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Management of tree fodder banks for quality forage production and carbon sequestration in humid tropical cropping systems – An overview

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ABSTRACT

Livestock forms an integral component of humid tropical cropping systems, providing food and financial security, employment, and insurance against crop failure for small scale farmers. However, livestock sector is seriously constrained by the drastic decline in fodder base and high cost of feeds, incurring huge economic loss to farmers. Hence fodder production should be intensified in cropping system by including alternate feeds like nutrient rich fodder trees and shrubs to supplement conventional fodder. Fodder trees serve as a potential source of quality green fodder to livestock especially during lean periods. Moreover, tree leaves can be cheaper feed supplements than the commercial concentrates and can easily be grown by the small-holder farmers. Leucaena, mulberry, kadamba, calliandra, agathi, moringa and gliricidia are promising fodder tress by virtue of their nutritive foliage, fast growing nature with higher biomass production, amenable to heavy pruning, good coppicing ability and easy management. Moreover, these trees can be grown in close hedgerows as fodder banks in integration with existing crops to maximize productivity in land crunch humid tropical areas. Enhancing tree cover in cropping systems also offers ecosystem services like enhanced carbon storage and associated global warming issues. Forage and nutrient yields, and carbon accretion can be substantially elevated and crop–tree competition can be minimized by appropriate stand management practices and proper regulation of overstorey and understorey components. Extensive studies conducted on tree fodder bank establishment, management and their productive and protective functions in humid tropical cropping systems of South India are reviewed in this paper.

Keywords: Carbon sequestration, Coconut Garden, Forage yield, Harvest interval, Homestead, Planting density, Tree fodder banks

Livestock production is a major means of livelihood and risk mitigation strategy for small and marginal farmers in humid tropical regions. They provide traction to plough fields, manure for crop nutrition and maintaining soil health, and food and nutritional security to people. The estimated doubling of demand for meat and milk in developing countries in the next two decades offers significant opportunities to poor livestock producers to increase their income from livestock farming (Hall *et al*. 2007). However, scarcity of quality fodder, high cost of commercial feeds and seasonal fluctuation in forage availability are the major deterrents that limit profitable livestock production in India. As per the reports of the Standing Committee on Agriculture 2016-17, the fodder deficit in India in terms of green fodder, dry fodder, and concentrates is expected to reach 40 MT, 23 MT, and 38 MT, respectively by 2025, which warrants immediate intervention. This gap in demand and supply may further rise due to consistent growth of livestock population in the coming years.

Majority of livestock farmers in humid tropical regions are small holders wherein the livestock are integrated with other cropping systems or in homesteads. Animal feeding is mainly dependent on forage availability in these areas, wherein animals are mainly stall-fed through cut and carry systems. However, the fodder base in many of the mixed farming systems in humid regions have reduced drastically in the recent decades due to intense population pressure on the land and associated fragmentation, change in cropping pattern, high cost of land, alternative options of land use and other socio-economic reasons. Due to poor fodder availability, the farmers rely on crop residues, local grasses and weeds, and other opportunistic feed with very poor nutritive value resulting in poor livestock diets and low animal productivity. During dry season, availability and quality of forage declines drastically affecting milk yields. Much of the crude protein requirement of animals is met from highly expensive commercial concentrate feeds which offsets farmer's profit to considerable extent. Hence, cultivation of quality fodder on farm itself is a pre-requisite for profitable livestock rearing, as feed alone constitutes 60-70% of the production cost (DARE 2013).

Fodder trees, with their nutrient rich leaves, constitute a potential source of quality green fodder to livestock

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especially during dry periods. The majority grass vegetation available in the dry season is poor in digestibility, protein as well as in overall nutrient content. Hence, introducing fodder trees in existing cropping systems is one of the promising ways for enhancing production of protein and nutrient rich fodder all-round the year, thereby saving farmer's expenses on purchased feeds. Humid tropical regions are characterized with hot and humid summers, and cold to mild winters. Monthly mean summer temperatures are normally between 24°C and 27°C with an annual rainfall more than 2800 mm, which are highly conducive for growth of trees. However, due to intensive cultivation of food crops in humid tropical regions, the scope for large scale tree fodder cultivation is limited. Hedgerow planting of fast-growing fodder trees in blocks with higher tree densities, known as ʹfodder banksʾ or ʹprotein banksʾ, in the available interspaces of existing crops is a possible option for enhancing productivity from limited land area. Maintaining fodder trees as hedges also regulates the possible competition between the component crops in the systems and facilitate easy harvesting of fodder.

In addition to fodder production, the integration of fodder trees in cropping systems offers ecosystem services like enhanced carbon storage and associated climate change mitigation. Global climate change caused by rising levels of carbon dioxide is a serious environmental issue of the 21st century. Between 2000 and 2010, the atmospheric CO_2 levels have increased from 369 to 388 ppm (5.1% increase) over the last 10 years let alone 280 ppm in 1850 (Tans *et al*. 2010). 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 *et al.* 2017). Hence, expansion of tree cover in cropping systems is recommended as a promising strategy for reducing atmospheric CO_2 levels.

Leucaena, moringa, mulberry, calliandra, sesbania, gliricidia, erythrina, and kadamba are some good fodder tree species suitable to be grown as fodder bank in humid regions (Raj *et al*. 2016, Patrick *et al.* 2020). Higher biomass productivity, nutritive value of forage and better survival of fodder tree hedges can be ensured through their optimum management involving judicious regulation of key factors such as tree density, cutting height, harvest interval, etc. which should be considered while establishing plantations. Moreover, carbon accretion by trees being a function of their biomass production, higher tree densities and harvest schedules may also influence the carbon fixation rates.

Why fodder trees?

Cultivation of trees has been recognized as one of the effective means for enhancing the production of quality forage in tropical smallholder livestock systems, especially during the summer period (Gutteridge and Shelton 1994). The greatest value of fodder trees lies in their role as diet supplements rich in protein, energy, minerals and vitamins. Fodder trees have almost double the amount of protein (18 to 25%) and high levels of essential elements such as calcium, sodium and sulphur as well as critical micronutrients such as iron and zinc when compared to fodder grass species, which can save farmers expenses on purchased concentrate feeds (Moleele 1998). Tree leaves are a rich source of supplementary protein, vitamins and minerals and their use in ruminants helps to enhance microbial growth and digestion (Cheema *et al.* 2011). Leguminous tree species are favoured than non-leguminous because of their high foliar protein content and ability to fix nitrogen (Gutteridge and Shelton 1994), which in turn enrich the soil nutrient content. Jamala *et al.* (2013) claimed that leguminous species contain 25 to 50% more crude protein than non-leguminous plants.

