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Fodder production and carbon stock of calliandra under coconut plantation

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Abstract
The influence of management factors like tree densities and pruning intervals on forage yield and carbon stocks of three-year old calliandra hedgerows underneath coconut plantation indicated significant enhancement in forage and coconut yields and carbon fixation due to calliandra intercropping and management practices. Intercropping calliandra with tree density of 27,777 trees ha^{-1} and harvesting fodder at an interval of 12 weeks yielded maximum dry forage of 35.16 Mg ha^{-1}, apart from an additional carbon capture of 90 Mg ha^{-1} against coconut monoculture, over three-year period. High density calliandra cultivation also had favourable impact on coconut productivity. Establishment and management of such fodder banks in the unutilized interspaces of existing coconut gardens is a promising practice to enhance quality forage production and carbon sequestration in land crunch humid tropical areas.

Keywords: Calliandra, Carbon stocks, Coconut, Forage yield, Pruning interval, Tree density

Introduction
Since time immemorial, livestock rearing has been an integral part of global rural economy. The increasing demand for livestock products in developing countries in the coming two decades offers vast opportunities to poor livestock farmers to increase their income from livestock farming (Hall *et al*., 2007). However, scarcity of good quality feed and fodder is the major obstacle for livestock production, especially during the dry periods in the tropics (Ogunbosoye and Babayemi, 2010). In India, there is a shortage of 40.4% dry fodder and 24.7% green fodder (Mathukia *et al*., 2016). The forage tree species contain appreciable amounts of nutrients that are lacking in other feeds such as grasses during dry periods due to extraction of water and nutrients from deeper soil horizons (Aregawi *et al*., 2008). In addition, forage based economical feeding strategies can reduce the cost of livestock production as the feed alone comprises 60-70% of the total milk production cost (IGFRI, 2015). Trees and shrubs can play a significant role not only in improving fodder production but also providing assured supply of fodder throughout the year (Singh and Singh, 2017).

Calliandra (*Calliandra calothyrsus* Meissn.), a native of Central America, is a fast growing, multipurpose leguminous tree, grown primarily for forage. The high palatability of calliandra to various livestock, including cattle, goats, sheep, rabbits and chickens has been reported earlier (Roothaert *et al.,* 1998; Franzel *et al.,* 2003; Nyeko *et al.,* 2004). Studies conducted in milch cows of Kerala also confirmed the nutritional superiority of calliandra with relatively high protein (18.45 %), minerals, ether extract and energy contents and suitability as a partial substitute for concentrate feeds without affecting animal health and productivity (Jayaprakash, 2016). Moreover, calliandra is a proficient coppicer and can withstand severe pruning, which makes it an ideal species for high density hedgerow planting. The trees grow well in the areas with rainfall exceeding 1100 mm (Roothaert and Paterson, 1997). The tolerance of calliandra to acid soils has also encouraged its use as fodder tree in the humid tropics (Berhe and Mohamed-Saleem, 1996; Palmer *et al.,* 1989). However, due to high demographic pressure and consequent land constraints in tropical areas, the scope for growing calliandra as a monocrop in open lands is rather limited. Only alternative is to integrate calliandra with the existing cropping systems in these areas. Coconut, being one of the most prominent plantation crop in the world stretching over an area of 122 lakh ha (APCC, 2015), any attempt to integrate forage trees like calliandra with coconut would be a desirable strategy for profitable animal rearing.

