GROWTH, GREEN BIOMASS PRODUCTION AND CROP INTERACTION OF SELECTED TREES AND SHRUBS ON WETLAND PADDY BUNDS

By

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(2021-17-001)

THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"GROWTH, GREEN BIOMASS PRODUCTION AND CROP INTERACTION OF SELECTED TREES AND SHRUBS ON WETLAND PADDY BUNDS"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Place: Vellanikkara

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INTRODUCTION

1. INTRODUCTION

Agriculturally, rice (*Oryza sativa* L.) is a major crop in India, and Kerala is known for its favourable agro-climatic conditions for rice cultivation. The fertile lands and abundant rainfall in Kerala make it an ideal region for rice production. Rice production in India is estimated to be 122.27 million tonnes in 2020-21. Rice productivity in India is about 2717 kg/ha (India stat Agri, 2021), which is quite low compared to that of many countries in the world. The current production of rice in Kerala is 6.27 lakh tonnes (GOK, 2021), which satisfies only one-fifth of the annual requirement. The deficit in rice production in Kerala has been increasing over the years, primarily due to the decline in the area under rice cultivation. To address this challenge, the best approach for increasing rice production in the state is to boost the productivity of existing agricultural lands. This can be accomplished by promoting sustainable and eco-friendly rice farming practices, including organic farming and integrated farming systems, enhancing rice productivity in Kerala.

India has achieved food sufficiency through increased chemical fertilizer use, but the use of organic manures, including green manure, has declined substantially. Excessive and imbalanced use of chemical fertilizers causes severe consequences on soil health, water quality and human health. The increasing cost of inorganic fertilizers and the negative environmental impacts such as pollution and soil degradation have raised concerns about the sustainability of soil productivity in agricultural systems. To ensure long-term food security and environmental sustainability, it is critical to encourage sustainable agriculture practices that balance chemical fertilizers, organic manures, and other soil health management techniques. There is an increasing demand for alternative nutrient sources to complement or replace inorganic fertilizers and green manuring is one such low-cost and effective solution that can address the above issue. Green manuring is an economical and effective agricultural technique that can reduce fertilizer costs while simultaneously benefiting soil and crop yields. It offers advantages such as improved soil health, adding organic matter and nutrients, biodiversity enhancement, and climate resilience. Green manure's rich organic matter enhances soil structure, water retention and microbial activity, boosting soil fertility and reducing the need for chemical fertilizers. Hence, there is ample scope to increase rice productivity in India with the continuous supply of green manures.

Some farmers practice in-situ green manuring in paddy fields, but it is often complained that they lose a valuable crop season by growing green manure crops. However, an alternative method known as green leaf manuring can be employed to address this problem. Green leaf manuring involves collecting green biomass from nearby trees or shrubs and incorporating it into the soil as a source of organic matter. This method, like in-situ green manuring, can provide several advantages for soil fertility and crop productivity without sacrificing a crop season. Green leaf manuring has been traditionally followed in the rice fields of Kerala. However, due to the non-availability of conventional green leaf manures, labour and transportation constraints, the practice is almost neglected by farmers.

One potential solution to address these issues is planting fast-growing green manure trees or shrubs in the bunds, which are the raised earthen bunds that separate rice fields. Farmers can ensure a continual supply of green biomass on farms by planting these fast-growing species in bunds, which can be collected and put into the soil as green leaf manure. This method can solve supply, labour, and transportation issues while also providing a sustainable source of organic matter for boosting soil fertility, enhancing nutrient cycling, and supporting overall soil and crop health.

Several tree species such as *Gliricidia, Garuga, Sesbania, Calliandra, Terminalia*, mulberry and *Gmelina*, as well as shrubs like red gram (perennial), are known to be fast-growing and capable of producing abundant biomass within a short period. These species have been documented in various studies, including those by Patrick (2019), Lei *et al*. (2022) and Rodenburg *et al*. (2022), as being highly productive in terms of biomass accumulation. *Terminalia arjuna* has been observed to be a promising species in waterlogged areas as it survives well, even in sodic soils (Jain and Sing, 1998). *Gliricidia sepium* and *Gmelina arborea* were the most suitable tree species for hedgerow agroforestry system practices in rice paddy fields and help to improve soil nitrogen, rice yield, biomass, provide fodder, and control weeds. However, *Gmelina arborea* has a poor survival rate in paddy conditions (MacLean *et al.,* 2003; Panwar *et al.,* 2013*)*. Fresh leaves of *Sesbania grandiflora* provide higher and immediate N mineralization under both anaerobic and aerobic conditions of soil (Watanabe *et al.,* 2017). *Terminalia arjuna* was intercropped with rice, and the result showed a higher soil organic and microbial content (Panwar *et al.,* 2013). Saito *et al.* (2008) investigated the effect of *Cajanus cajan* on upland paddy rice for five years and concluded that there was no significant effect on rice yield in the first year and then decreased yield, but nitrogen input and phosphorus availability increased. Dhyani *et al.* (1996) reported that sericulture with mulberry trees planted on bunds of lowland rice fields was two times more profitable than rice alone and 1.25 times more profitable than mulberry alone. They can be pruned frequently and show good regeneration and coppicing ability, which ensures a frequent supply of green manure. There is a possibility to integrate these trees in paddy internal bunds and maintain them as hedges by regular lopping of green biomass beyond 1 m height.

A lot of literature is available regarding the growth and productivity of the above trees on upland well-drained soils. However, their survival, growth and biomass production under ill-drained conditions of wetland paddy bunds are not much explored. Similarly, the cultivation of trees on bunds can cause a shading effect by the canopy and the roots of these trees may also intrude into the fields and disturb the growth and productivity of paddy. Hence, the performance of trees on bunds and their effect on paddy has to be assessed to evaluate this system's overall feasibility and productivity.

Green leaf manuring, a traditional practice in Kerala, involves collecting green leaves from nearby areas and using them as green manure. However, this practice has become obsolete due to the increased use of inorganic fertilizers. To develop effective production strategies and to revive green manuring in paddy fields, one must document and understand current farming practices, explore the potential and limitations of tree planting in bunds, identify farmer’s preferred tree species and collect feedback. Documenting indigenous knowledge about green manuring, mainly green leaf manuring, can help preserve traditional wisdom and provide insight into the historical context of these practices.

The study goes beyond agronomic aspects and includes a survey of indigenous knowledge on green leaf manuring practices and current farmer practices in the study area. This involves interviewing farmers to understand their perspectives, preferences and constraints on green leaf manuring in paddy fields. Understanding farmer's perspectives can provide valuable information for designing production strategies compatible with local preferences and feasibility.

The findings of this study can contribute to the knowledge of the growth and green manure production of selected tree/shrub species on wetland paddy bunds, as well as their impact on paddy growth, yield and soil properties. The documentation of indigenous knowledge and farmers' perspectives can also provide insights for designing context-specific interventions to revive green manuring practices in paddy fields and promote sustainable agriculture in the study area.

In this backdrop, this study was undertaken with the following objectives:

- To assess the growth and green biomass production of selected fast-growing trees/shrubs on wetland paddy bunds of Kerala
- To study the impact of bund-grown trees on paddy growth and yield and soil properties
- Survey and documentation of the green manuring practices in paddy fields of Ollukkara and Wadakkanchery blocks in Thrissur district.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Rice holds significant importance in India and the state of Kerala, both as a staple food and as a crucial aspect of the agricultural sector. Rice paddies, or "paddy fields," are common in Kerala's landscape, with farmers working diligently throughout the year to cultivate and harvest this vital crop. The success of rice cultivation directly impacts the economic well-being of farmers and contributes to the overall agricultural economy of the state. However, rice production is declining nowadays due to the decline in the area under rice cultivation. Therefore, the only option to enhance production is to increase the productivity of available lands. Green manuring is a low-cost and effective technology in minimising the cost of fertilizers and safeguarding and improving the productivity of soil and crops. Green manuring adds organic matter to the soil, protects the soil surface from erosion, enhances nitrogen supply and water holding capacity and improves the availability of nutrients like phosphorus. The performance of green manuring trees/shrubs under ill-drained conditions of wetland paddy bunds is not much explored. In this context, a field study has been envisaged to evaluate the survival, growth and biomass production of green manuring trees/shrubs *viz*., *Gliricidia, Garuga*, *Sesbania*, *Calliandra*, *Terminalia,* mulberry, *Gmelina*, red gram (perennial) and *Cassia* under ill-drained conditions of wetland paddy bunds and their effects on paddy. The study also envisaged surveying and documenting the indigenous knowledge, the current practices and the farmer’s perspective on green manuring in paddy fields of Ollukkara and Wadakkanchery blocks in Thrissur district. Relevant literature pertaining to the above aspects is reviewed hereunder.

2.1 Rice Production; India and Kerala scenario

Rice is the staple food of India and Kerala. Rice production in India is estimated to be 122.27 million tonnes in 2020-21. Rice productivity in India is about 2717 kg /ha (India stat Agri, 2021), which is quite low compared to many countries in the world. The current production of rice in Kerala is 6.27 lakh tonnes (GOK, 2021), which satisfies only one-fifth of the annual requirement. Every year, the shortage in rice production in Kerala is increasing due to the reduction in the rice cultivation area. The only option to enhance production is to increase the productivity of available lands.

2.2 Green manuring and crop production

Restoring agricultural soil fertility is a crucial problem in developing and populous countries. The current trend of crop production dropping or crop yields stagnant in India which is the result of a variety of soil-related constraints. Acceptance of poor soil management methods, widespread crop residue burning, hasty adoption of agronomic practices and asymmetric nutrient management are all indicators of low crop yields. Additionally, decreased agricultural output per unit of land area is conceivable due to declining organic matter in soil, sparse application of organic and bio-fertilizers and insufficient management (Salahin *et al*., 2013; Reddy *et al*., 2022). The principal causes of low crop production and soil fertility include increased agricultural technologies that deplete soil organics which may be seen as a serious threat to agricultural sustainability. Using green admixture crops through agricultural practices provides organic matter to the soil, making green manures essential for sustainable production. So, the only option is to use organic manures and the benefit of green manuring should be considered for the addition of organic material to deficient soils (Maitra *et al*., 2018)**.**

A prominent characteristic found in many effective, sustainable systems involves deriving essential resources for growth from organic rather than chemical fertilizers. Nitrogen, a crucial nutrient for crop development, poses significant challenges in terms of management. Synthetic fertilizer N tends to leach easily from the soil and crop system, resulting in substantial economic and environmental costs. Additionally, the presence of organic carbon within the soil boosts microbial processes and enhances soil richness. Green manuring serves various valuable purposes and has a wide range of positive effects. As a result of growing awareness during challenging times, there is increasing interest in organic farming, which contributes to a cleaner and healthier environment. The significance of nutrient management using organic sources, particularly green manuring, becomes more pronounced in this context (Maitra *et al*., 2018).