Trees require less management and care, and give consistent yield for a prolonged period. In a comparative study with various fodder legume trees and shrubs in Ghana, *Desmanthus virgatus* was among the low-yielding species and much less productive than *Gliricidia sepium*, *Calliandra calothyrsus* or *Cajanus cajan* (Barnes 1999). The growth pattern of various crops over two-year period reveals that trees require care during the establishment phase and once it is established, they show more persistence and the yield increases over the passage of time. However, herbaceous/shrub legumes require more careful tending throughout the crop growing period and yield declines with subsequent cutting over years.

Fodder trees are considerably less affected by dry conditions as they have deep root systems which enables in extraction of water and nutrients from soil even during dry season (Teferi *et al*. 2008). This characteristic enables these plants to retain fresh foliage into the dry season. Moreover, the hot and wet climate of humid tropical zone favours luxuriant growth of fodder trees.

Tree fodder banks

Fodder banks are plantings of high-quality fodder species in dense stands. Usually, low density planting patterns are followed for fodder trees in semi-arid and arid regions due to the constraints in soil nutrients and moisture. However, in land crunch humid tropical regions, there is a need to utilize the available land and other resources in the most effective manner. Hedgerow planting of fodder trees with higher tree densities as fodder banks is a possible option for enhancing productivity from limited land area (Sagaran 2017). Fast growing fodder tree species like calliandra, leucaena, gliricidia, erythrina and mulberry permit high density intensive cultivation in close hedge rows in humid high rainfall tropical conditions. Fodder bank is practiced more frequently in humid and sub-humid regions, due to the high moisture requirement by the trees (Sanchez and Sanchez 2002). Tree fodder banks can be maintained as protein banks for reducing the purchased concentrate feed, for year-round fodder production or to bridge fodder scarcity during annual dry seasons. Moreover, while integrating with existing cropping systems, maintaining fodder trees as hedges also regulates

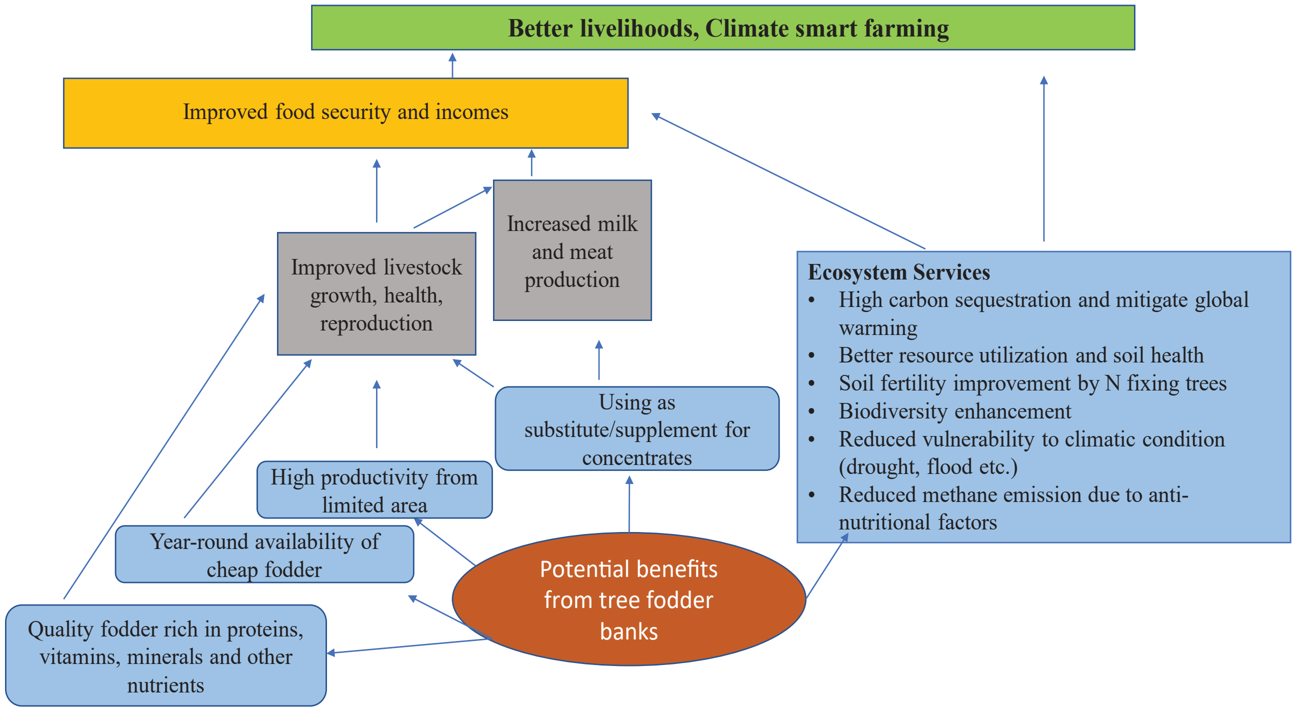


Fig.1. Potential benefits from tree fodder banks (*Source*: Adapted and modified from Franzel *et al*. 2014).

the possible competition to the main crop and facilitates easy harvesting of fodder (Raj *et al*. 2016).

Suitable trees as fodder banks

The fodder tree selection is based on its easy regeneration capacity, coppicing ability, fast growth, nitrogen fixing ability, higher biomass production, palatability and nutritive foliage with high crude protein content and less toxic substances, remain productive during dry seasons, and tolerance to shading and drought (Sharma *et al.* 1998). The suitable fodder bank trees for humid tropical regions include subabul (*Leucaena leucocephala*), calliandra (*Calliandra calothyrsus*), Gliricidia (*Gliricidia sepium)*, mulberry (*Morus indica*), moringa (*Moringa oleifera*), agathi (*Sesbania grandiflora*), erythrina, kadamba (*Neolamarckia cadamba*), *Cratylia argentea, Flemingia macrophylla* etc. (Sanchez 2006, Ghimire *et al*. 2013, Joy *et al*. 2018, Raj *et al*. 2019, Patrick *et al*. 2020). They can be grown in close hedge rows and can be harvested frequently to yield quality forage. All these trees except moringa can be integrated as understorey components in partially shaded tree-based systems like homegardens, coconut plantations, as boundary hedges and live fences, without interfering with other food crops. Calliandra, mulberry and subabul are highly palatable and relished by goats as well as cattle, followed by moringa, gliricidia and kadamba (Jayaprakash *et al.* 2016, Patrick 2019).