While integrating calliandra with coconut, hedgerow planting of trees with higher tree densities and harvesting at optimum interval are the possible management options for enhancing productivity from limited land area. Moreover, calliandra being a tree species with fast growth and extensive deep rooting system, as the age advances, interaction within the species as well as with the main crop coconut, leads to either complementary or competitive effects and ultimately influences the yield of both the trees. Moreover, adoption of recurrent pruning over years may have a detrimental effect on tree health and longevity. Hence, a sound understanding of the long-term effects of tree density and pruning frequency on tree growth and regrowth, yield and longevity of calliandra, as well as its effect on coconut yield is important in determining sustainable production strategies for the fodder production system. In addition to fodder production, the integration of fodder trees in agricultural farms offers multiple ecosystem services like carbon storage and associated climate change mitigation. Cultivation of trees outside conventional forests has been an accepted strategy to meet the targeted carbon emission reduction commitments by the country. Fast growing trees are reported to have higher carbon capture efficiency owing to their enormous growth potential and the ability to produce large quantum of biomass within short periods (Rocha, 2017). Carbon accretion by trees being a function of their biomass production, stand management practices like density regulation and harvest schedules may also influence the carbon fixation rates. However, carbon dynamics of tree fodder banks is one of the promising, but least studied ecological service of agroforestry systems. In this context, a comprehensive field study was conducted to assess the influence of stand management practices like tree density and pruning interval on forage yield, coconut yield and carbon stocks of three-year old calliandra hedgerows underneath coconut plantation in comparison with coconut monoculture systems.

Materials and Methods

***Study site*:** The study was conducted in an existing field trial with calliandra intercropped in mature coconut plantation (7.6 x 7.6 m spacing), established during 2014, at Instructional Farm, College of Horticulture, Vellanikkara, Thrissur, India (10^{o} 33'04.9" N latitude; 76^{o} 18'03.1" E longitude; and 40.29 m altitude; Sagaran *et al*., 2018). The site experiences a warm humid climate and is benefited both by the southwest and north-east monsoons, with a greater share from southwest monsoon. The mean maximum temperature ranged from 29.8 to 36.1^{0} C in the months of June and March, respectively. While the mean minimum temperature varied from 21.6 to 26.2^{0} C in the months of July and April, respectively. The soil of experimental site was deep well drained sandy clay loam of Ultisol order. Soil tests of the experimental site indicated acidic soil reaction (pH: 5.5), with medium levels of organic carbon (1.2%), available nitrogen (0.16 g kg^{-1}), exchangeable potassium (0.11 g kg^{-1}) and low level of phosphorus (3.39 mg kg^{-1}) (Sagaran *et al*., 2018).

***Field culture*:** The fodder tree, Calliandra (*Calliandra calothyrsus* Meissn) was intercropped under varying management practices, in the interspaces of coconut (variety- west coast tall; age 35 years; spacing of 7.6 x 7.6 m), during the year 2014.The calliandra was intercropped in coconut plantations under three levels of tree density (27,777; 22,222 and 17,777 plants ha^{-1}) and three levels of pruning interval (8, 12 and 16 weeks) in all possible combinations in factorial randomized block design replicated thrice. The field area (excluding coconut basin of 2 m radius) was ploughed and the layout was done allocating a plot size of 4 m x 3 m (12 m^{2}) for each treatment. Pits were taken at prescribed spacing for each treatment and seedlings of 3-month-old calliandra were transplanted to the main field with the onset of pre-monsoon showers. Blanket application of 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 done for all treatments. FYM was applied as a basal dose before the onset of south west monsoon. Fertilizers were applied through N: P: K mixture (18: 18: 18) in two split doses before onset of south west and north-east monsoons.Plants were weeded regularly and irrigated at weekly intervals during summer.

***Dry fodder biomass production*:** All plants were cut uniformlly at one meter height in June 2014. 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. The trees were harvested leaving a stubble height of 1m.

Fodder biomass from 5 trees/ plot avoiding border plants was recorded at each harvest. Biomass was separated into leaf, edible green stem and inedible brown stem and their individual fresh weights and total biomass was determined. Thereafter, forage yield from all harvests over an year was pooled to get annual yields and using the net harvested area and fresh weight, annual green fodder yield was scaled to the area of calliandra under one-hectare coconut garden (7827 sq. m), excluding the functional area of coconut palms, in a radius of 2 m around its basin. The yield observations were collected for three years from June 2014 to 2017. Triplicate samples of leaf and stem fractions from each harvest of calliandra were oven dried at 70^0C for 48 hours for dry matter (DM) determination. The fresh fodder yields from each harvest were multiplied with dry matter content and summed up to get annual dry fodder yield per hectare. The edible forage yield of calliandra was estimated by summing up the yields of leaf and green stem fraction of calliandra.