Green manuring is an excellent strategy for maximising crop development. Green manure is a type of manure that is made from un-decomposed plant material (Rani *et al*., 2021). Green manuring refers to agricultural practices that involve incorporating both leguminous and non-leguminous green plants into the soil. This can be achieved by growing these plants in the same location (in situ) or cultivating them elsewhere and then transferring them to the soil for the purpose of improving fertility. Green manuring serves as a valuable resource in both organic and conventional farming methods, effectively enhancing the overall soil quality (Maitra *et al*., 2018). According to Pandey *et al*. (2008), green manuring enhanced the biochemical and physical structure of the soil, reduced nutrient depletion through leaching and increased water retention capacity. Egodawatta *et al*. (2011) declared that the regular adoption of green manuring led to significant increases in organic matter stocks, enhancing both the chemical and physical properties of the soil in contrast to controlled plots. Moreover, incorporating green manures into crop sequences facilitated nutrient recycling, thereby boosting the soil's capacity to sustain crops. As a result of these improved soil attributes, the fertile land exhibited higher crop yields. Some research revealed that green admixture has a high potential for nutrient exchange to crops and improving soil characteristics (Adediran *et al*., 2004; Shah *et al*., 2010; Imoro *et al*., 2013; Carvalho *et al*., 2015). Green manure crops are typically legumes, which means that they can fix nitrogen from the atmosphere. This is a valuable characteristic, as nitrogen is an important nutrient for plant growth. Green manure crops are grown in the field and then incorporated into the soil after reaching a certain size. The practice of adding biomass, either through the use of green manure (preferably from leguminous plants) or by keeping crop residues in the soil, is recognized for boosting the buildup of soil organic carbon. This practice holds significance in the sequestration of carbon within soils found in tropical and subtropical areas (Jastrow *et al*., 2007; Nandan *et al*., 2019).

Eriksen (2005) acclaimed that using green manures in soil encourages the growth of beneficial microorganisms, leading to the release of essential nutrients for plants. Green manures derived from leguminous plants have the capability to capture nitrogen from the atmosphere and offer organic nutrients, while non-leguminous ones increase organic nutrient content in the soil, which has been known to improve soil quality since ancient times. Previous studies showed that compared to chemical fertilizers, green manure and organic manure amendments provide nitrogen to the soil for a longer period, leading to nutrient accumulation (Ma *et al*., 2020; Zhou *et al*., 2022). Park *et al*. (2017) reported that green manures like white clover, rat thatch and smooth vetch applied in the soil markedly enhanced the availability of N, P and K. Newly incorporated green manure additionally stimulates soil microbe growth, enhances soil structure and aids in nutrient retention and cycling (Garcia-Franco *et al*., 2015; Ma *et al*., 2020). Organic amendments with a narrow C/N ratio (< 25), such as rapeseed cake and smooth vetch, can satisfy microbial nutrient demands and lead to net nutrient mineralization (Hadas *et al*., 2004).

2.3 Green leaf manuring in wetland paddy fields

Green leaf manuring refers to the practice of applying twigs and leaves from herbs, shrubs and trees that are collected from different locations. Leaves from forest trees serve as the primary source of green leaf manure, while plants growing in field bunds, wastelands and similar areas also contribute to this type of organic fertilizer (Rani *et al*., 2021). The following are examples of long-lasting, versatile shrubs and trees utilized for green leaf manuring: wild indigo (*Tephrosia purpurea*), mahua, Calotropis, karanji (*Millettia pinnata*), *Sesbania* (*Sesbania grandiflora*), *Gliricidia* spp., *Leucaena leucocephala* (subabul), *Cassia auriculata*, *Cassia siamea*, *Cassia tora*, *Tephrosia candida*, *Azadirachta indica* (neem), *Dodonea viscosa*, *Cassia accidentalis*, *Delonix elata*, *Vitex negundo*, *Hibiscus viscosa*, *Cassia nigricans*, *Peltophorum ferrugenum* and *Delonix regia* (Maitra *et al*., 2018).

According to Ansari *et al*. (2022), *Sesbania* utilized as green leaf manure exhibited the greatest total biomass buildup (exceeding 30 Mg ha^{-1}) and introduced a significant quantity of carbon input (more than 14.0 Mg ha^{-1}) into the soil. The nitrogen level of *Sesbania* above ground biomass was 2.0 per cent, whereas the C content was 47 per cent, with a significant addition of 47.5 kg N ha^{-1} $year^{-1}$. Because it was leguminous, it possessed a narrow C: N ratio (23.5:1.0), which favoured rapid breakdown and the release of more labile fractions of the C pool. *Sesbania*'s decreased C: N ratio might have played a major role in nutrient release and soil quality improvement. Hence, *Sesbania* can be used as a green leaf manure to improve soil C and nutrient dynamics. It can also help to enhance soil biological processes related to nutrient buffering, organic C cycling and microbial biomass C.

Traditionally, farmers apply neem (*Azadirachta indica*) leaves as green leaf manure to rice fields. It is recommended to blend neem cake with urea to inhibit nitrification and improve nitrogen use efficiency. Applying either 5 t/ha of fresh neem leaves or 1.25 t/ha of dried neem leaves along with urea led to a greater percentage of nitrogen recovery and an improved nitrogen response ratio, resulting in enhanced grain yield in paddy compared to using urea alone. Moreover, neem leaf application can reduce N application by about 50 per cent and provide greater net returns to the farmer. Neem is a vigorously branching, large, evergreen tree that produces abundant foliage. It grows well in various soil types and is commonly planted along field borders, riverbanks, roadsides, wastelands and garden lands. Trees are usually spaced 5 to 6 meters apart and one or two loppings are done in favourable seasons, yielding about 150 to 200 kg of green matter each time. Neem leaves contain approximately 2.83 per cent nitrogen, 0.28 per cent P_2O_5 and 0.35 per cent K_2O (Santhi and Palaniappan, 1986).

Karanj (*Millettia pinnata*) is a nitrogen-fixing tree that enhances soil fertility in various crops (Usharani *et al*., 2019). It's an evergreen leguminous tree found in wastelands, coastal forests, tank bunds, along river banks, roadsides and streams. Lopping can be done once or twice a year, producing around 100 to 150 kg of green material per lopping. Leaves of Karanj contain approximately 3.31 per cent nitrogen, 0.44 per cent P_2O_5 and 2.39 per cent K_2O.

Subabul (*Leucaena leucocephala*), a shrub native to Central America, shows great promise as a forage tree crop. Its leaves contain approximately 3-4 per cent nitrogen and it fixes around 500-600 kg of nitrogen per hectare per year. A study by Sharma and Behera (2010) found that combining green leaf manure, Leucaena pruning and urea fertilizer on an equal nitrogen basis resulted in higher productivity, profitability and efficient nitrogen utilization. This approach contributed to fertility improvement, leading to the long-term sustainability of the maize-wheat cropping system.

Cassia is also the most famous green leaf manuring tree in India. *Cassia* (*Cassia auriculata*) is a shrub adorned with large, vibrant yellow flowers. It is propagated through seeds and during flowering, the tree is pruned by cutting the stem and branches and the cuttings are used for green leaf manuring. The plant can reach a height of 7 meters and blooms twice in India during early and late monsoons. It is highly valuable as a green manure crop and thrives in light, porous soils. *Cassia* is not susceptible to browsing by cattle and goats, making it easy and inexpensive to raise plantations. The most cost-effective cultivation method is sowing in furrows spaced 2 to 5 inches apart and 4 to 6 inches deep. This plant is native to India and the seeds are collected between May and June (Maitra *et al*., 2018).

Many farmers are adding green leaf manuring into their practices as a result of the expanding difficulties confronting agriculture, such as climate change, extreme weather events, soil degradation and land pollution caused by the overuse of chemical fertilizers (Pappa *et al*., 2006). However, not all farmers utilise green leaf manuring nowadays. Human-induced land degradation is particularly important, given the enormous loss of soil fertility caused by poor agronomic practices. Green leaf manuring is a practical and cost-effective technique to ensure agricultural soil production in the long run. Some farmers have chosen to use green leaf manures as a result of improved soil fertility management and have proclaimed their commitment to long-term agricultural sustainability. Green leaf manures can play an important role due to their good impacts on the physical, chemical and biological quality of the soil, as well as the adequate maintenance of soil fertility (Iderawumi and Kamal, 2022)

2.4 Status of Green leaf manuring in Kerala

Some farmers engage in on-site green manuring within paddy fields; however, a common concern is that this practice leads to the loss of a valuable crop season since the field is occupied by the green manure crop. This issue can be addressed through the practice of green leaf manuring, which involves gathering green biomass from nearby areas and incorporating it into the soil. Green leaf manuring (GLM) is a sustainable agricultural practice that involves incorporating freshly cut green leaves of various plant species into the soil to improve soil fertility and crop productivity. Historically, green leaf manuring has been practiced in various forms across different agricultural systems. In Kerala, paddy fields have a long tradition of utilizing green leaf manures to enhance soil fertility and support sustainable rice cultivation (Jayanarayanan, 2001). The declining ratio of forests-to-agricultural lands and the increased intensity of land use increased the pressure on remaining forests due to the illicit cutting of trees (for firewood, charcoal and for making agricultural implements), overgrazing and collection of fodder, green leaf manure, litter and non-wood forest products (Amruth, 2004; KFRI, 2005).

Small-scale farmers with limited access to chemical fertilizers were obligated to gather green leaves and litter from the forest floor. They did this to assist in the growth of subsistence crops or for fuel purposes. Moreover, prioritized attention should be given to generating organic manure and cultivating green manure crops within the farm. Additionally, there should be an emphasis on enhancing on-farm timber and fodder production through integrated tree and crop production systems (Kumar *et al.,* 2018).

Kumar *et al*. (1992) explained that in Kerala, there were common occurrences of live fences made from small trees and shrubs. Species such as *Vitex negundo*, *Jatropha curcas*, *Gliricidia sepium*, *Manihot glaziovii*, *Morinda tinctoria*, *Adhatoda vasica*, etc., were commonly found. Bamboo thorns were also widely used for fencing. Moreover, in many upland agricultural production systems, multipurpose trees like *Gliricidia sepium, Macaranga peltata, Leucaena leucocephala,* etc., provided green leaf manure and fodder. Larger farmers (with holdings larger than 2.5 hectares) were self-reliant in terms of green leaf manure and firewood. They mainly fulfilled their green leaf manure needs from fast-growing tree species planted along the farm boundaries. Additionally, medium and large farmers maintained separate farm woodlots to meet the demands for green leaf manure, fuelwood and timber. However, in various instances, a significant portion of the green leaf manure requirement was fulfilled using resources from nearby reserve forests, wherever they existed.