A number of comparative trials in humid and subhumid zones on high base status soil have shown *L. leucocephala* to be superior to other species and this may partly explain its widespread use (Kang and Reynolds 1986). However, on acidic low base status soils in humid tropical regions, leucaena has not been found as successful as species such as calliandra, gliricidia and mulberry (Raj 2017, Joy 2017, Patrick 2019). Kadamba (*Neolamarckia cadamba)* is promising fodder tree for humid and sub-humid tropics. It is fast growing in nature and has high forage quality and comparable to the traditional *L. leucocephala* and *M. sativa* as forage for ruminants and non-ruminants (Zayed *et al.* 2014). Chichaghare *et al*. (2021) observed higher biomass production with high leaf-stem ratio in kadamba compared to all other fodder tree species in a smallholder farm in Central Kerala. *Erythrina variegata* foliage has high crude protein (CP) content, 19 to 22% in dry matter, and can be an excellent feed for most livestock (Kongmanila and Ledin 2009). It can be grown as live fence or boundary plantations. A list of fodder trees and the nutrient components of fodder under hedgerow planting in humid tropical Kerala are given in Table 1.

All the species are amenable for management as hedgerows for year-round fodder production and protein requirements or to meet the fodder needs during lean seasons. These trees can be grown as boundary plantations as single, double or triple hedgerows, shade trees, standards for pepper, grass-tree mixtures, fodder banks and as live fence in homesteads, rice field bunds and as intercrops in coconut and other plantations.

Fodder bank establishment and management

Raising planting stock: Calliandra, moringa, kadamba, subabul and sesbania are to be raised from seeds; and gliricidia, mulberry and erythrina from cuttings. Seeds can be directly sown to the main field, but the initial growth of many fodder tree seedlings is often slow, making young plants susceptible to weed competition. However, most fodder tree species are readily established from transplanted

Table 1. Chemical composition of harvested fodder under hedgerow planting in cropping systems of humid tropical Kerala

Tree species	Dry matter content (%)	Crude protein content (%)	Crude fibre content (%)	Ash content (%)	P (%)	K (%)
Morus indica (Mulberry)	28.73	16.74	27.39	6.8	0.61	0.79
Sesbania grandiflora (Agathi)	21.04	22.81	28.42	8.51	0.23	0.78
Moringa oleifera (Drumstick)	29.79	20.06	28.12	8.96	0.28	1.04
Gliricidia sepium (Gliricidia)	22.06	19.99	23.72	7.44	0.19	0.92
Calliandra (*Calliandra calothyrsus)*	30.40	22.57	26.74	4.76	0.20	0.89
Leucaena leucocephala (Subabul)	31.5	18.51	29.95	5.9	0.52	0.61
Neolamarckia cadamba leaf	22.27	17.10	31.25	6.87	0.27	3.21

Source: Raj 2016, Patrick 2019.

seedlings. Seedlings or saplings should be grown in nursery in polybags and later transplanted on attaining 30-50 cm height which usually takes 3 to 4 months. Certain seeds require seed treatment for enhancing germination. Seeds of calliandra and sesbania should be pre-soaked in water for 48 and 12 h, respectively before sowing for ensuring good germination. Subabul seeds should be treated with concentrated sulfuric acids for 4 min and then washed with hot water for successful germination. Submerging seed in boiling water for 30 sec and allowing it to cool for 24 h improves germination for many of the seeds with hard seed coat (Prinsen 1986). For mulberry, six to eight months old cuttings of pencil thickness having 20 cm length and with 4 to 5 active buds should be planted in polybags and later transplanted at 3 months stage (Raj *et al.* 2015). Gliricidia and erythrina can be easily established using thick stem cutting of not less than 3 cm diameter and 40 cm length directly in the field (Patrick *et al.* 2020).

Selection of planting site: Acute land scarcity and intensive multi-tier cropping in humid tropical regions limits large scale fodder tree cultivation in open lands. Only alternative is to integrate trees in the unutilized spaces within the existing cropping systems like coconut gardens and other plantations, home gardens, boundary planting, live fences, tree-grass mixtures, as shade trees, standards for pepper, etc. Coconut is an important plantation crop in around 15 states in India covering an area of more than 20 lakh ha (Coconut Development Board 2017). On account of the wide inter spaces between coconut rows (7.6 m × 7.6 m), there is ample scope for intercropping fodder trees especially during the early growth phase (up to 8 yrs) and later mature phase (>25 years) of the coconut plantation. Several studies illustrate that calliandra, mulberry, gliricidia and leucaena perform well in the coconut understorey (Liyanege and Jayasundara 1987, Raj 2016, Joy 2017). Similarly, shade tolerant trees like calliandra, mulberry and gliricidia can also be integrated as an understorey component in the unutilized spaces within home gardens and small holder farms (Patrick 2019). Fodder trees can also be grown along farm borders to save crop fields. In such situations, single, double or triple hedge row system of planting can be followed depending on the space availability along the boundary. Trees like erythrina can be grown as live fence due to its thorny nature.

Trees can also be grown along with fodder grasses in definite proportion as grass-tree mixtures so as to provide balanced feed for animals and to ensure year-round supply of fodder. The intercropping of grasses and legumes may be an option to increase the production, the forage quality, and the profitability and sustainability of the system in tropical