Coconut productivity**:** Annual nut yield from coconut during the third year of intercropping, and the number of nuts of various size classes now existing in the palms were estimated to study the influence of intercropping calliandra and various management regimes on coconut productivity. During the third year of the experiment, both the intercropped and monoculture coconut palms were harvested at bimonthly intervals and the yields from six harvests were summed up to get the annual yields and expressed on hectare basis. At the end of the experiment, the intercropped palms and the sole coconut palms were climbed to count the number of nuts in each developing bunch (9-10 bunches per palm) and the nut count was scaled to hectare basis.

Above ground biomass and root biomass of callliandra**:** The harvested fodder biomass from calliandra over three year period and the left over woody stem and root biomass at the end of the third year were estimated to calculate the carbon stocks in calliandra during the three year intercropping period. The annual dry fodder yield obtained from verious treatment plots of calliandra during three years were pooled and scaled to hectare basis. At the end of the third year, left over woody stem samples were collected destructively from the centre zone of each plot using a quadrat of 1 m^2 area and their fresh weight determined. The soil below the quadrats used for taking above ground observation was excavated to pull out the roots completely, thoroughly washed to remove the soil and root fresh weight was determined. Then triplicate samples of root and woody stem were taken for DM determination and dry stem and root biomass of calliandra for various treatments were estimated and expressed on hectare basis.

Carbon stocks in the whole plant biomass of calliandra**:** The oven dried plant samples (leaves, stem and roots fractions of fodder trees) were ground thoroughly and used for analyzing the organic carbon (OC) concentration in the various tissue types, by using the loss-on-ignition method in muffle furnace (Gaur, 1975), and using the allometric equation OC (%) = (100 - Ash %) × 0.58 (Allen *et al*., 1986). The carbon content in the individual tissue types were multiplied with the corresponding component dry biomass (Nair *et al*., 2010) and summed up to calculate the overall plant carbon stocks of various treatments. This was also computed on hectare basis.

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

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

The bole dry weight of a palm was estimated by multiplying the volume of the bole with the density.The average density of the coconut bole (variety: west coast tall, aged 37 years) was estimated destructively and was found to be 509.60 kg m^{-3} (George, 2017). 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 quarter girth formula (the shape of the coconut stem was assumed to be cylindrical). Dry weight of total fronds per palm was estimated by using the actual dry weight of the most mature frond and the crown leaf load (Navarro *et al*., 2008). The carbon content of the dry mass was assumed to be 0.5 g C g DM^{-1} (Matthews, 1993; Navarro *et al*., 2008). The total carbon stock per hectare was determined by extrapolating the stock per palm for 173 palms.

Soil carbon stocks**:** The soil sampling was done from the same 1 m^2 quadrat area that was taken for recording plant observations. The soil below the quadrats was excavated to 1 m depth, and soil samples were collected from five soil depths (0-20 cm, 21-40 cm, 41-60 cm, 61-80 cm and 81-100 cm) from each plot. A total of 27 soil profile pits were excavated for taking soil samples of 9 treatments. Triplicate samples were collected from different depths, with sample size in proportion to their area and mixed to get the composite sample. Sub sample from the composite sample were used for carbon analysis by using Walkley and Black's permanganate oxidation method (Walkley and Black, 1934). Similarly, soil from control plots (sole coconut plantation) was collected for comparison.

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-content (%) (Anderson and Ingram, 1989). Soil carbon stocks in individual soil depths were summed up to get the overall soil carbon sequestration under various treatments.