Nevertheless, because conventional sources of green leaf manure were not accessible and due to limitations in labour and transportation, farmers largely overlooked this practice. Given this situation, the cultivation of rapidly growing trees and shrubs for green leaf manure within rice bunds could offer solutions to these challenges and guarantee the presence of on-farm green biomass.

2.5 Selected tree species for this study

Gliricidia sepium **(Jacq.)Walp.**

Gliricidia sepium is a rapidly growing tree with nitrogen-fixing abilities, widely utilized across tropical regions for its numerous environmental benefits and valuable products. It is commonly employed to offer ample shade for cacao, coffee and other crops that thrive in shaded conditions. Additionally, *Gliricidia* serve as living fence posts for pastures and property boundaries and help improve degraded land when used as a fallow tree. They can be planted on alternate field bunds in wetlands, spaced 1 to 2 meters apart, or densely as hedges in three to four rows at 0.5 meter spacing. Additionally, they are suitable for planting along field borders as tall shrubs to support the fence line or along farm roads on both sides to produce green leaves. The presence of *Gliricidia* trees does not negatively impact the growth of cultivated crops due to their shading effect. Farmers find it convenient to propagate through seeds and small or large cuttings, making it an easily multiplied tree, providing green leaf manure, fodder and fuel wood. It exhibits robust regrowth when pruned, especially during periods of active growth (Elevitch and Francis, 2006). To utilize the shrub for green leaf purposes, it is recommended to keep it at a height of 2-3 meters through regular pruning or lopping. The shrub can withstand repeated lopping and can be pruned two or three times a year. After two years of planting, the shrub is ready for lopping and each plant yields 5 to 10 kilograms of green leaves annually. The leaves have a composition of 2.76 per cent nitrogen, 0.28 per cent phosphorus (P_2O_5) and 4.60 per cent potassium (K_2O) (Bah and Rahman, 2001). Cultivating *Gliricidia* on farm bunds fulfils a dual role: it generates nitrogen-rich green leaf manure and aids in soil conservation by minimizing soil erosion (Manasa *et al*., 2022).

Significant research was carried out in the 1920s in India and Sri Lanka regarding the utilization of *Gliricidia* for green leaf manuring (Anonymous, 1928). Studies investigated the impact of *Gliricidia* mulch on aspects like soil moisture, C-to-N ratios and yields under various pruning methods (Joachim and Kandiah, 1934). The Indian Government recommended the planting of *Gliricidia* around rice fields to lessen the need for traditional fertilizers. Research conducted in the 1950s at Coimbatore revealed that when *Gliricidia* was planted with a 2-meter spacing along bunds, it could generate 4.0 tons of dry leaf matter per hectare (equivalent to 120 kg of nitrogen). Applying 5 tons of *Gliricidia* mulch per hectare three weeks before rice planting boosted grain and straw yields by 15-45 per cent. Experiments carried out in Sri Lanka demonstrated that incorporating *Gliricidia* green leaf manure alongside chemical fertilizers led to a 60 per cent increase in rice yields. *Gliricidia* has proven effective as green manure for various crops such as rice, cassava, cowpea, maize, taro, sugarcane and yam (Agboola *et al*., 1982; Gohl, 1981; Kidd and Taogaga, 1985). Notably, in-depth investigations into maize production with *Gliricidia* mulch were carried out at the International Institute of Tropical Agriculture (IITA) in Nigeria (Kan *et al*., 1985). *Gliricidia* exhibits robust coppicing and can endure regular pruning. Data on green leaf yield indicates that approximately 1-3 tons of dry leaf material can be produced monthly from 10,000 trees per hectare.

In numerous countries, the process of nodulation in various species plays a role in generating nitrogen-rich (with nitrogen content ranging from 2.9 per cent to 4.3 per cent) green manure. As outlined by Kan *et al*. (1985), a single ton of *Gliricidia* leaf meal (in terms of dry matter) offers the subsequent nutrient quantities: Nitrogen ranging from 29 to 43 kilograms, Phosphorus at 2.9 kilograms, Potassium between 16 and 26 kilograms, Calcium at 14.0 kilograms and Magnesium at 5.4 kilograms.

***Garuga pinnata* Roxb.**

Garuga pinnata, recognized by the popular names Kanji or Kanju, is a deciduous tree that falls within the Burseraceae family. Its origins trace back to diverse parts of Asia, encompassing the Indian subcontinent and Southeast Asia. This tree finds its place in Indian home gardens, valued not only for its consumable fruit but also for its role as a supportive growth *for Piper nigrum* (Chavan *et al.*, 2019). The exploration of *Garuga*'s capacity for green leaf manuring remains an area that has received limited attention in research.

***Sesbania grandiflora* (L.)Pers.**

Sesbania grandiflora is a small, loosely branching tree with a height of 8 to 15 meters. The stem is covered in fine hairs with no thorns and the roots typically have noticeable nodules. Additionally, the tree has the ability to produce floating roots. *Sesbania grandiflora* is commonly cultivated in gardens and around crop fields to enrich the soil with nitrogen. The light shade provided by its canopy doesn't hinder the growth of companion plants and its falling leaflets and flowers contribute nutrients to the soil. Its rapid growth makes its seedlings useful for green leaf manuring, much like other annual green manure crops. The fruits, leaflets and flowers are effective as green leaf manure or mulch, enhancing soil fertility. This plant is especially valuable for rehabilitating eroded soils. It is well-suited for hot and humid climates. It thrives in lowland regions and doesn't tolerate cooler temperatures below around 10 °C. It displays excellent resilience to waterlogging, making it ideal for environments with seasonal flooding. During floods, it produces floating roots and shields its stems. It prefers a rainfall pattern with two distinct peaks, growing rapidly in the wet season, yet it can endure extended dry spells of up to 9 months. While it lacks resistance to strong winds, it's commonly found along rice bunds, roadsides, home gardens and mixed croplands. *Sesbania* is the best suited for wetter and humid locations and can flourish in a variety of soils, including poor, waterlogged, saline, alkaline and even heavy clay soils. It also exhibits some tolerance for acidic soils (Karmakar *et al*., 2016).

***Calliandra calothyrsus* Meissner**

Calliandra calothyrsus is a versatile plant widely employed in various agroforestry applications across tropical regions. Among farmers, *Calliandra* emerged as the top choice for hedgerows due to its popularity. The plant has proven effective in rehabilitating erosion-prone sites like recently cleared forests and steep slopes at high risk of erosion. Its strong lateral root structure contributes to soil stabilization. As a nitrogen-fixing tree, *Calliandra* has been utilized as green leaf manure in soil improvement strategies. Notably, the ability of *Calliandra* to produce abundant high-protein leaf material on less fertile soils renders it an excellent choice for green manure. The plant has shown adaptability to various soil types and environmental conditions, including nutrient-deficient soils, attributed to its symbiotic relationship with beneficial fungi and its rapid nodulation capability. Moreover, *Calliandra* helps to enhance nutrient uptake, increases topsoil organic matter without excessively shading annual crops, improves soil structure and reduces soil erosion (Kisaka *et al*., 2023). Kabi and Bareeba (2008) found that *Calliandra* could yield up to 45.9 Mg ha^{-1} yr^{-1} in quarterly harvests within just two months, thus rendering it valuable for green residues. Mucheru-Muna *et al.* (2014) found that *Calliandra* has the capacity to effectively enhance the chemical, physical and biological attributes of soils in a sustainable manner. Additionally, it plays a crucial role in enhancing soil nutrient levels by harnessing atmospheric nitrogen through its symbiotic relationship with rhizobium bacteria. Therefore, *Calliandra* is a viable solution for crop reduction due to nutrient deficiency.

***Terminalia arjuna* (Roxb.) Wight & Arn.**

Terminalia arjuna has shown promise on sodic soils due to its ability to thrive even in waterlogged conditions, which are common in such locations (Jain and Singh, 1998). *Terminalia* is an impressive evergreen tree with a distinctive buttressed and fluted stem, wide crown and drooping branches. Typically, it reaches a height of around 24 meters and a girth of 3 meters. In more favourable areas, such as along stream banks, it can grow up to 30 meters tall and 3.6 meters in girth (Kumar *et al*., 2018). Various tree leaves biomasses like *Terminalia*, neem, pitraj, mahogany and eucalyptus serve as valuable sources of organic matter. They contribute significantly to improving soil fertility and supplying crucial nutrients like nitrogen, phosphorus, potassium and sulphur. The decomposition of leaf litter impacts the availability of nitrogen for plant uptake. Leaf litter delivers essential carbon, nitrogen, phosphorus, potassium and other nutrients to the soil, which are key indicators of soil productivity and ecosystem health. Unfortunately, leaf litter is often wasted through various means. Utilizing these materials as sources of organic matter for rice cultivation could lead to reduced reliance on chemical fertilizers like urea (Khan *et al*., 2010). Similarly, Akter *et al*. (1993) found that combining green manure with chemical fertilizer resulted in significantly higher yield parameters compared to using chemical fertilizer alone. These treatments notably affected plant height, panicle length, effective tiller count per hill, grains per panicle and grain yield.

***Morus indica* L.**

Mulberry stands as a rapidly growing deciduous tree of medium size, holding substantial promise due to its nutritionally rich leaves containing abundant crude protein. Its noteworthy attributes encompass a higher yield of biomass, which can endure extensive pruning, alongside a commendable capacity for coppicing (Raj *et al*., 2016). In nations like India, where mulberry primarily serves sericulture, surplus leaves and remnants serve as feed for livestock such as cattle, sheep and goats while also finding utility as organic fertilizers (Patrick, 2019). Akbulut and Ozcan (2009) delved into mulberry's chemical composition, revealing its remarkable richness in essential elements like calcium, magnesium, potassium, phosphorous, sulphur and sodium. Cronje (2001) conducted a study about the impact of plant materials from *Morus alba* (mulberry) on soil characteristics through small plots and greenhouse trials. The results of that study revealed that mulberry thrives in various environments and can supply materials for fuel, fodder, or improving soil quality. In the short term, using mulberry as green manure or mulch led to improved water use efficiency and plant growth. *Morus alba* can provide materials for fuel, fodder and soil improvement in the form of green manure or mulch.

