberry (*Morus indica* L.) and subabul (*Leucaena leucocephala* Lam.) based high density fodder production system in coconut" was conducted at Instructional farm, College of Horticulture, Vellanikkara during 2017-18, to evaluate the influence of tree density and harvest interval on forage yield and carbon stocks of three- year- old mulberry and subabul fodder banks in coconut garden. The study also examined the variation in coconut productivity and soil fertility changes associated with intercropping these fodder trees in coconut plantations.

Salient findings of the study are summarized hereunder:

1. Mulberry had significantly higher survival percentage (86.82%) as compared to subabul (72.37%) in coconut plantation. However, management factors like tree density and harvest interval had no significant influence on the survival percentage of these fodder trees.

2. Annual fresh fodder yield from fodder tree banks per hectare of coconut garden in the third year of intercropping also showed significant variation between the tree species. Total forage yield from mulberry was significantly higher (33.93 Mg ha^{-1} yr^{-1}) than that of subabul (20.14 Mg ha^{-1} yr^{-1}). Edible forage (leaves + green stem) and dry forage yields also followed similar trend.

3. Density management of fodder trees also had significant effect on forage yields. Annual fresh forage yield of trees per hectare of coconut garden increased from 18.97 Mg at low tree density (27,777 plants ha^{-1}) to 35.04 Mg at the highest tree density (49,382 plants ha^{-1}). The total dry fodder biomass also followed the similar trend.

4. Harvest interval also showed significant effect on forage yield. The edible (24.17 Mg ha^{-1} yr^{-1}) as well as total (33.98 Mg ha^{-1} yr^{-1}) forage yield was higher for trees at medium harvest interval of 12 weeks than longer or shorter intervals. The total dry fodder biomass was also found maximum in 12 weeks interval.

5. Comparing the cumulative effects of stand management practices like density and harvest interval, forage yields of mulberry and subabul stands underneath coconut plantation ranged from 16.40 to 63.38 and 9.33 to 30.96 Mg ha^{-1} yr^{-1} respectively under various management levels. This indicates the critical role of management factors for maximizing productivity from fodder tree banks. Maximum yield was obtained from the highest density stand (49,382 plants ha^{-1}) and at medium harvest interval of 12 weeks.

6. In general, fodder tree intercropping and various management regimes showed no significant influence on coconut productivity. However, a slight decrease in nut yield was observed under very high fodder tree density (49,382 plants ha^{-1}), there by pointing out the need for additional nutrient and moisture supplementation to prevent competition and yield loss in coconut.

7. Intercropping of fodder trees and various management practices resulted in significant improvement in total biomass production and carbon storage potential of coconut plantations. In general, mulberry fodder banks accumulated total biomass of 41.82 Mg with carbon stocks of 22.56 Mg per hectare of coconut garden and were comparable with that of subabul. Significantly higher carbon capture (26.97 Mg ha^{-1}) was observed in the highest tree density when compared to the lowest one (15.44 Mg ha^{-1}). Harvesting at a medium interval of 12 weeks yielded the maximum dry fodder over three year period with carbon stocks of 14. Mg ha^{-1} and was significantly higher than longer or shorter interval of 16 and 8 weeks.

8. In general, carbon capture in fodder trees under different management regimes (11.84- 32.85 Mg ha^{-1}) was found to be considerably higher than that of the understorey grass vegetation of sole coconut palms (0.76 Mg ha^{-1}).

9. Fodder trees as well as the management regimes like tree density and harvest interval showed significant effect on the total aboveground carbon stocks in coconut palms. Subabul intercropped coconut palms (31.92 Mg ha^{-1}) had higher carbon stocks than that of mulberry (31.60 Mg ha^{-1}). Palms recorded higher

carbon stocks (32.58 Mg ha^{-1}) when intercropped with lower fodder tree densities (27,777 plants ha^{-1}) compared to higher levels. Similarly, adoption of longer pruning intervals of 16 weeks (32.04 Mg ha^{-1}) produced higher carbon stocks than the shorter intervals. This indicates that adoption of extremely high densities and frequent pruning of fodder trees, which depletes the soil resources, can initiate competition with coconut as indicated by the lower growth rate of coconut and carbon accretion in the long run.

10. Different fodder tree species and various management practices had no significant effect on the soil carbon content. In general, soils under subabul had slightly higher carbon content (0.80%) and stocks (44.76 Mg ha^{-1}) than that of mulberry (0.79%). However, the sole coconut plots (0.69%) had comparatively lower carbon percentage than most of the intercropped plots. Similar trend was also followed in the case of soil carbon stocks.