Statistical analysis: The data were subjected to statistical analysis by analysis of variance (ANOVA) using general linear model procedure in SPSS version 21.0 (SPSS Inc., USA), to ascertain the significance of various parameters. All data were examined for homogeneity of variance and normality. The Duncan's Multiple Range Test (DMRT) was used to test the differences among treatment means at 5% significance level.

Results and Discussion

Dry fodder yield from calliandra: The dry edible forage (leaves + green stems) yield from intercropped calliandra per hectare of coconut garden over three-year period increased from 24.08 to 33.36 Mg/ha from lower to higher density classes, thereby indicating the necessity of closer planting of fodder trees for maximising forage production per unit area (Fig 1-2). Similar reports were given earlier by several researchers in leucaena, mulberry, sesbania, and calliandra (Ella *et al.,* 1989; El-Morsey, 2009; Raj, 2016; Sagaran *et al*., 2018). Higher yields under closer spacing could be due to dense canopy cover and root system that prevents weed growth and reduces evaporation and loss of nutrients from the soil surface, there by promoting better growth of plants (Erkan and Aydin, 2016).

In the case of pruning interval, the forage yield was significantly higher ($P<0.05$) from stands pruned at a medium interval of 12 weeks (31.38 Mg ha^{-1} yr^{-1}), followed by the longest interval of 16 weeks.Whereas in case of longer pruning intervals, the fodder biomass consists of woody stem which is non-palatable in nature, thereby reducing the forage fraction. Basavaraju and Rao (1995) obtained maximum herbage yields from calliandra at cutting interval of 60 days compared to higher intervals.

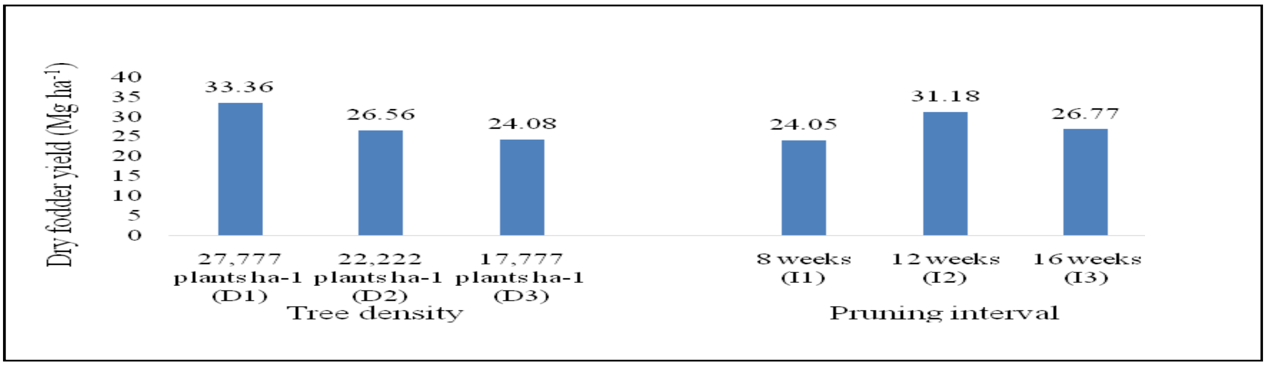

Fig 1. Effect of tree density and pruning interval on dry edible fodder biomass (leaves + green stems) of calliandra intercropped in coconut plantation over three year period