***Gmelina arborea* Roxb. ex Sm.**

Gmelina arborea is a woody species and is suggested for planting along bunds and boundaries. *Gmelina* showed the highest yields of dry matter and nitrogen. Over cropping seasons, the prunings of *Gmelina* accumulated approximately 524 kg N per hectare. Research even suggested higher nitrogen fixation with *Gmelina* (Amara *et al*., 1996). *Gmelina* leaves decompose easily and are known to contain more protein, making them a valuable source of nitrogen and phosphorus when used as green manure. Using them for this purpose improved organic carbon, total nitrogen, available phosphorus and exchangeable potassium in the soil compared to control soil (Bora *et al*., 2008).

Wilson *et al*. (1986) explained *Gmelina* as a rapidly growing timber tree native to Asian rainforests. However, it isn't well-suited for acidic soils or unfavourable climates due to its transitional nature. Successful introductions of *Gmelina* have been carried out in Nigeria, where it is integrated into a taungya system during its initial two years of growth alongside root crops, grains and vegetables.

***Cajanus cajan* (L.)Millsp.**

Sarkar *et al*. (2018) explained cultivating *Cajanus cajan*, also known as pigeon pea, can provide 40-60 kg N/ha for the next crop. Its leaves and young stems can be used as green manure and fallen leaves help prevent erosion from heavy rains and lower soil temperatures. The plant's strong root system improves soil structure and water retention, extracting nutrients like phosphorus from deep layers and depositing them where other crops can benefit. They also found that after 75 days of decomposition, the plant material has a C/N ratio of 14.4, N content of 29.99 g/kg, P content of 3.0 g/kg, K content of 19.91 g/kg, Ca content of 7.21 g/kg and Mg content of 2.50 g/kg. Cardoso *et al*. (2006) suggested combining pigeon pea and sun hemp to manage bacterial wilt. Another study found that upland rice production was the most successful with *Gliricidia sepium*, followed by *Leucaena leucocephala*, *Cajanus cajan* and *Cassia siamea* (Yasmin *et al*., 2022). In the Eastern Vidharbha region, paddy field bunds are used for pigeon pea cultivation due to their size. Multiple seeds are sown in a single hill and plants develop many branches along the bunds. If some plants die, others compensate for the biomass loss (Saxena *et al*., 2010). Numerous studies also reported red gram cultivation on rice bunds in India (Joshi *et al*., 2005; Soyam *et al*., 2022; Bankar *et al.*, 2016). Red gram (perennial) is also widely cultivated in the paddy bund of the Palghat region of Kerala, mainly for serving as windbreaks.

***Senna siamea* (Lam.)H.S.Irwin & Barneby**

Senna siamea, often still referred to by its previous name, *Cassia siamea*, has leaves that are used as green manure in fields. This practice contributes significantly by slowly releasing nitrogen to crops and addressing weed control problems as the leaves decompose gradually. *S. siamea* is a medium-sized tree, typically not surpassing 20 meters in height, more commonly ranging from 10 to 12 meters, although it can reach up to 30 meters in exceptional cases. It features a dense, round, evergreen crown and a short trunk with smooth, gray bark that shows slight longitudinal fissures. In India, these trees consistently have leaves, although a new set of leaves emerges in February-March. Despite being a member of the

Fabaceae family (legume family), it's now widely understood that *S. siamea* does not engage in nitrogen fixation through Rhizobium symbiosis in nodules (Meena *et al*., 2020). Significant studies showed *Cassia siamea* is the most suitable tree in Asia for green leaf manuring due to its adaptability and foliage production (ICSU, 1988). Manasa *et al*. (2022) recommended *Cassia siamea* as the best tree species for planting on rice bunds. Based on research conducted by MYRADA (Mysore Resettlement and Development Agency) during 2005-06 in Karnataka, *Cassia siamea* emerged as the predominant tree in both dryland and irrigated fields. Farmers noted its rapid growth and ability to yield high-quality fuelwood (Manasa *et al*., 2022).

Cassia displays vigorous coppicing behaviour, generating 2 to 5 new shoots from each stem. Approximately 70 per cent of its biomass comprises leaves and *Cassia* has the potential to yield up to 10 tons of dry matter per hectare annually and forms a beneficial partnership with annual crops. *Cassia* prunings break down at a rate of 85 per cent of their dry biomass in 120 days. Although the leaves of *Cassia* offer nutrients to growing crops, applying its prunings as mulch might result in nitrogen loss due to volatilization or leaching, especially in sandy soils. Nutrients from *Cassia* prunings become available for release 3 to 6 weeks after application. Additionally, as *Cassia* can be used for fuelwood, integrating it into alley-cropping systems leads to economic returns nearly twice as high as those from crops grown without trees (Danso and Morgan, 1993).

2.6 Agroforestry in Paddy Fields

"Agroforestry is the deliberate integration of trees with agricultural crops and/or livestock on the same plot/unit of land, either simultaneously or sequentially" (Nair, 1993). Agroforestry can also be described as a dynamic and ecologically grounded approach to managing natural resources. Incorporating trees into farmlands and the agricultural environment enhances production diversity and sustainability, leading to greater social, economic and environmental advantages for land users at all levels. In essence, agroforestry involves deliberately integrating trees and shrubs with crop and livestock farming, often organized in specific spatial or temporal patterns within the same area (FAO, 2015). They are very important for conservation because of their structural complexity, rich floral diversity and striking resemblance to real forest ecosystems. The broad spectral potential of agroforestry practices in agricultural sustenance as they provide food, fodder, fruit, vegetables, fuel wood, timber, medicines, fibre and so on from the same piece of land at the same time, which not only meets people's needs but also raises their socioeconomic status and standard of living (Pathak *et al*., 2000). Agroforestry is practised in a variety of ways in India, including trees on farmlands, shelterbelts, windbreaks, home gardens, various tree-based agroforestry practices, pasturelands, alley cropping, block plantings, dispersed trees in the field and so on (Handa *et al*., 2015).

Additionally, the Indian government is supporting tree-centred farming to increase farm profits and offer sustainable livelihoods to farmers. This involves a program called the Sub-Mission on Agroforestry that began in 2016-17. The aim is to encourage planting trees on farmland, known as "Har Medh Par Ped," alongside crops (GOI, 2021). In line with this, bunds and boundaries within farmlands provide an excellent opportunity to fulfil the mission's goals without causing major competition with agricultural crops. Bunds on farms are seen as promising areas for agroforestry. In such cases, versatile tree species are usually selected for planting on field bunds to yield benefits like fruits, fibre, fuelwood, fertilizer, food and medicine. Planting trees and shrubs as boundaries around individual plots, which also serve as markers, can offer various advantages like fences, timber sources, windbreaks and shelterbelts (Manasa *et al*., 2022).

A bund is a line of earthen ridges used to control soil erosion and water runoff, demarcate plot boundaries and for other purposes (Nair, 1993). A bund is a raised line of soil designed to manage water flow and prevent soil erosion, as well as mark plot boundaries or serve other purposes. These structures control the length of the slope, reducing the speed of runoff to prevent gullies formation. Bunding is a cost-effective method with two advantages: conserving soil and water and promoting sustainable intensification of agriculture. This approach aids in boosting crop yields without the need to expand farmland (Birhanu *et al*., 2019).

Boundary planting is often called living fences or barrier planting, as it involves planting trees along various types of boundaries. This usually includes planting trees alongside these borders, which serves the dual purpose of preventing soil erosion and enhancing soil fertility. Many tree species have extensive root systems that, along with the fibrous roots of some species like bamboo, help protect the soil from erosion and runoff. These tree root systems improve soil fertility through nitrogen fixation and the transportation of minerals from deep soil layers to the surface through leaf litter. In agroforestry, a well-chosen mix of versatile and nitrogen-fixing trees with field crops is vital. This combination greatly improves crop productivity, enriches soil nutrient levels, enhances microbial activity and ultimately maintains a balanced ecosystem through effective nutrient cycling (Manasa *et al*., 2022).

It was determined that agroforestry covers approximately 25.32 million hectares in India, accounting for 8.2 per cent of the total land area of the country (Dhyani *et al*., 2013). Using information from CAFRI, Jhansi and Bhuvan LISSIII, the extent of agroforestry covers about 13.75 million hectares (Rizvi *et al*., 2014). About 1.58 million hectares of land in India have been planted with trees on bunds or boundaries of agricultural fields through social forestry programs (Arunachalam *et al.*, 2022). In the state of Maharashtra, out of the total 14.321 million farmers, 85 per cent were engaged in dry land farming. Their primary occupation involves seasonal agriculture combined with perennial woody elements along the boundaries and bunds of their crop fields. An assessment of traditional agroforestry methods in districts like Bagalkot, Gulbarga, Koppal and Raichur in the dry northern region of Karnataka revealed that around 88.4 per cent of farmers practiced bund planting as the predominant approach, especially in rainfed conditions (Manasa *et al*., 2022).

2.6 Scope of bund planting in paddy fields

In dryland regions of agricultural fields, trees are commonly planted on raised field edges called bunds and/or along the borders to mark the field boundaries. This strategy optimizes the space on the bund. If a tree species grows upright, the crops nearby aren't negatively affected by the tree's shade. Planting trees in linear strips has always been recognized as a beneficial approach to conserving soil, either on its own or alongside certain herbs or grasses. Trees planted alongside grasses on bunds or boundaries serve two key roles: they stabilize the structure and check erosion. Additionally, bund planting on terrace edges can help stabilize structures and prevent erosion on the terraces' contours. This approach maximizes usable land for farming on these terraces. In areas with sandy and weakly structured soils, particularly in paddy field regions, long-lasting bunds require reinforcement, often provided by tree roots. In such cases, these bund plantations assist in maintaining their shape and making the occupied area productive. Generally, gentle slopes (less than 6%) are suitable for tree planting alone, whereas steeper slopes necessitate combining trees with herbs or grasses (possessing fibrous root systems) as both tree and grass roots contribute to stabilization. Studies have indicated that trees planted along field bunds, serving as windbreaks or shelterbelts, mainly decrease wind speed and modify the local climate. This alteration impacts the growth and progress of nearby crops, consequently influencing crop yield. Utilizing farm bunds could be a valuable strategy for cultivating nitrogen-fixing shrubs and trees, which can contribute to nitrogen-rich prunings. For instance, growing *Gliricidia* on farm bunds accomplishes two objectives: it yields nitrogen-rich green leaf manure and contributes to soil conservation by decreasing soil erosion (Manasa *et al*., 2022).