11. Total carbon storage potential of mulberry and subabul intercropping in coconut garden increased from the lowest tree density of 27,777 plants ha^{-1} to the highest tree density of 49,382 plants ha^{-1} (93.14 Mg ha^{-1} to 102.55 Mg ha^{-1} respectively). The highest carbon storage potential of the system (100.10 Mg ha^{-1}) was observed in the harvest interval of 12 weeks, followed by 16 weeks and 8 weeks interval. On comparing the intercropped and coconut monoculture systems, all fodder tree intercropping systems at different management levels (82.70-108.48 Mg ha^{-1}) had higher carbon capture than coconut monoculture system (75.35 Mg ha^{-1}). The carbon stocks in the contiguous open areas with grass vegetation were substantially lower (34.43 Mg ha^{-1}) when compared to the coconut monoculture and intercropping systems.

12. Significant difference was observed in nutrient uptake by the two fodder tree species, tree density and harvest schedule. N, P and K uptake was found to be significantly higher for mulberry (70.77, 4.80 and 38.22 kg ha^{-1}) than that of subabul (51.62, 2.97 and 24.45 kg ha^{-1}). N, P and K uptake enhanced by 81, 113 and 96 per cent from lower to higher densities. The nutrient uptake was higher in the medium interval of 12 weeks when compared to shorter or longer intervals.

13. Fodder trees and tree density had significant effect on soil pH in mulberry and subabul plots intercropped in coconut plantation. Soil pH was observed higher in subabul (4.84) than mulberry (4.58). Highest pH (4.92) was obtained from the lowest tree density (27,777 plants ha^{-1}) when compared to other densities. The mean soil pH of sole coconut plots were comparatively lower (4.64) than most of intercropped plots.

14. Fodder trees as well as various management regimes had no significant influence on bulk density of soil. Bulk density values ranged from 1.34-1.47 g cm^{-3} in various intercropping treatments with no specific trend. The soil bulk density in sole coconut plots and contiguous open areas was 1.52 and 1.38 g cm^{-3} respectively.

15. On comparing the fodder trees, significantly higher water holding capacity (WHC) was observed in mulberry plots (53.96 %) than that of subabul (50.84%). However, tree density and harvest interval had no significant effect on WHC of soil.

16. Total N concentration of soil in various intercropped plots ranged from 0.103 to 0.149 per cent with no specific trend. However, sole coconut plots (0.098%) had comparatively lower total nitrogen concentration in soil when compared to all the intercropped plots. The fodder trees and tree density had no significant effect on the available nitrogen content in the soil. On the contrary, harvest interval had significant effect on the available nitrogen content in soil and the highest value (203.76 kg ha^{-1}) was recorded in the 12 weeks harvest interval. The available nitrogen in the sole coconut (163.03 kg ha^{-1}) plots was comparatively lower than most of the intercropped plots.

17. The fodder trees, tree density as well as harvest interval had no significant effect on available phosphorous in the soil. The P content in soil ranged from 5.3 to 30.75 kg ha^{-1} in various intercropped plots with no specific trend. However all the intercropped plots have higher P content in soils when compared to the coconut monoculture plots (4.32 kg ha^{-1}).

18. In general, no noticeable trend could be observed in potassium content of soil due to intercropping practices in coconut plantation.

19. Comparing the economics of fodder tree cultivation and management practices in coconut, significantly higher B: C ratio was obtained by intercropping mulberry (2.94) than subabul (2.54). B: C ratio showed an increasing trend (2.26 to 3.05) from lower to higher density classes. The highest B: C ratio (3.07) was obtained from 12 weeks harvest interval followed by 16 weeks and then 8 weeks. Comparing all the systems, the highest fodder production over three year period (171.31 Mg ha^{-1}) and B: C ratio (3.99) was in mulberry at the highest tree density (49,382 plants ha^{-1}) and 12 weeks harvest interval.

Hence, to summarize, the present field investigation clearly indicates the possibility of integrating mulberry and subabul fodder banks in coconut gardens of Kerala to enhance quality forage production, so as to minimize farmer's expenses on feed cost. In addition, adoption of ideal stand management practices viz., tree density of 49,382 plants ha^{-1} and scheduling fodder harvests at interval of 12 weeks, can generate higher edible fodder biomass than other management options. However, adoption of higher tree densities and frequent harvesting should be followed with crop specific nutrient and moisture supplementation, especially for mulberry, to avoid any possible competition and yield loss in coconut. The study also revealed that, apart from fodder production, the intercropped fodder trees have fixed more carbon to a maximum of 33 Mg ha^{-1} in the plant biomass and in soil up to 40 cm depth, when compared to coconut monoculture systems, thereby making considerable contribution for reducing atmospheric carbon dioxide levels to minimize global warming. Thus, establishment and proper management of mulberry and subabul fodder banks in coconut garden is a low cost technology to enhance quality forage production in humid tropics, and a promising strategy for climate change mitigation via carbon sequestration.