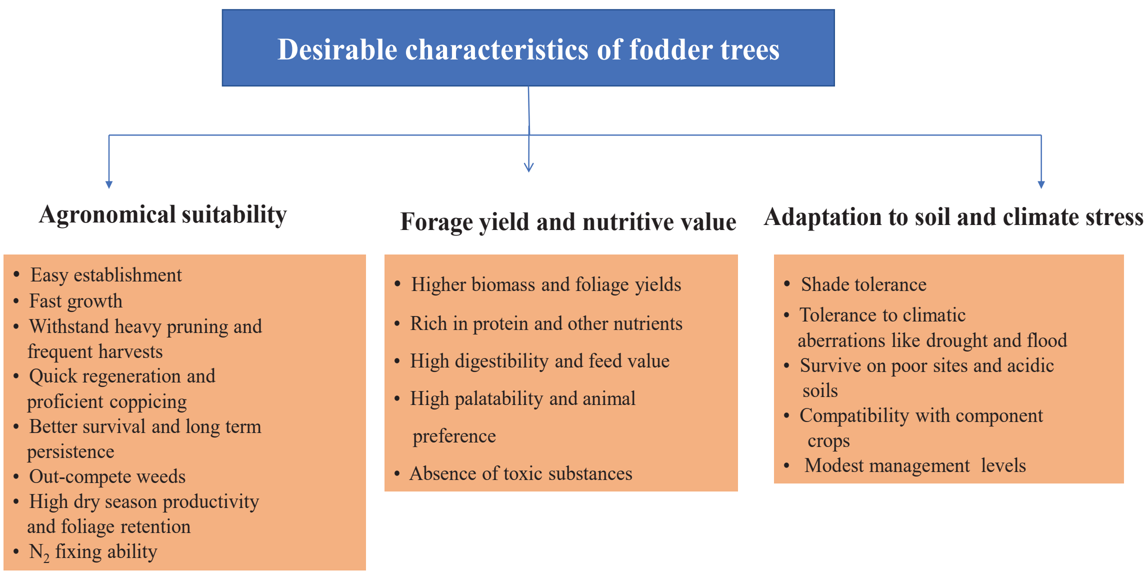


Fig. 2. Desirable characteristics of fodder tree species for fodder bank cultivation in humid tropical regions.

Table 2. Productivity of calliandra fodder banks as influenced by varying densities and harvest intervals underneath coconut garden

Factor	Dry forage yield (Mg/ha)			Leaf-stem ratio (Mean value for 3 years)	Crude protein yield (Mg/ha)		
	1st year	2nd year	3rd year		1st year	2nd year	3rd year
Tree density							
27,777 plants/ha (D_1)	13.86^a	15.68^a	16.97	1.14	2.25^a	2.55^a	2.76^a
22,222 plants/ha (D_2)	10.38^b	12.76^b	14.02	1.06	1.67^b	2.05^b	2.25^b
17,777 plants/ha (D_3)	8.00^b	12.47^b	13.87	1.07	1.23^c	1.92^c	2.14^c
p value	<0.01	<0.01	0.06^{ns}	0.102 ^{ns}	<0.01	<0.01	<0.01
Harvest interval							
8 weeks (I_1)	8.09^b	10.32b	11.13^c	1.33^a	1.45^b	1.85b	4.31b
12 weeks (I_2)	9.91^b	14.70a	15.33^b	1.32^a	1.77^a	2.63a	5.57a
16 weeks (I_3)	14.24^a	15.90a	18.41^a	0.61^b	1.70^a	1.90b	3.19b
p value	<0.01	<0.05	<0.01	<0.01	<0.01	<0.01	<0.01
D_1 I_2	14.20	15.36	17.42	1.47	2.59	2.93	3.32

Source: Sagaran 2017, Joy 2017.

regions. On-station trials conducted at Kerala Agricultural University revealed that leguminous fodder tree, calliandra and non-leguminous species like mulberry can be intercropped with hybrid napier grass to yield protein rich forage than grass monoculture (Raj *et al*. 2016). Under partially shaded farming conditions, shade tolerant grass like guinea grass can be a preferred species for mixture. Such systems are immensely suitable for the improvement of farming systems through soil fertility maintenance and increased availability of high-protein feed for livestock.

Field planting: The available unutilized space within the cropping systems should be demarcated for planting fodder trees. In case of coconut plantations, the fodder trees should be planted 2 m away from the palms (Sagaran 2017). In case of homesteads and small holder farms, crop free zone of 1-1.5 m radius should be maintained around the existing trees to prevent above ground and below ground competition (Patrick 2020). The crop-free zone could be widened depending on over storey tree canopy to prevent competition. The overstorey components could also be pruned judiciously into an open form, which will allow more light transmission beneath them.

Field planting must coincide with rainy season which assures high plant survival and establishment. Thorough land preparation is needed for planting trees. The field area should be ploughed twice and leveled. All weeds and stubbles should be removed from the area. Seedlings should be planted as hedgerows. Pits should be taken at required spacing and 1 kg farmyard manure should be added in each pit and mixed well. Seedlings should be planted at the onset of monsoon. During initial period of growth (first six months), proper weeding and climber cutting should be done at least once in a month. Irrigation should be provided at 3 to 4 days interval for the first two years to avoid tree mortality.

Tree spacing: In general, most previous researchers have found that productivity per unit area has been highest at the highest densities, even though there is a decline in individual tree yield. Sanchez (2006) observed that for intensive biomass production, moringa and cratylia should be planted densely @ 50 to 75 plants per square meter for moringa, and at least 40,000 plants/ha for Cratylia. Intercropping trials of calliandra fodder banks in coconut gardens of Kerala indicated significant yield increment at higher densities (Sagaran 2017). Maximum forage yields (13.86 t/ha on dry matter basis) were obtained from the highest density stand (27,777 plants/ha) with 60 cm × 60 cm spacing in the initial year, which was 42% higher when compared to the lowest density (17,777 plants/ha). Significant yield increase in the densest stands was noticed even in the third year of tree growth (Joy 2017) (Table 2). Raj *et al*. (2016) and John *et al*. (2019) compared still higher densities (49,382, 37037, and 27,777 plant/ha) for mulberry and subabul fodder banks underneath coconut garden for three successive years and obtained significantly higher yield at the highest density with an inter and intra-row spacing of 45 cm each. Patrick (2019) also recommended closer inter and intra-row spacing of 45 cm for yield maximization from fodder banks of agathi, callindra, mulberry and gliricidia in homesteads in the initial year of planting. In humid tropical regions which receive ample rainfall, there is a need for closer planting of fodder trees for maximizing productivity 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 understory 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 utilization (John *et al*. 2019). In addition, Turgut *et al.* (2005) explained the increase in yield in the case of narrow spacing due to greater solar energy interception.

Unlike yield parameters, nutritive parameters showed diverse response in relation to plant density for various species of fodder trees. Foliage fraction as indicated by the high leaf-stem ratio and crude protein (CP) content in calliandra fodder (Table 2) increased significantly from lower to higher density classes (Sagaran 2017). Plant density