In 1991, MYRADA and the International Institute for Rural Reconstruction (IIRR), supported by the Ford Foundation, initiated a project in partnership with Kamasamudram farmers in Karnataka's Kolar District. A significant aspect of the program involved enhancing soil organic matter through the utilization of leaves as fertilizer. This practice is familiar to wetlands where tree leaves, such as *Pongamia*, are added to cultivated soils. Nonetheless, dryland farmers rely solely on farmyard manure (cattle dung) for their fields. The concept of producing and integrating leaf matter on-site was unfamiliar. The proposed approach employed bunds to facilitate the growth of additional vegetation (trees). This study focused mainly on the impact of trees on agriculture. Farmers reported using green leaves as manure either alone (in irrigated paddy fields) or mixed with cow dung (in drylands, usually 30-50% of FYM). Traditionally, irrigated land farmers apply green leaves to paddy fields. Before planting trees on their bunds, they were used to gather leaves from nearby forests, which were inadequate. Farmers who applied 400 kg of leaf matter per acre after the implementation of the project used 2,000-3,500 kgs from their trees. *Cassia siamea* is used more widely than Pongamia leaves. Some farmers still supplemented their leaf production with those harvested from the forest. This led to a significant reduction, around two-thirds, in the application of chemical fertilizers (MYRADA, 2009).

2.7 Growth and green biomass production of green manuring trees in paddy bunds.

The existing body of literature regarding the growth and biomass production of green manuring trees in paddy bunds is quite limited. Only a handful of researchers have undertaken studies on this particular subject. A study conducted in Coimbatore during the 1950s revealed that planting *Gliricidia* trees at a distance of 2 meters along bunds resulted in a production of 4.0 tons of dry leaf matter per hectare (equivalent to 120 kg of nitrogen). Application of 5 tons of *Gliricidia* mulch per hectare three weeks prior to planting increased rice grain and straw yields by 15-45%. Similarly, experiments conducted in Sri Lanka demonstrated that incorporating *Gliricidia* green leaf manure alongside inorganic fertilizers led to a remarkable 60 per cent increase in rice yields. Typically, a mature plant produces approximately 12-15 kg of fresh vegetation. Around 400 plants situated along the outer edges of bunds result in a total of 5-6 tonnes of fresh organic material per hectare, according to research by Yasmin *et al*. (2022).

In the case of *Eucalyptus tereticornis,* the trees experience significant growth in height during the period from planting paddy to harvest. *Eucalyptus tereticornis*, for instance, saw its average height rise from 8.60 meters to 8.64 meters after the paddy crop was harvested. The Diameter at Breast Height (DBH) of eucalyptus also exhibited growth after paddy harvesting, increasing from an initial 24.23 centimeter to 24.96 centimeter. Intercropping with paddy had a positive impact on both tree height and DBH, unaffected by paddy crops, diseases, or pests. This observation underscores the mutual benefits of intercropping (Tripathy *et al*., 2021). Certain research studies have indicated that *Sesbania grandiflora* exhibits increased foliage production when cultivated along paddy fields (Yasmin *et al*., 2022). The literature review in this field highlights the scarcity of studies and the need for further exploration.

2.8 Crop interaction of green manuring trees in paddy bunds

The relationship between crop interactions and green manuring trees in paddy bunds has garnered attention in various research studies. Numerous studies present conclusive evidence supporting the advantageous effects of trees planted along bunds and boundaries, which enhance crop yields by improving the soil's physicochemical properties. Additionally, in arid regions, a significant number of farmers can utilize pruned branches, combining them with farmyard manure in a ratio of 30 to 50 per cent for composting purposes. These branches can also serve as fuelwood. An average observation from MYRADA's study in the Kolar region of Karnataka indicated that farmers noted a roughly 98 per cent increase in rice yields since they began incorporating larger amounts of leaf matter into irrigated plots. Similarly, there was an approximately 67 per cent rise in dryland crop yields. All participating farmers highlighted the augmented moisture-holding capacity in their fields, which contributed to improved crop yields by enabling the crops to endure longer dry periods without experiencing moisture-related stress (MYRADA, 2009). The impact of planting *Populus deltoides* 'G-3' trees in a single row along the southern aspect of the field, aligned in an east-west direction, on the growth and yield of wheat crops was examined. The findings indicated an enhancement in wheat grain yield in close proximity to the trees (Sharma and Singh,1992). In a similar vein, Sahoo *et al*. (2009) noted that introducing *Jatropha* *curcas* plantations along the bunds maintained agricultural production levels while also generating extra biomass and seed yield from these plants.

While integrating trees with rice offers numerous advantages, careful consideration is necessary due to potential factors: (i) the competition for light, nutrients and water; (ii) the potential for harbouring plant diseases and pests, along with their natural adversaries; and (iii) the limited compatibility with mechanized rice farming. Some tree species could have adverse effects, such as shading on rice and the risk of hosting pests and diseases. Additionally, tree roots might compete with rice for water and nutrients. Effective agroforestry systems should include trees that utilize water that would otherwise evaporate, runoff, or drain from the rice fields. However, trees can tap into underground water sources inaccessible to rice's shallow root system. This competition over nutrients can be mitigated by pruning the trees, which benefits rice and the trees. The residues from pruning can serve as fodder and organic fertilizer, offering further advantages to the system (Wangpakapattanawong *et al*., 2017).

Mankur *et al*. (2022) conducted a study about the interaction of rice and teak in Chhattisgarh. The findings of this study revealed that the presence of boundary plantations of teak (*Tectona grandis*) negatively affected the growth and yield of rice due to the shading caused by the trees. The impact on the growth of teak boundary plantations varied based on the diameter at breast height (dbh) and width of the tree crown, as well as the distance from the tree line. The yield and attributes of rice increased as the distance from the tree lines increased. The width of the crown played a significant role, with the maximum crown width of the trees causing a more substantial reduction in rice yield and yield characteristics than the minimum crown width. Light availability is the primary factor in the competition between trees and crops. The tree canopy reduced light intensity to different degrees at varying distances from the tree line. Consequently, it can be deduced that a smaller crown width and increasing distance from the tree line of *Tectona grandis* has a lesser impact on the growth and yield of rice than trees with a larger crown width located closer to the tree line.

The observations from the study of Tripathy *et al*. (2021) indicate that within the agroforestry framework, the distinct yield characteristics of paddy crops, encompassing plant height, tiller count per plant, panicle length, grains per panicle, weight of 100 grains and grain yield per hectare, experienced only minimal reduction in comparison to the control crop field where paddy was cultivated as a sole crop. The presence of trees established on field bunds exerted a favourable influence on the microclimate within the field. Additionally, at the stage of maturity, these trees generated substantial income through their woody biomass, underscoring the sustainability of this agricultural system.

Because of the overshadowing impact and robust root system of trees along bunds and boundaries, they engage in competition for available resources with crops, leading to relatively diminished grain yield near the tree lines. Trees positioned at the edges offer supplementary income to farmers while causing minimal disruption to diverse agricultural activities and crops. Moreover, in India, there exists a significant number of small-scale and subsistence farmers who find it economically unfeasible to establish forest plantations at the expense of agricultural crop productivity. This is due to the fact that yield reduction can range from 30 to 50 per cent in block plantations, whereas it amounts to 15 to 20 per cent in boundary plantations. Furthermore, with increasing distance, there is a corresponding rise in grain yield (Manasa *et al*., 2022).

2.9 Soil fertility changes associated with tree planting in paddy bunds

Green manure trees are often cultivated between the major crops to minimise soil erosion, act as winter cover crops, or boost the productivity of depleted land. It helps to preserve soil fertility and general soil condition by integrating nutrients like nitrogen into the soil. Green manuring trees promote the growth of beneficial bacteria while also increasing soil diversity.

Growing green manures offers several benefits, including the release of nutrients from plant biomass. Nitrogen (N) is a crucial nutrient and its mobility in the soil has gained attention (Giacomini *et al*., 2003). Members of the Fabaceae family, capable of fixing nitrogen, are particularly suitable for green manuring. This trait reduces the reliance on conventional chemical fertilizers while increasing the economic returns from agricultural activities. Moreover, green manure planting helps reduce herbicide residues and weed growth in paddy fields. Additionally, it enriches the soil by transferring certain heavy metals like Cd, Pb and Zn, thereby assisting in soil remediation (Lei *et al*., 2022).

Previous research indicates that the growth of green manuring trees in the soil stimulates the growth of soil microorganisms, leading to the mineralization of plant nutrients and improving soil quantity and quality (Doran *et al*., 1987; Eriksen, 2005). Green manures provide organic carbon-rich nutrients for the microbial biomass, converting dormant nutrients in plant residues into forms accessible to crops and promoting the diversity of soil microorganisms. Trees also maintain the soil moisture content. Some tree species form a beneficial partnership with specific soil bacteria that fix atmospheric nitrogen in nodules on the roots, providing nitrogen for current or future crops when dug into the soil during late winter or early spring.

2.10 PAR availability under bund plantations

The concept of PAR availability under bund plantations pertains to the way in which the design, spacing, orientation and canopy structure of the plantation impact the quantity and quality of light that crops under the canopy receive. PAR availability for crops growing under the bund is mainly affected by the shade of trees growing on the bund.

Mankur *et al*. (2022) explained the presence of tree shade is often identified as a factor leading to decreased crop yields in clustered plantations, affecting both plants that benefit from shade and those sensitive to it. The issue becomes more pronounced when trees are not properly pruned. Shade significantly influences the productivity of rice cultivation, leading to reductions in plant height, panicle formation per hill, panicle-to-grain ratio and, ultimately, grain production. The shade-induced effects on crops are further exacerbated if trees are left untrimmed.

This shading effect encourages rapid cell division and elongation, causing an increase in the length and height of plant blades. It is observed that the shading impact of trees often leads to diminished rice yields in the proximity of trees located at the plantation's edge.

Light competition can result in reduced nutrient utilization by shaded rice, particularly within a 5 m radius of certain non-nitrogen-fixing trees like Eucalyptus hybrids (Wangpakapattanawong *et al*., 2017). Shade from *Tectona grandis* trees had an adverse influence on the maximum growth and yield of rice (Mankur *et al*., 2022). Manasa *et al*. (2022) found that the presence of *Gliricidia* trees does not adversely affect the growth of cultivated crops due to their shading effect and the light shade from the *Sesbania* canopy does not impede the growth of companion plants; additionally, the falling leaflets and flowers of the *Sesbania* tree enrich the soil with nutrients.