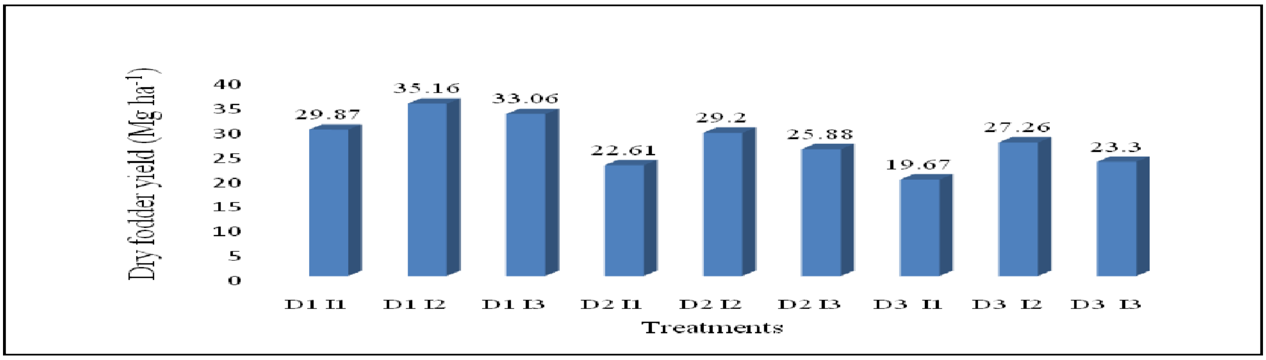

Fig 2. Interaction effect of tree density and pruning interval on dry edible fodder biomass (leaves + green stems) of calliandra intercropped in coconut plantation over three year period

Table 1. Effect of tree density and pruning interval on harvested fodder biomass, standing biomass and carbon stocks of calliandra over three- year period under coconut plantation

Treatments	*Total dry fodder biomass (Mg ha^{-1})	Carbon stocks in fodder (Mg ha^{-1})	Carbon content in standing biomass (Mg ha^{-1})					
			Dry standing biomass			Carbon content		
			Stump	Root	Total	Stump	Root	Total
Tree density								
27,777 plants ha^{-1} (D1)	46.51^{a}	25.81^{a}	10.77^{a}	1.25	12.02^{a}	6.18^{a}	0.71	6.88^{a}
22,222 plants ha^{-1} (D2)	37.17^{b}	20.63^{b}	9.28^{ab}	1.12	10.40^{ab}	5.32^{ab}	0.64	5.96^{ab}
17,777 plants ha^{-1} (D3)	34.35^{b}	19.05^{b}	7.81^{b}	1.01	8.83^{b}	4.48^{b}	0.57	5.05^{b}
P value	0.02	0.02	<0.05	0.29^{ns}	<0.05	<0.05	0.29 ^{ns}	<0.05
Pruning interval								
8 weeks (I1)	29.54^{b}	16.21^{c}	7.18^{b}	0.77^{b}	7.95^{b}	4.12^{b}	0.43^{b}	4.55^{b}
12 weeks (I2)	39.94^{a}	22.08^{b}	11.07^{a}	1.25^{a}	12.32^{a}	6.35^{a}	0.71^{a}	7.06^{a}
16 weeks (I3)	48.55^{a}	27.20^{a}	9.61^{a}	1.37^{a}	10.98^{a}	5.51^{a}	0.78^{a}	6.28^{a}
P value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

*Total dry fodder biomass includes leaves, edible green stems and non-edible brown stems
Values with the same superscripts in a column do not differ significantly

Table 2. Effect of tree density and pruning interval of intercropped calliandra on fractional and total carbon content (Mg ha^{-1}) of coconut palms

Factors	Fractional and total carbon content of coconut palms				
	Harvested nuts	Existing nuts in palms	Leaves	Bole	Total
Tree density					
27,777 plants ha^{-1} (D1)	0.080	1.88	3.10	28.31	33.37
22,222 plants ha^{-1} (D2)	0.079	1.94	3.05	27.99	33.06
17,777 plants ha^{-1} (D3)	0.079	1.87	3.08	28.28	33.30
F value	3.34^{ns}	0.63^{ns}	0.20^{ns}	0.32^{ns}	0.24^{ns}
P value	0.06	0.54	0.83	0.73	0.79
Pruning interval					
8 weeks (I1)	0.080	1.92	3.10	28.18	33.28
12 weeks (I2)	0.079	1.90	3.08	28.24	33.30
16 weeks (I3)	0.079	1.87	3.05	28.16	33.16
F value	2.85^{ns}	0.34^{ns}	0.20^{ns}	0.02^{ns}	0.05^{ns}
P value	0.09	0.72	0.83	0.98	0.95
Coconut monoculture	0.079	1.70	2.99	27.62	32.39
F value	0.15^{ns}	4.68*	1.14^{ns}	0.76^{ns}	1.57^{ns}
P value	>0.05	<0.05	>0.05	>0.05	>0.05