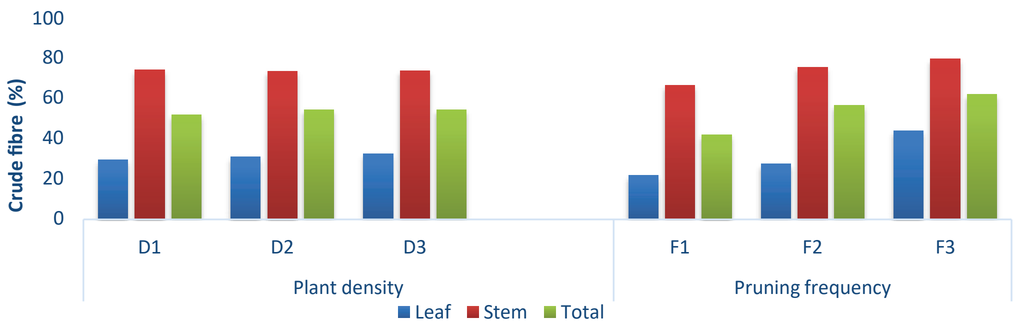
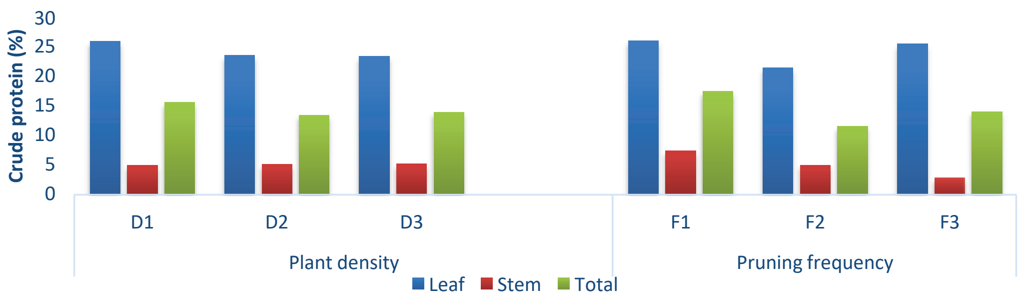


Fig 3. Influence of plant density (D1, D2 and D3 - 49382, 37037 and 27777 plants/ha) and pruning frequency (F1, F2 and F3 – 8, 12 and 16 weeks) on CF content of mulberry fodder underneath coconut garden.



(D1, D2 and D3 - 49382, 37037 and 27777 plants per ha), (F1, F2 and F3 – 8, 12 and 16 weeks)

Fig. 4. Influence of plant density and pruning frequency on CP content of mulberry fodder underneath coconut garden.

had greater influence on crude fibre (CF) content, which declined from 40.53 to 37.73 at higher densities indicating closer spacing for production of tender fodder. This could be attributed to the fact that in closely spaced stands, the loss of nutrients from the soil is much lower due to closed canopy and limited exposure of soil to erosion, thereby enhancing the nutrient retention and uptake of nutrients by the plants. This is particularly true under good soil moisture and fertility conditions, wherein moisture stress and nutrient deficiencies may adversely affect nutrient uptake and forage quality. Similar results of elevated CP% and lower CF% at higher population density had been reported by El-Morsey (2009) in *Sesbania aegyptica* and Raj (2016) in mulberry and subabul (Fig. 3 and 4). However, Sanchez (2006) reported that the nutritive composition of Moringa was not affected by planting density. Bharadwaraj *et al.* (2001) observed that the nutrient accumulation in the biomass differed with tree density.

However, most of the studies had been done in young stand of trees, wherein the above and below ground competition has not yet started. Perhaps the high-density stands could give a different response at later stages of tree stand wherein interferences between trees and tree-crop could be great. As per the reports of John (2018), density management of understorey tree fodder banks showed significant effect on productivity of coconut palms. Maximum nut yield (11,245 nuts/ha) was obtained from the lowest fodder tree density of 27,777 plants/ha when compared to higher density levels (10,899 nuts/ha). This shows that enhancement of tree density beyond a particular level will result in competition with the main crop (Coconut) for various resources which results 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.

Considering the yield and nutrient outputs, an inter and intra-row spacing of 45 to 60 cm has been recommended by several researchers for establishing fodder banks in humid tropical regions. Over a period of time, the trees may undergo self-pruning mortality to maintain the optimum plant population and sustainable production.

Tree management: In land crunch small holder farms, most fodder banks are intensively managed through a cut-and-carry system in which the fodder is frequently harvested and then carried to the livestock. Numerous studies on fodder trees indicated that management factors such as age of first harvest, cutting height and cutting interval not only affected fodder yield per unit area but also long-term productivity and quality of the forage, which should be considered while establishing fodder banks.

Age of first harvest: After planting, first harvest can usually be done when plant reaches a height of at least 1.5 m. This usually happens 3 to 6 months after field planting, depending on soil moisture and fertility conditions and growth habit of trees. In humid tropical conditions of Kerala with an average annual rainfall of over 2500 mm, nursery grown saplings of calliandra, sesbania and leucaena planted at the onset of monsoon during May-June can be given first harvest 3 to 6 months after planting. However, delaying harvest until 9-12 months gives more healthy and sturdy trees with strong well developed root system and thick trunk diameters (Raj 2016, Sagaran 2017). Such healthy plants have ample carbohydrate reserves and respond well to frequent harvesting. Under arid or poor soil conditions, growth will be slow and the first harvest should be later. When growth is fast, the first harvest may be sooner. Moreover, forage yields, persistence and long-term production of fodder banks are favourably influenced under delayed first harvest. Patrick *et al*. (2020) observed faster growth in sesbania, calliandra and gliricidia, which attained harvestable growth at three months after planting (MAP) when grown as understorey component in homesteads of Kerala. Several other authors also reported extremely rapid growth rate in sesbania and calliandra (Duke 1983, Gutteridge and Shelton 1994, Sagaran 2017, Joy 2017) under humid tropical conditions. Slow growth of mulberry and subabul in the initial year of planting was reported by Raj *et al.* (2016), wherein it was advisable to delay harvest up to 6 MAP. In case of direct planting of stem cuttings of mulberry and gliricidia, first harvest can be taken only after 1 year of planting for attaining satisfactory growth.

Cutting height and method: Maintaining proper cutting height is highly essential for retaining adequate foliage to ensure rapid regrowth and tree longevity and also for the ease of harvest without much bending and reaching by the harvester. Numerous studies indicate cutting heights ranging from 50-150 cm for maximizing production and ensuring the tree longevity. In an intercropping trial of calliandra hedgerows in coconut gardens of Kerala, Sagaran (2017) reported vigorous coppicing, higher forage yields and higher leaf-stem ratio at cutting height of 1 m than 0.5 m. The increment in forage yields with increasing pruning height was possibly due to more reserve food materials in taller stands that promoted vigorous and rapid regrowth. Moreover, lower cutting heights reduced the ability of the plants to withstand drought conditions, causing drying of stems and poor regeneration, which in turn affect tree longevity in the long run. Basavaraju and Rao (1996) from Karnataka also confirmed the requirement of 1 m cutting height for getting maximum yield from calliandra when compared to lower levels. Similarly, Tipu *et al.* (2006) obtained higher number of branches, length of branches, leaves per plant and fodder yield from subabul when pruned at 100 cm height than 50 cm. Cutting height of 1 m for mulberry, subabul, moringa, gliricidia and subabul hedgerows integrated under coconut gardens and home gardens has also been recommended by Patrick *et al.* (2020) and Raj (2016) which enabled easy harvest, less interaction with main crops, better plant survival and biomass yields.