2.11 Limitations and future perspectives of green leaf manuring in paddy bunds

Green leaf manuring was formerly extensively used, but interest in it has waned in recent years due to rising food production pressures, the emergence of other competitive and profitable crops and the availability of both cheap and expensive chemical fertilizers. To prevent and manage potential issues of crop interaction with green leaf manuring trees growing on bund: (a) Trees should be strategically planted along the path of the sun's movement to minimize shading and (b) Regular pruning of trees should be undertaken to optimize light availability and facilitate rainwater capture for the rice crop (Wangpakapattanawong *et al*., 2017).

In recent times, green manures have once again become relevant for both organic farmers and conventional low-input farms due to concerns about soil accessibility, soil fertility decline and public awareness regarding mismanagement and energy preservation (Kumar *et al*., 2006). Various research efforts have investigated the potential of utilizing green leaf manuring trees to enhance the growth and biomass production of paddy fields. However, it is evident that only a small number of researchers have taken on this topic. Consequently, the available literature primarily consists of a modest collection of studies and findings, often leaving gaps in our understanding. Researchers who have explored this area emphasize the significance of green leaf manuring trees in paddy bunds as a means to enrich soil quality and enhance crop productivity. These studies often underline the dual benefits of this practice: not only does it contribute to the nitrogen-rich foliage serving as organic fertilizer, but it also aids in soil conservation by stabilizing bunds and preventing erosion.

The limited literature suggests that the focus has primarily been on evaluating specific tree species' effectiveness, growth rates and biomass production within paddy bunds. Studies have occasionally highlighted the role of tree-root systems in nutrient cycling, soil structure improvement and the overall ecosystem health of paddy fields. However, the scarcity of comprehensive research on this topic underscores the need for a more comprehensive understanding of the interactions between tree species, their growth patterns and the resulting impact on soil fertility and crop yields. There is also room for research that investigates the potential of various green leaf manuring trees under different agroclimatic conditions.

In conclusion, the literature related to the growth and biomass production of green leaf manuring trees in paddy bunds remains limited, with only a few researchers having delved into this subject. As the importance of sustainable agriculture and soil conservation gains prominence, further research in this area is warranted to unlock the full potential of utilizing green leaf manuring trees for enhancing paddy field productivity and environmental sustainability.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The present study entitled "Growth, green biomass production and crop interaction of selected trees and shrubs on wetland paddy bunds" was carried out as two separate experiments. The main objectives of the study are to assess the growth and green biomass production of selected fast-growing trees/shrubs on wetland paddy bunds of Kerala and to study the impact of bund grown trees on paddy growth and yield. The study also documented green manuring practices in paddy fields of Ollukkara and Wadakkanchery blocks in the Thrissur district. The materials used and the methods adopted for the study are discussed in this chapter.

3.1 Experiment I. Green biomass production and crop response of selected trees/shrubs on wetland paddy bunds

3.1.1 Study area

The studies on the assessment of growth, green biomass production and crop response of selected fast-growing trees/shrubs on wetland paddy bunds was carried out in State Seed Farm, Mannuthy, Thrissur district of Kerala (Plate 1), which is the midland area lying within the geographical extremes of Latitude and longitude 10° 32' 24" N and 76° 15' 36" E.

3.1.2 Climate and Soil

The soil of the study area was sandy loam in nature with acidic pH (5.0), low level of organic carbon (0.41%), high level of phosphorous (31 kg/ha) and low level of exchangeable potassium (22 kg/ha).

The study area experiences a warm, humid tropical climate. The maximum and minimum temperature of the area was 36.8°C (April 2023) and 21.9°C (January and February 2023), respectively. Rainfall fluctuated significantly, the average annual rainfall experienced during the study period was 4113.8 mm. Mean relative humidity ranged from 49 per cent in February 2023 to 88 per cent in July 2022 and July 2023. Data on weather conditions such as temperature, rainfall and relative humidity obtained from the Department of Agricultural Meteorology, College of

Agriculture, Vellanikkara, are given in Appendix I and graphically depicted in Fig.1.

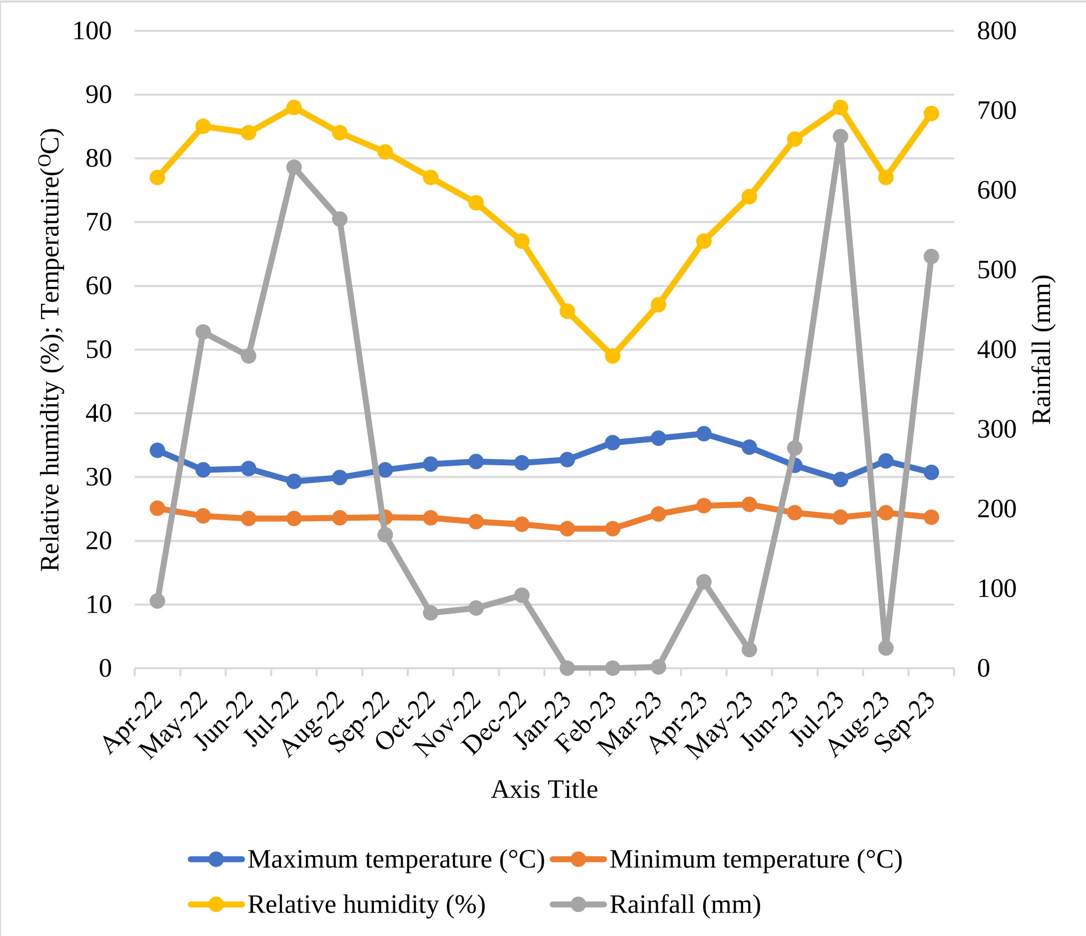

Fig 1. Mean monthly rainfall, temperature, and relative humidity data from April 2022 to September 2023 at State Seed Farm, Mannuthy

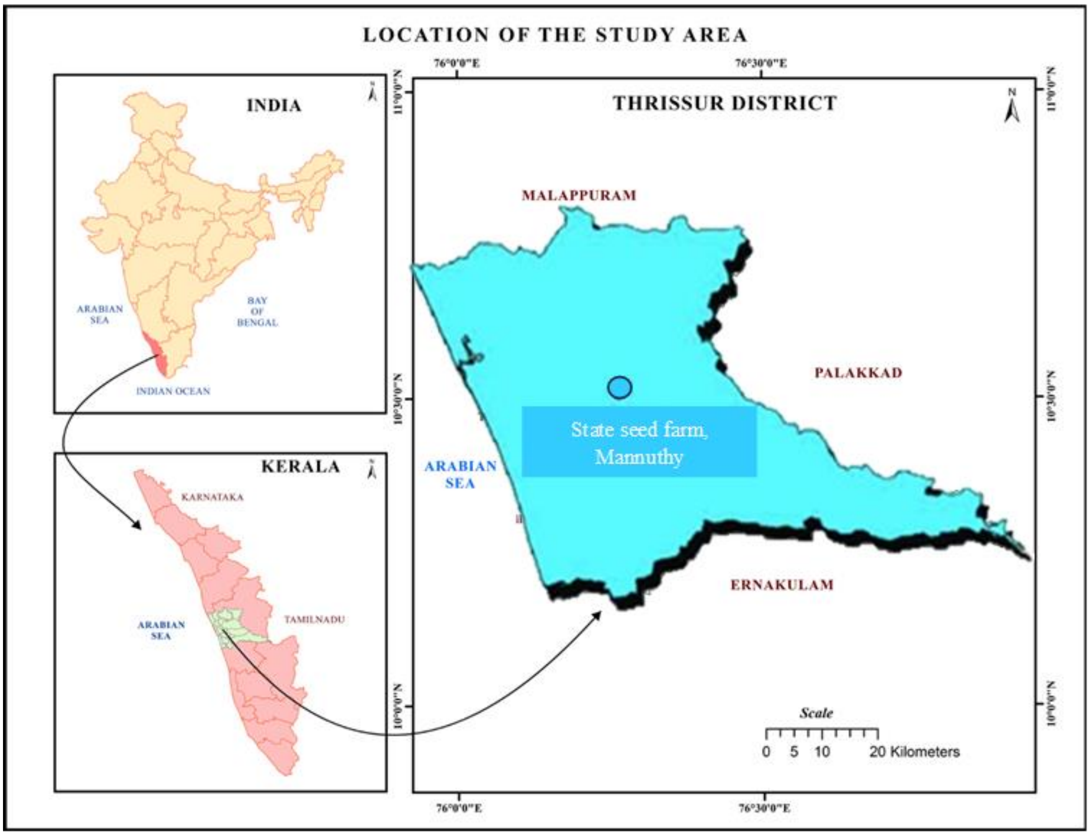

Plate 1. Location of study area experiment I

3.1.3 Materials

3.1.3.1 Plant species selected for the study

Gliricidia, *Garuga*, *Sesbania*, *Calliandra*, *Terminalia*, mulberry, *Gmelina* and *Cassia* were the tree species and red gram (perennial) was the shrub species selected for the study. Most of the species chosen are fast-growing and produce ample green biomass. These species are amenable to frequent pruning, with good coppicing ability.