*Significant at P<0.05; ns= not significant at P>0.05; Values with the same superscripts in a column do not differ significantly

Coconut productivity: Calliandra intercropping and management practices had no significant effect on the harvested nut yield of intercropped and sole coconut palms in the third year. However, the count of existing nuts in coconut monoculture palms was significantly lower (15,454 nuts ha^{-1}) when compared to that of the coconut palms intercropped with calliandra trees (16,680-16,751 nuts ha^{-1}). The increment of coconut productivity in calliandra intercropped plots could be attributed to the nitrogen fixing nature of calliandra which could have provided a part of the nitrogen fixed to the component coconut. Other workers also reported that intercropping nitrogen fixing trees had no negative impact on the yield of coconut (Liyanage and Jayasundara 1987; Kumar, 2007). Moreover, since calliandra is regularly pruned, it remains as a lower layer and never interferes with the coconut canopy avoiding any vertical competition for above ground resources. It was also found that calliandra performed well under the partial shaded conditions of coconut. Hence, the results reiterate the scope for high density calliandra cultivation in coconut plantations and frequent harvesting of fodder with favourable effect on coconut yield, especially in the early years of cultivation.

***Plant biomass and carbon stocks from calliandra*:** The maximum harvested dry biomass (46.51 Mg ha^{-1}) (leaf + green edible stem + woody inedible stem) and C stocks in the harvested dry biomass (25.81 Mg ha^{-1}) were obtained from the highest density stand and significantly ($P<0.05$) higher when compared to the lower densities, D2 and D3 (Table 1). Tree density had significant effect on biomass and carbon stocks in stumps and roots. Similar results of enhanced C capture at closer spacing were reported earlier in *Pinus brutia* (Erkan and Eydin, 2016) and in mulberry fodder banks (Varsha, 2015).

Pruning interval also had prominent influence on the harvested biomass and corresponding C stocks. The highest fodder biomass (48.55 Mg ha^{-1}) and C stocks (27.20 Mg ha^{-1}) were recorded for the stands with the longest pruning interval of 16 weeks (Table 1). Highest carbon stocks in longest pruning interval could be attributed to higher dry matter production in stem fraction with advancing age. Maximum carbon content in stump and root standing biomass (6.35 and 0.71 Mg ha^{-1}, respectively) were obtained for 12 weeks pruning interval. Hence, the above results revealed the profound influence of density regulation and harvest management on carbon fixation rates of calliandra fodder banks.

***Carbon stocks in coconut palms*:** Carbon stocks in the coconut bole (27.99 to 28.31 Mg ha^{-1}), leaves (3.05 to 3.10 Mg ha^{-1}) and harvested nuts (0.079 Mg ha^{-1}) showed no significant variation due to calliandra intercropping and various management regimes (Table 2). However, the carbon stocks (1.87-1.94 Mg ha^{-1}) in the existing nuts of intercropped palms were higher when compared to that of the coconut monoculture (1.70 Mg ha^{-1}), which could be attributed to more nut production in intercropped trees when compared to that of coconut monoculture. This implied the possibility of introducing intercrops like calliandra with no negative effect on coconut growth and biomass production and the carbon storage potential. Similar findings were reported by Raveendra *et al.* (2017) where no significant differences were noticed in the carbon stocks of stem, nuts and leaves and overall biomass of coconut palms intercropped with either glyricidia or cocoa and coconut monoculture in Srilanka.