However, a notable exception to the general recommendation is the management of *Sesbania grandiflora*. This species shows a high degree of mortality when it's main stem is cut. Side branches can be harvested, instead of overhead pruning below 150 cm height (Patrick *et al.* 2020).

Every 2-3 years of production, it is recommended to cut leucaena and calliandra back to 25 cm during rainy season. This lower height removes much of the dead wood and rejuvenates foliage production. The same may be true for other species also. However, regular cutting below 50 cm is not recommended as it causes increased mortality and decreased long-term productivity. The best way to cut the fodder is with secateurs so as to avoid any possible tree damage.

Cutting frequencies: Several studies in different fodder tree species indicate that cutting frequency or cutting interval is a critical management factor that influences forage yield and quality as well as tree longevity and sustainable production. Several researchers have recommended a great variety of cutting frequencies ranging from 6 to 18 weeks. Generally, longer cutting frequencies, 12 to 18 weeks, generate more total biomass but majority of the fodder comprised of woody stem fraction. Shorter cutting frequencies, 6-12 weeks, favour fodder yields and fodder quality. Younger foliage tends to have a higher nutritive value and palatability. Calliandra fodder banks underneath coconut plantation yielded more edible forage with higher crude protein, phosphorus and potassium content and lower crude fiber content at 8 to 12 weeks harvest interval compared to that of 16 weeks (Sagaran 2017). Raj *et al*. (2016) also observed higher foliage yield and feed value from mulberry and subabul by pruning at shorter interval of 8 weeks than at higher intervals (Fig. 3 and 4). In Karnataka, Basavaraju and Rao (1996) obtained maximum herbage yields from calliandra at cutting interval of 8 weeks compared to higher intervals. *Flemingia macrophylla* could produce higher biomass of 4.46 t dry matter/ha at planting density of 15,873 plants/ha; with defoliation interval of 12 weeks and maintaining 0.75 m defoliation height (Ghimire *et al*. 2013).

In humid tropical regions, a well-established stand can be harvested 4 to 6 times a year based on moisture availability from rainfall or irrigation and nutrient supply. During peak rainy season, the cutting interval can be as short as 8 weeks, but during the dry season regrowth is slower, and the cutting interval may be as long as 12 to 16 weeks (Patrick 2019). A regrowth of 50-60 cm is a good indication that the tree is ready for the next harvesting. However, repeated cutting in shorter intervals can decrease tree longevity. This is particularly true for sesbania which shows severe tree mortality with intensive harvesting. Since sesbania establishes very rapidly and yields abundant biomass in short periods, frequent replanting is a management option if heavy harvesting results in tree decline (Karmarkar *et al*. 2016).

Under rainfed conditions, cutting intervals of fodder trees can also be managed to provide feed during dry seasons. Trees should be cut back to 1 m height four to six weeks before the end of the rainy reason. The new shoots produced over the next few weeks will be retained well into the dry season when it is most needed. However, when left uncut for 4-6 months, most of the species shed their foliage and will not retain leaves into the dry season. Sometimes during the rainy period, the quantity of fodder available may exceed normal needs. The excess fodder may be used to make silage or leaf meals and stored for dry season use (Patrick 2019).

Tree nutrition and irrigation: Fodder banks are perennial crops that must be properly manured and fertilized to continue high productivity. Tree roots are aggressively competitive and remove large amounts of soil nutrients from the site. These nutrients must be replenished by application of manures or chemical fertilizers. Little is known of the nutrient requirements of most fodder bank species. However, as with most crops, nitrogen, phosphorus and potassium are important nutrients. Application for these and other nutrients should be determined locally. Availability and costs of fertilizers may restrict their use. The nitrogen requirement may be self-provided if the species used are nitrogen-fixing. 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 component crops (John 2018).

Availability of moisture also influences the productivity of fodder banks. Several authors reported that, in humid tropical regions of Kerala around 70 to 75% of the annual yield is obtained during the six months rainy period from June to December, and the remaining yield during dry spell from January to May with minimal irrigation (Raj 2016, Joy 2017). Continuous supply of moisture during dry period can further elevate the yield levels especially during the initial years of planting. Irrigation intervals can be extended in the later year when the tree roots are well developed and deep rooted to tap moisture from deeper soil levels. However, while integrating tree fodders with other crops, it is always advisable to provide moisture to both crops to maintain sustainable production.

Forage and crude protein yield: Forage and protein yield from tree fodder banks show considerable variation with respect to species, age of stands, management factors, nutrient, moisture and light availability, pest attack and other site-specific properties. With adequate nutrition and irrigation, calliandra fodder banks underneath coconut garden yielded the maximum green and dry forage, and CP yield of 42, 14.2 and 2.59 Mg/ha respectively, under management conditions of 60 cm × 60 cm spacing, pruning height 1 m and harvest interval 12 weeks, in the initial year of planting (Sagaran 2017). Considerable yield increment was noticed in the subsequent years (56, 17.42 and 3.32 Mg/ha green fodder, dry fodder and CP in the 3rd year) owing to the development of deep roots and healthy shoots and better drought tolerance (Table 2). However, due to the slow initial growth of mulberry and subabul compared to calliandra, still closer spacing of 45 cm × 45 cm has to be adopted for getting the maximum green and dry yield of 40 and 12.5 Mg/ha in the initial year of planting. In the subsequent years, the respective annual green and dry yield of mulberry rose to 60 and 15 Mg/ha, however subabul suffered yield loss due to pest attack and casuality (John *et al*. 2019). An average annual green forage yield of 30 to 40 tonnes can be expected from calliandra or mulberry from 1 ha coconut garden with light availability of 60 to 70% during the initial year of establishment. Subsequently higher yields of 50 to 60 tonnes can be expected with proper management for a period of 8 to 10 years. However, prolonged dry spells can cause 25 to 40% yield decline, in the absence of irrigation.