3.1.3.1.1 *Gliricidia*

Gliricidia sepium, a member of the Fabaceae family, is an exceptionally adaptable agroforestry tree characterized by rapid growth and the ability to fix nitrogen. It exhibits versatility in thriving across a broad spectrum of humid and sub-humid climates and in various soil conditions, even moderately acidic and infertile ones. Its ease of propagation and management makes it suitable for a wide range of smallholder farming systems, providing diverse, high-quality products and services. *Gliricidia* is a genuine multipurpose tree (Elevitch and Francis, 2006).

3.1.3.1.2 *Garuga*

Garuga pinnata, a deciduous tree belonging to the Burseraceae family, serves as a natural support for the cultivation of pepper plants. This tree is indigenous to the regions stretching from India to China and Indo-China. It predominantly thrives in the wet tropical biome and takes the form of a tree (Royal Botanical Garden, 2017).

3.1.3.1.3 *Sesbania*

Sesbania grandiflora is a fast-growing perennial, deciduous or evergreen N-fixing legume tree commonly called *Sesbania*. It is from the family Fabaceae (Karmakar *et al*., 2016).

3.1.3.1.4 *Calliandra*

Calliandra calothyrsus, a member of the Fabaceae family, is a speedy-growing, compact and thornless tree, typically reaching heights of 5 to 6 meters, though under optimal circumstances, certain specimens can attain heights of up to 12 meters. It is commonly cultivated for soil enhancement purposes and as a companion plant (Kisaka *et al*., 2023).

3.1.3.1.5 *Terminalia*

Terminalia arjuna, known as arjun in India, is an evergreen tree categorized within the Combretaceae family. It is a substantial tree that can reach towering heights of 20 to 30 meters (Kumar *et al*., 2018).

3.1.3.1.6 Mulberry

Morus indica, more commonly called mulberry, are deciduous trees hailing from the Moraceae family. These trees have their origins in temperate regions of

Asia and North America and many varieties are intentionally grown for their fruits and aesthetic value. Mulberry plants also hold significance as a primary food source for silkworms. They are typically propagated from substantial cuttings, which readily develop roots (Raj *et al*., 2016). Mulberry variety V1 (Victoria 1, a cross of the S-30 and Berc 776 mulberry cultivars), released from Central Sericulture Research Institute, Mysore, Karnataka, was used for the study.

3.1.3.1.7 *Gmelina*

Gmelina arborea, commonly recognized as gamhar or kumizh in local regions, is a rapidly growing deciduous tree within the Lamiaceae family. This tree possesses favourable attributes for agroforestry, including rapid growth, straight forward establishment and a notable resistance to pests when grown outside its native habitat (Wilson *et al*., 1986).

3.1.3.1.8 Red gram

Cajanus cajan, known as pigeon pea or red gram (perennial), is a versatile member of the Fabaceae family. Pigeon pea serves multiple purposes, functioning as a contour hedge for erosion control and a beneficial nitrogen-fixing legume. Moreover, the extensive root system of *Cajanus cajan* plays a role in enhancing soil structure by breaking up plough pans and improving the soil's capacity to retain water (Sarkar *et al*., 2019).

3.1.3.1.9 *Cassia*

Cassia siamea is an evergreen, moderately sized legume tree with numerous branches. It belongs to the Fabaceae family. When planted in hedgerows, *Cassia* enhances soil absorption, decreases runoff and acts as a barrier against soil erosion. A thriving tree of this species can produce approximately 500 kg of fresh leaves each year, which can be utilized as green manure (ICSU, 1988).

3.1.3.1.10 Rice

In this study, we employed the rice variety Jyothy (PTB 39) as the test crop. This particular variety was developed and introduced by the Regional Agricultural

Research Station, Pattambi (RARS Pattambi). The Jyothy (PTB 39) rice variety typically has a growth cycle that spans from 110 to 125 days, starting from the time of sowing to the point of harvest (KAU, 2016).

3.1.4 Methods

The field study was conducted in wetland paddy fields of State Seed Farm in Mannuthy as part of the bund and boundary programme under the All India Coordinated Research Project (AICRP) on Agroforestry. The selected fast-growing tree/shrub species were planted in the internal bunds of paddy as per the following details to assess their growth, green manure production and interaction with the adjacent paddy crop. The experimental details are given below.

3.1.4.1 Design and Layout of the Experiment

Treatment details : The treatments consisted of nine green manuring tree/shrub species planted in the internal bunds (40-50 cm height) of paddy during the onset of monsoon in a single row at a spacing of 1 m, the details of which are given below.

a. *Gliricidia sepium* (T1)
b. *Garuga pinnata* (T2)
c. *Sesbania grandiflora* (T3)
d. *Calliandra calothyrsus* (T4)
e. *Terminalia arjuna* (T5)
f. *Morus indica* (Mulberry)(T6)
g. *Gmelina arborea* (T7)
h. *Cajanus cajan* (Red gram) (T8)
i. *Cassia* - *Cassia siamea* (T9)

Design : Randomized Block Design

Treatments : 9

Replication : 3

3.1.4.3 Field culture of green manuring trees/shrubs in paddy bunds

3.1.4.3.1 Preparation and layout of paddy bunds

The available internal bunds (40-50 cm width and 40-50 cm height) within the paddy fields were cleared and the weeds were removed in May 2022. Paddy bund of 10 m in length was allocated for each treatment plot. Pits were taken at the prescribed spacing of 1 m within each plot. As per the layout plan, proper alignment and staking were done and plants were sown or planted as follows.

3.1.4.3.2 Planting of seedlings/saplings

Planting materials were collected from COF Nursery (College of Forestry Nursery), Kerala Agricultural University, Vellanikkara. *Gliricidia* and *Garuga* were planted using mature stem cuttings of 1 m length; *Calliandra*, *Cassia*, *Terminalia*, mulberry and *Gmelina* using seedlings/saplings of 3 months of age; and seeds of *Sesbania* and red gram (perennial) directly sown on bund, during June 2022 with the onset of monsoon.

3.1.4.3.3 Manures and Fertilizers

FYM @ 1kg/pit was applied for each tree/shrub at the time of planting. NPK mixture (18:18:18) @ 50 g/plant was given in two split doses at intervals of 3 months for proper establishment of trees.

3.1.4.3.4 After cultivation

Gap filling was done one month after planting/sowing to maintain the required plant population. Regular weeding has been carried out at frequent intervals for the successful management of trees and shrubs.

3.1.4.3.5 Plant protection

All the trees and shrubs were fenced properly using green shade nets for protection from the cattle and goats. No special plant protection chemicals or preparations were applied. No serious incidences of pests and diseases were noted.

3.1.4.3.6 Harvest of trees/shrubs

All tree/shrub species, except *Cassia*, *Gmelina* and *Garuga*, exhibited rapid growth and two harvests were taken at an interval of six months. *Gmelina* and *Cassia* were found to be comparatively slow growing and harvest was taken at the end of the first year. *Garuga* was very slow-growing and was not ready for harvest at the end of the first year. Trees/shrubs were maintained as hedges by pruning or lopping at height of 1m from the ground for all tree species except *Sesbania*. In the case of *Sesbania*, only side branches were pruned and growing tips were kept intact.

3.1.4.4 Field culture of paddy

High yielding short duration paddy variety Jyothy (PTB 39) was grown in the paddy field during the Kharif season to assess the interaction effect with bund grown trees/shrubs. The field was ploughed extensively to incorporate the weeds and straw into the soil, creating a smooth and even surface for planting seedlings. Manures and fertilizers were applied, as detailed below. Paddy seedlings were raised in mat nurseries in wet conditions. When the seedlings were of the appropriate age (14 days), they were transplanted into the field with 2-3 seedlings per hill in rows. The transplanting was done at a depth of 3-4 cm. The water level was maintained at approximately 1.5 cm during the transplanting process. It gradually increased to around 5 cm until the maximum tillering stage. The water was drained 13 days before the harvest. The rice fields were kept free from weeds for up to 45 days, either through manual weeding or the application of herbicides. To take observations, the sampling of paddy at harvesting was done in a 1x1 m quadrat.

3.1.4.4.1 Manures and Fertilizers

FYM @ 5 ton/ha was applied as a basal dose at the time of ploughing. Fertilizers @ 70:35:35 kg N, P_2O_5 and K_2O were applied per ha. The entire dose of phosphorous, 2/3rd of nitrogen and half of potassium was given as basal dose. The remaining dose of nitrogen and potassium was given at the panicle initiation stage.

3.1.5 Observations

3.1.5.1 Growth and biomass of trees/shrubs (at the interval of six months)

Five plants were randomly selected from each plot, avoiding plants on the borders and the following observations were recorded.

3.1.5.1.1 Plant height

The height of the plant was measured from the base of the stem to the top of the growing shoot and the results were expressed in centimeter (cm).

3.1.5.1.2 Number of branches

The number of branches was counted for each plant in each treatment group. The average number of branches was then calculated for each treatment group and the results were expressed as mean values over the entire study period.

3.1.5.1.3 Collar diameter

The diameter of the collar of each plant was measured using a calliper and expressed in millimeter (mm).

3.1.5.1.4 Survival percentage

The number of trees/shrubs that survived in each treatment plot was calculated after the experimental period of one year and the results were expressed as percentages.

3.1.5.1.5 Number of coppice shoots

The number of coppices per plant after each pruning for each treatment was counted and expressed as mean values over the period of study.

3.1.5.1.6 Green biomass yield (Annual and seasonal)

For each cut, green biomass from 5 plants/plot avoiding border plants was separated into leaf and stem and their individual fresh weights and total biomass were determined. Thereafter, the green yield from all harvests in a year was pooled to get the annual gross yield per plant.

3.1.5.1.7 Incidence of pest and diseases

There were no significant disease or pest problems noticed during the experiment

3.1.5.2 Growth and yield attributes of Paddy

Observations on growth and yield parameters of paddy were collected from three positions from the tree/shrub base, *viz*., within 1m radius, 1m -2 m radius and from the centre of the field beyond the reach of trees/shrubs. For the measurements of paddy crop, sample plots of 1 m^2 were taken in a line running perpendicular to the tree line for each treatment.

3.1.5.2.1 Plant height

The height of the plant was measured from the base of the stem to the tip of the longest leaf and the results were expressed in centimeter (cm).

3.1.5.2.2 Number of tillers/hill

The number of tillers per hill was determined by counting the number of aerial shoots arising around a single hill.