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Abstract

PRODUCTIVITY, CARBON AND NUTRIENT STOCKS IN MULBERRY (*Morus indica* L.) AND SUBABUL (*Leucaena leucocephala* Lam.) BASED HIGH DENSITY FODDER PRODUCTION SYSTEM IN COCONUT

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ABSTRACT OF THE THESIS

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ABSTRACT

The research programme entitled "Productivity, carbon and nutrient stocks in mulberry (*Morus indica* L.) and subabul (*Leucaena leucocephala* Lam.) based high density fodder production system in coconut", was conducted at Instructional farm, College of Horticulture, Vellanikkara during 2017-18, to evaluate the influence of tree density and harvest interval on forage yield, carbon and nutrient stocks of three- years- old mulberry and subabul fodder banks in coconut garden. The study also examined the variation in coconut productivity and soil fertility changes associated with fodder bank integration in coconut plantations. The treatments included intercropping of fodder tree species like mulberry and subabul at three levels of tree densities (49,382; 37,037 and 27, 777 plants ha^{-1}) and three levels of harvest intervals (8, 12 and 16 weeks) in all possible combinations with randomized block design replicated thrice.

The study indicated that annual fresh fodder yield from fodder tree banks per hectare of coconut garden in the third year of intercropping was significantly higher in mulberry (33.93 Mg ha^{-1} yr^{-1}) than that of subabul (20.14 Mg ha^{-1} yr^{-1}). Forage yields of tree banks increased from 18.97 to 35.04 Mg $ha^{-1}yr^{-1}$ from lower to higher density classes, and were also found to be higher (33.98 Mg ha^{-1} yr^{-1}) for medium harvest interval of 12 weeks than longer or shorter intervals. Comparing the cumulative effects of stand management practices, forage yields of mulberry and subabul stands showed drastic variation which ranged from 16.40 to 63.38 and 9.33 to 30.96 Mg ha^{-1} yr^{-1} respectively under various management levels, there by indicating the critical role of proper management for productivity enhancement from tree fodder banks. Maximum yield was obtained from the highest density stand (49,382 plants ha^{-1}) and at medium harvest interval of 12 weeks in both the tree species.

In general, fodder tree intercropping and various management regimes showed no significant influence on coconut productivity. However, a slight decrease in nut yield was observed under very high fodder tree density (49,382 plants ha^{-1}), especially with that of mulberry, there by pointing out the need for crop specific

nutrient and moisture supplementation to prevent competition and yield loss in coconut under high density intercropping.

Intercropping of fodder trees and various management practices resulted in significant enhancement in total biomass production and carbon storage potential of coconut plantations (82.70-108.48 Mg ha^{-1}) than that of coconut monoculture system (75.35 Mg ha^{-1}). The intercropped fodder trees have fixed additional carbon to a maximum of 33 Mg ha^{-1} in the plant biomass and in soil up to 40 cm depth, thereby making considerable contribution for reducing atmospheric carbon dioxide levels.

Significant difference was observed in nutrient uptake by the two fodder tree species, tree density and harvest schedule. N, P and K uptake was found to be significantly higher for mulberry (70.77, 4.80 and 38.22 kg ha^{-1}) than that of subabul (51.62, 2.97 and 24.45 kg ha^{-1}). N, P and K uptake enhanced by 81, 113 and 96 per cent from lower to higher densities. The nutrient uptake was higher in the medium interval of 12 weeks when compared to shorter or longer intervals. In general, intercropping practices in coconut have overall improved the fertility status of soil compared to coconut monoculture. However, proper nutrient supplementation should be ensured while adopting very high tree densities to avoid any possible competition with coconut palms.

Fodder tree species and tree density had significant effect on soil properties like pH and water holding capacity (WHC) in mulberry and subabul plots intercropped in coconut plantation. Soil pH was observed higher in subabul (4.84) than mulberry (4.58). Water holding capacity (WHC) was observed higher in mulberry plots (53.96 %) than that of subabul (50.84%).

Comparing the economics of tree fodder integration in coconut garden, significantly higher B: C ratio was obtained from mulberry (2.94) than subabul (2.54). B: C ratio showed an increasing trend (2.26 to 3.05) from lower to higher density classes. The highest B: C ratio (3.07) was obtained from 12 weeks harvest interval.

Hence, the present field study clearly demonstrates the possibility of integrating mulberry and subabul fodder banks in coconut gardens of Kerala to enhance quality forage production, so as to minimize farmer's expenses on feed cost. Adoption of ideal stand management practices viz., tree density of 49,382 plants ha^{-1} and 12 weeks harvest interval, can generate higher forage yields from limited land area. Moreover, the intercropped fodder trees have fixed additional carbon to a maximum of 33 Mg ha^{-1}, thereby making considerable contribution for reducing atmospheric CO_2 levels to minimize global warming. Thus, establishment and proper management of mulberry and subabul fodder banks in coconut garden is a low cost technology to enhance quality forage production in humid tropics, and a promising strategy for climate change mitigation via carbon sequestration.