***Soil carbon stocks*:** Management practices in calliandra had significant impact on soil organic carbon content and stocks (68.80-131.84 Mg ha^{-1}) of coconut-calliandra intercropping system. Higher plant density (27,777 plants ha^{-1}) in combination with medium pruning interval (12 weeks) accumulated more carbon (131.84 Mg ha^{-1}) in the soil. High planting densities contribute more carbon to soil through litter fall and root turnover than lower densities. Litter production is a major process in the transfer of organic matter and nutrients from above-ground tree parts to the soil (Szott *et al.*, 1991). Comparing the intercropped and monoculture coconut systems, soils under coconut monoculture accumulated very less carbon (75.57 Mg ha^{-1}) than the best calliandra treatment of D1xI2 (131.84 Mg ha^{-1}).

***Carbon storage potential of the system*:** Tree density as well as pruning interval had significant influence on carbon storage potential of the system (Table 3). On comparing the interaction effects, the highest amount of carbon capture (199.19 Mg ha^{-1}) was observed in the combination of 27,777 plants ha^{-1} tree density and 12 weeks cutting interval and the lowest value (118.84 Mg ha^{-1}) was recorded for 17,777 plants ha^{-1} and 8 weeks cutting interval (Table 4). The carbon storage potential of

Table 3. Effect of tree density and pruning interval of calliandra on carbon storage (Mg ha^{-1}) potential of coconut-calliandra intercropping system

Factors	Components of coconut-fodder integrated system			
	Carbon in plant	Carbon in coconut palms	Carbon in soil	Total carbon
Tree density				
27,777 plants ha-1 (D1)	32.69^{a}	33.37	97.84^{b}	163.90^{a}
22,222 plants ha-1 (D2)	26.58^{b}	33.06	103.43^{a}	163.10^{a}
17,777 plants ha-1 (D3)	24.11^{b}	33.30	90.83^{c}	148.23^{b}
P value	0.01	0.79 ^{ns}	<0.001	<0.001
Pruning interval				
8 weeks (I1)	20.76^{b}	33.28	86.75^{c}	140.79^{c}
12 weeks (I2)	29.14^{a}	33.30	114.27^{a}	176.71^{a}
16 weeks (I3)	33.48^{a}	33.16	91.07^{b}	157.71^{b}
P value	<0.01	0.95 ^{ns}	<0.001	<0.001

ns= not significant at P>0.05; Values with the same superscripts in a column do not differ significantly

Table 4. Interaction effect of tree density and pruning interval of calliandra on carbon storage (Mg ha^{-1}) potential of coconut–calliandra intercropping system

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

Values with the same superscripts in a column do not differ significantly

sole coconut plantation was 108.73 Mg ha^{-1}.The best calliandra system was accumulated 90.46 Mg ha^{-1} more carbon than the coconut monoculture system over three-year period, out of which 56.27 Mg ha^{-1} (63%) was sequestered in the soil and 8.10 Mg ha^{-1} in woody stump and root (9%) which accounts for the permanent carbon, and 25.98 Mg ha^{-1} in fodder biomass (28%) representing the labile fraction. Raveendra *et al.* (2017) reported 138 Mg ha^{-1} total ecosystem carbon stock in coconut intercropped with glyricidia (1m x 1m spacing), when compared to 60 Mg ha^{-1} from coconut monoculture. Bhagya *et al.* (2017) reported carbon sequestration of 140.06 Mg ha^{-1} from coconut + jamun system when compared to 98.2 Mg ha^{-1} under coconut monocrop in Kerala.

Conclusion

Hence, this field study indicated substantial enhancement in quality forage yields and carbon capture, and improvement in coconut productivity by the integration of calliandra fodder banks underneath coconut plantation. Based on our results, establishment of calliandra fodder banks with tree density of 27,777 plants ha^{-1} and scheduling harvests at 12 weeks interval underneath coconut garden in humid tropical regions can be recommended to farmers to promote quality forage production. In addition, the intercropping practices can almost double the carbon fixation rates than in coconut monoculture systems.

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