However, productivity of trees declines drastically under severe light and space constraints as observed under home gardens. According to Patrick (2019), calliandra, gliricidia and mulberry fodder banks (spaced 45 cm × 45 cm and pruned at 1 m height from ground) grown in the interspaces of home gardens with 52% light availability yielded 6.61, 5.38 and 2.46 Mg/ha/year dry forage in the initial year of planting. There was progressive increase in yield in the subsequent years but overall performance was poor when compared to that under coconut gardens with 60-70% light transmittance. Mulberry suffered higher yield loss than calliandra and gliricidia, due to its higher light requirement. Meerabai (1997) also observed yield reduction in mulberry when grown under partially shaded situations. However, regular lopping and pruning of component tree/ shrubs in homesteads to enhance light transmission can further elevate the yield levels of fodder banks.

Raj *et al*. (2016) observed remarkable improvement in crude protein yield by integrating high density tree fodders along with fodder grasses, instead of the existing practice of grass monoculture. Two-tier fodder cropping systems with the combination of hybrid napier grass (variety CO_4) and fodder trees (mulberry + calliandra; @ 11111 trees/ha), planted in 3:2 ratio area wise, yielded higher dry matter (31.5 Mg/ha) and almost double crude protein (4.75 Mg/ha) than grass monoculture (30.18 Mg of dry yield and 2.83 Mg of crude protein/ha) in Kerala. Trees were planted at 60 × 60 cm spacing, pruned at 1 m height at 3 months interval. Moreover, in the establishment year, the share of grass and trees to total dry matter yields of 2-tier systems was 69 and 22%, whereas the tree share doubled to 43% in the subsequent year, which imply the better performance of trees with advancing age. Hence, such tree-grass mixture is a better option for producing quality forage from a small area in humid tropical small holder stall-fed livestock farms.

Feeding and economics: About 5 to 7 kg of tree leaves can be fed to cattle daily. However, due to mimosine content, leucaena should be fed only up to 4 kg/day. About 500 to 600 fodder trees will be needed to feed a dairy cattle or 3-4 goats @ 2 kg dry matter/day. This can save the cost of purchased feeds by 25 to 30%. Introduction of fodder trees like mulberry, leucaena and calliandra in small holder farms in African countries like Uganda and Kenya has improved livestock diets, milk production and income of small-scale dairy farmers (Franzel *et al.* 2014). Studies conducted in milch cows of Kerala also confirmed the nutritional superiority of fodder trees and shrubs like calliandra and desmanthus and suitability as a partial substitute for concentrate feeds up to 20% without affecting animal health and productivity (Jayaprakash *et al*. 2016). For dairy cows, 1 kg of concentrates can be successfully replaced by 3 kg of fresh *Calliandra calothyrsus.* Calliandra also increased butterfat content by about 0.5% (Pye-Smith 2010). An economic analysis from Chikwaka district, Zimbabwe found that the use of fodder tree (*L. leucocephala, A. angustissima, L. diversifolia* and *L. pallida*) in smallholder dairy had gross margins of $US 13 to $US 334 and benefit–cost ratios of 1.12–3.03. Ewes supplemented with *S. sesban* in Ethiopia showed a 13% increase in milk production over ewes supplemented with concentrates (Franzel *et al*. 2014). Moringa and Cratylia fed at 2 kg or 3 kg DM/day can significantly improve DM intake and milk yields of creole dairy cattle (Reyna) without affecting milk composition or organoleptic characteristics of milk as observed by Sanchez (2006).

Soil fertility improvement: Several studies indicate that fodder banks of calliandra, mulberry, subabul and gliricidia improve soil physico-chemical parameters like bulk density, water holding capacity, soil *p*H and buildup of soil nutrients, by addition of fertilizers, mineralization of litter, deep and intensive rooting by trees, avoiding leaching losses of nutrients by reducing surface runoff and through soil binding by the intensive root system of densely planted intercrops (Varsha 2015, Raj 2016, Joy 2017, John 2018, Patrick 2019). Gunesena *et al*. (1991) also observed that by growing gliricidia and leucaena, soil bulk density reduced and infiltration capacity increased in clay soil compared to the control. Water quality benefits of maintaining trees and other vegetation on farms are realized by reducing run-off, maintaining long-term water cycle, and recharging ground water aquifers (Wu *et al.* 2001). Leguminous fodder trees play a critical role in nitrogen enrichment of soil by their nitrogen fixing nature (Rejili *et al.* 2012). Intercropping calliandra, subabul and gliricidia with coconut enhances carbon levels throughout the profile mainly through litter fall, deep rooting, root exudates and fine root dynamics (Raj 2016, Joy 2017). However, adoption of extremely high densities and frequent pruning in non-leguminous and aggressive trees like mulberry, can deplete the soil resources and initiate intercrop competition, adversely affecting the system productivity in the long run (John 2018).

Carbon storage potential of tree fodder banks

Increasing atmospheric CO_2 levels and alarming rate of global warming and climate change is a reality in the current world. It is the need of the hour to find cheap methods to sequester carbon in terrestrial ecosystems. Trees are important carbon sinks because they can hold large amount of carbon per unit area in comparison to other kinds of vegetation (Lasco *et al*. 2002). More biomass results in increased production of above ground litter and below ground root activity and these make trees an important factor for SOC sequestration (Lemma *et al.* 2007). Owing to the limited scope for the expansion of forest area, enhancing tree cover outside conventional forests has been an accepted strategy to meet the targeted carbon reduction commitments by India.

Incorporation of fast-growing tree species with higher biomass production potential over shorter periods is recognized as a promising strategy for enhancing carbon sequestration in cost effective way (Rocha 2017). In this context, fast growing fodder trees showed remarkable potential to capture and store large quantities of carbon in the plant biomass as well as soil, thereby making considerable contribution for reducing atmospheric carbon dioxide levels. Moreover, stand management practices like density regulation and harvest schedules may still elevate carbon fixation rates by enhancing biomass production. On an average, carbon locked in tree-based systems is estimated as 9, 21, 50 and 63 Mg C/ha in semi-arid, sub-humid, humid and temperate regions (Montagnini and Nair 2004). Introduction of tree crops in the interspaces of agriculture crops has a greater impact in enhancing carbon levels throughout the profile mainly through litter fall, deep rooting, root exudates and fine root dynamics.

Several studies conducted in the coconut based cropping systems of Kerala indicate substantial enhancement in carbon capture owing to tree fodder integration at different management levels. Intercropping calliandra with tree density of 27,777 trees/ha and harvesting fodder at an interval of 12 weeks reported maximum biomass production and carbon capture (199.19 Mg/ha) and the lowest value (118.84 Mg/ha) was recorded for 17,777 plants/ha and 8 weeks cutting interval (Table 3). Moreover, due to calliandra integration, an additional 90 Mg/ha carbon was captured in plant and soil up to 1 m depth, as compared to coconut monoculture systems over three-year period, out of which 56.27 Mg/ha (63%) was sequestered in the soil and 8.10 Mg/ha in woody stump and root (9%) which accounts for the permanent carbon, and 25.98 Mg/ha in fodder biomass (28%) representing the labile fraction (Joy *et al*. 2018). In a study conducted in Sri Lanka, Raveendra *et al*. (2017) reported higher carbon fixation (78.60 Mg/ha) by gliricidia fodder banks in coconut garden over six-year period.

In another study, carbon storage potential of three-year-old mulberry and subabul stands in coconut garden increased from the lowest tree density of 27,777 plants/ha to the highest tree density of 49,382 plants/ha (93.14 Mg/ha to 102.55 Mg/ha respectively) and at harvest interval of 12 weeks compared to 16 or 8 weeks. The above studies indicate the profound influence of tree density on carbon capture per unit area. 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). 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. Moreover,

Table 3. Carbon storage potential of coconut-calliandra intercropping systems in comparison with sole coconut and tree less systems at humid tropics of Kerala

Factor	Carbon content in various components and systems (Mg/ha)			
	Total carbon stocks in calliandra over 3-year period	Carbon in coconut palms	Carbon in soil	Total
Tree density				
27,777 plants/ha (D_1)	32.69[a]	33.37	97.84[b]	163.90[a]
22,222 plants/ha (D_2)	26.58[b]	33.06	103.43[a]	163.10[a]
17,777 plants/ha (D_3)	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 (I_1)	20.76[b]	33.28	86.75[c]	140.79[c]
12 weeks (I_2)	29.14[a]	33.30	114.27[a]	176.71[a]
16 weeks (I_3)	33.48[a]	33.16	91.07[b]	157.71[b]
p value	<0.01	0.95 [ns]	<0.001	<0.001
Interaction effects				
D_1 I_2	34.08	33.27	131.84[Aa]	199.19[Aa]
Sole coconut plantation with understorey grass vegetation	0.77[*]	32.39	75.57	108.73
Treeless plots (control) with grass vegetation	0.80[*]	-	77.42	78.22
P value	<0.01	0.24[ns]	<0.01	<0.01

[*]Carbon stocks in grass vegetation.

following a medium harvest interval of 12 weeks is found to be ideal for many fodder species as too short or too long intervals reduce the overall biomass production from the stands and the carbon accumulation in soil (Joy 2017, John 2018). However, adoption of extremely high densities and frequent pruning in non-leguminous and aggressive trees like mulberry, can deplete the soil resources and initiate competition with the component crops, which may retard the system productivity and carbon accretion in the long run (John *et al*. 2019).

Casanova-Lugo *et al*. (2018) studied biomass carbon in various fodder banks planted at 2 m × 0.5 m spacing and reported 14.0 Mg/ha biomass carbon in *Leucaena leucocephala,* 14.3 Mg/ha in *Guazuma ulmifolia* and 15 Mg/ha in mixed species (*Leucaena* + *G. ulmifolia*) in humid climate of Mexico. These systems had soil organic carbon (SOC) stock of 150.3 Mg/ha. A fodder bank in Chiapas, Mexico stored about 190 Mg/ha SOC (at 30 cm depth) and 1.1 Mg/ha carbon stock in tree biomass (Aryal *et al*. 2022). McGroddy *et al*. (2015) estimated the carbon sequestration potential of the silvopasture system in Ecuador using allometric equations and reported that the aboveground live woody biomass ranged from 10.99 to 66.1 Mg/ha and the range of SOC pools was 85.0 to 97.6 Mg/ha. SOC at 15-30 cm depth was 7% higher under *C. calothyrsus* fodder bank (0.75 × 0.75 m) than that under *Vernonia amygdalina* at spacing 1 m ×1 m in Uganda. This study further found that 9 weeks is the optimum pruning frequency for obtaining higher fodder and SOC in fodder banks in Uganda (Fungo *et al*. 2020). Solarte-Guerrero *et al*. (2020) reported that *Acacia decurrens*-based fodder bank at 1 m ×1 m stored the highest (97.89 Mg/ha) SOC (60 cm depth) as compared to natural pasture (57.23 Mg/ha) in Colombia. Thus, integration of fast growing fodder trees and adoption of appropriate management practices can substantially elevate soil carbon sequestration of various cropping systems.

Conclusion and future perspectives

Livestock is an integral component of humid tropical cropping systems. Fodder scarcity, high cost of feeds and low net returns are the major constraints faced by small scale dairy farmers in these systems. The undisputed role of fast-growing fodder trees as a livestock feed resource and nutrient supplement in the humid tropics has been established. Leucaena, moringa, mulberry, calliandra, sesbania, gliricidia, erythrina, and kadamba are some good fodder tree species suitable to be integrated as fodder banks in humid cropping systems with light and space constraints. Higher forage and protein yield and long-term persistence can be ensured through the optimum management of tree density, cutting height, harvest interval, nutrient and irrigation management, which should be considered while establishing fodder banks. The main and intercrop components in the cropping system should be properly managed in time and space for getting maximum and sustainable yields and to minimize competition. Apart from addressing fodder issue, tree fodder banks could be a prudent approach for mitigation of global warming via carbon sequestration and the revival of biodiversity and sustainability of humid tropical regions, which has been dwindling at alarming rates in recent decades due to socio-economic changes. Such tree-based systems can bring a transformational change to the conventional land use and agricultural practices and can be extended to the wastelands and degraded areas for their restoration.

Researchable issues

- Small holder livestock farms in humid regions are intensive multi-storeyed systems with diverse cropping pattern. Hence location-specific and problem-oriented research need to be carried out with farmer participation for designing and managing tree-based fodder production systems without interfering with existing crops.
- Feeding trials are to be initiated in livestock to appraise the feed value of forages through animal production response (acceptability and consumption, milk production, growth, reproductive behaviour) and to standardize diets based on tree forages.
- Fodder banks are managed with frequent harvests which deplete the soil resources and compete with component crops. Little is known of the nutrient requirements of most fodder bank species, which should be determined locally. The nitrogen requirement may be self-provided if the species used are nitrogen-fixing.
- Long term studies of fodder banks in relation to persistence, fodder yield and quality, complimentary or competitive interaction among component crops, carbon and nutrient dynamics and other ecological benefits are to be studied to evaluate the full potential of the system.
- Screening fodder tree species and varieties with shade tolerance, and resilience to climatic aberrations like flood and drought, and soil constraints like acidity and salinity warrants further research.

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