3.1.5.2.3 Number of panicles/m^2

The number of panicles per square meter was determined by adding the number of panicles in one square meter area.

3.1.5.2.4 Incidence of pests and diseases

There were no significant disease or pest problems noticed during the experiment. The prophylactic spray of Takumi and Cymbush 5 EC was applied to prevent any pests or diseases.

3.1.5.2.5 Grain yield ha^{-1}

Total grain weight from one square meter sample plot was determined at the three random locations and the mean values were scaled on a hectare basis.

3.1.5.2.6 Straw yield ha^{-1}

The straw yield was taken in a similar manner from the same plot used for taking grain yield and scaled.

3.1.5.3 Understorey Photosynthetically Active Radiation (PAR) Measurements

PAR was monitored above the paddy crop at three positions from the tree/shrub base, *viz*., within 1m radius, 1m -2 m radius and from the centre of the field beyond the reach of trees/shrubs during the panicle initiation stage of paddy. PAR measurement was carried out using Line Quantum Sensor (LQI 2404, K131). A powered data logger integrated the mean PAR at hourly intervals from 8 a.m. to 5 p.m. from each plot. PAR was then converted to canopy transmittance, which is the light available beneath the canopy of trees/shrubs.

$$\text{PAR transmittance (\%)} = \frac{\text{PARi}}{\text{PARt}} \times 100$$

PAR_i : PAR in the shady area beneath trees/shrubs

PAR_t : PAR in the open area with full sunlight

3.1.5.4 Soil analysis

To study the changes in soil nutrient status on account of incorporating green manuring trees in paddy bunds, the soil samples were collected from three positions in the paddy field from the tree/shrub base, *viz*., within 1m radius, 1m -2 m radius and from the centre of the field beyond the reach of trees/shrubs. From the above locations, triplicate soil samples were collected from all treatment plots and analyzed for soil pH, organic C, available N, P and K following the standard procedures as detailed below.

3.1.5.4.1 Soil pH

Soil pH was determined by using a pH meter.

3.1.5.4.2 Soil organic carbon

Soil organic carbon content was assessed using the permanganate oxidation method developed by Walkely and Black (Walkely and Black, 1934).

3.1.5.4.3 Available nitrogen

The alkaline permanganate method was employed to determine the available nitrogen content in the soil (Subbaiah and Asija, 1956)

3.1.5.4.4 Available phosphorous

Bray-I extractant (Bray and Kurtz,1945) was used to extract available phosphorus, which was then quantified using a colourimetric assay employing the Chloromolybdic acid blue colour method. Ascorbic acid was employed as the reducing agent (Jackson,1973).

3.1.5.4.5 Available potassium

The available potassium content was assessed through flame photometry, employing a neutral standard ammonium acetate solution as the extracting agent. (Jackson,1973).

3.1.6 Statistical analysis

The data were subjected to statistical analysis by analysis of variance (ANOVA) using the general linear model procedure in R software version 4.3.1 to ascertain the significance of various parameters. Least Square Difference (LSD) was used to test the differences among treatment means. Comparison of the performance of green manuring trees in each treatment was done separately using RBD design. Comparison of the performance of rice growing under each treatment was done separately using the RBD design.

Plate 2. Experimental area before planting

Weeding

After weeding

Planting

Plate 3. Field preparation and planting

Plate 4. Selected trees/shrubs after planting

Plate 5. Established study area

Plate 6. Taking observations of growth and yield attributes of trees/shrubs

Plate 7. Experimental area after harvesting

Plate 8. Taking soil samples for soil analysis

Plate 9. Soil analysis

Plate 10. Taking observations of paddy

3.2 Experiment II. Survey and documentation of green manuring practices in Ollukkara and Wadakkanchery block

3.2.1 Materials

3.2.1.1 Study area

Survey and documentation of the green manuring practices in paddy fields were conducted in Ollukkara and Wadakkanchery blocks in Thrissur district.

The predominant agricultural activity in Thrissur is paddy cultivation, engaging a significant portion of its population. There are 16 block panchayats in Thrissur. Among them, Ollukkara and Wadakkanchery blocks were selected for conducting the survey. In the Ollukkara block, 227.39 hectares of paddy fields support 791 farmers, while the Wadakkanchery block accommodates 330 hectares of paddy fields with 850 farmers. There are 7 Krishibhavans in each block panchayat. Krishibhavans have various community groups, including the Padasekharasamithi of paddy cultivators, which link Krishibhavan and the farming community. The survey was conducted with the invaluable assistance of the Padasekharasamithies.

3.2.2 Methodology

Traditional and existing green manuring practices in the paddy fields of Ollukkara and Wadakkanchery blocks were documented through the questionnaire survey with the help of the Padashekharasamithi of local government bodies. The methodology involved a simple random sampling scheme. After the questionnaire survey, the field survey was conducted with 10 per cent of the total farmers who participated in the questionnaire survey.

3.2.2.1 Selection of samples

There were 14 Krishibhavans in Ollukkara and Wadakkanchery block panchayats. There were more than 60 Padashekharasamithies in these block panchayats. From this, the 30 Padashekharasamithies were selected randomly. The questionnaire survey was conducted in these Padashekharasamithies. Thus, 200 farmers were selected for the study (a minimum of 30 farmers per block) and a detailed study was conducted among the 30 farmers who participated in the questionnaire survey.

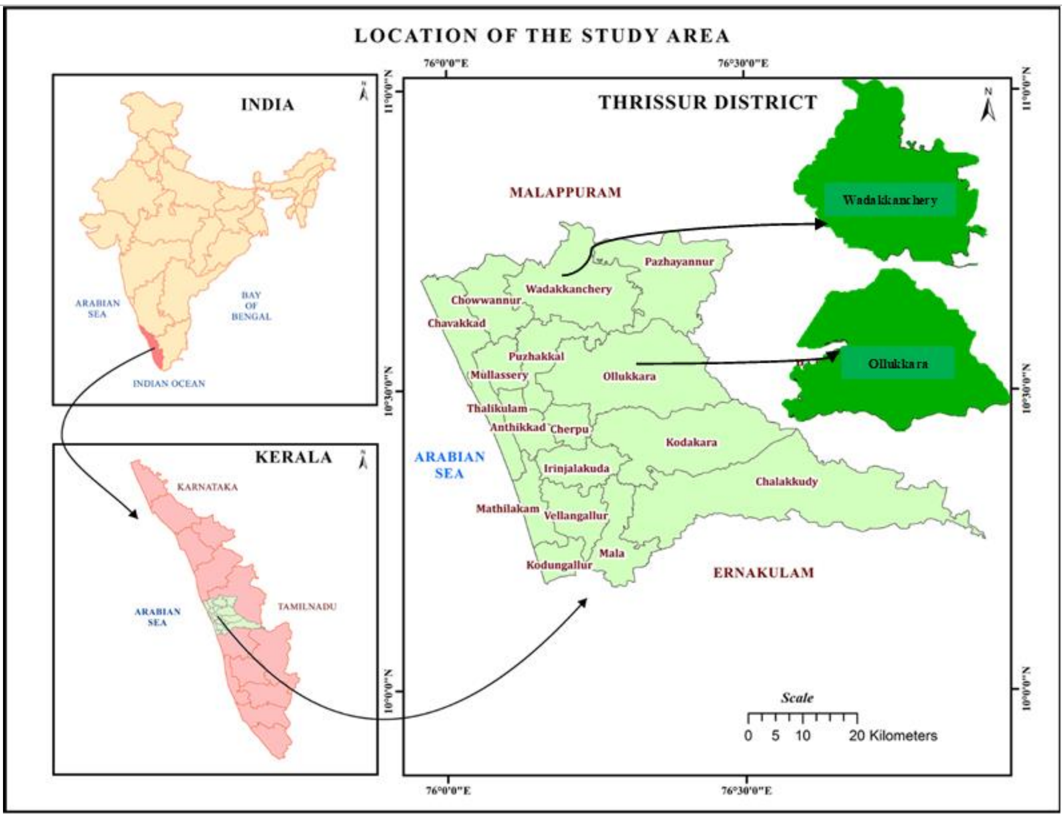

Plate 2. Location of the study area experiment II

3.2.2.2 Questionnaire survey

The survey was conducted using a structured questionnaire (Appendix II). Various quantitative and qualitative information on paddy cultivation was collected through this questionnaire survey. Various information related to the following parameters was collected.

- Existing manuring practices in paddy field
- Type of tree species and quantity (per ha) used for green manuring in paddy field

- Indigenous knowledge of green manuring practices (suitability of green manure tree species with respect to the crop, variety or season)
- Type and source of supplementary fertilizers used in paddy field
- Constraints in the adoption of green manuring

3.2.2.3 Field visit

The total number of selected paddy fields for detailed study through visit was 30 (i.e., a minimum of 10 per cent of total farmers who participated in the questionnaire survey).

3.2.2.4 Data tabulation and representation

The data collected were tabulated using Microsoft Excel software and represented as graphs and pie charts.

Plate 12. Interaction with farmers

RESULTS

4. RESULT

A year-long field evaluation was conducted to examine the green biomass production and crop interaction of selected trees/shrubs on wetland paddy bunds. The study also evaluated the survey and documentation of the indigenous knowledge, the current practices and the farmer's perspective on green manuring in paddy fields of Ollukkara and Wadakkanchery blocks in Thrissur district. The salient findings of the study, "Growth, green biomass production and crop interaction of selected trees and shrubs on wetland paddy bunds", are presented hereunder.

4.1 Experiment I. Green biomass production and crop response of selected trees/shrubs on wetland paddy bunds

4.1.1 Growth and biomass of trees/shrubs

All the trees/shrubs except *Sesbania* were given an initial uniform cut at 1 m height at the stage of six months after planting on bunds. The growth and yield parameters of trees/shrubs at the first and second cuts are given below.

4.1.1.1 Plant height

The data on plant height of the selected tree/shrub species grown in wetland paddy bunds at intervals of six months are presented in Table 1. Trees/shrubs cultivated in wetland paddy bunds showed significant differences in plant height throughout the study period. Statistical analysis of the data also revealed that appreciable differences existed among the selected trees/shrubs during both seasons. During the first six months, *Sesbania*-T3 (303.67 cm) was found to be significantly taller than other tree species in the paddy bunds. *Gliricidia* -T1 (197.33 cm) showed the second maximum plant height, which is found statistically on par with Redgram-T8 (195.60 cm). The lowest plant height observed in Mulberry-T9 (121.33 cm) is statistically comparable to that of *Cassia*-T9 (122.07 cm) and *Garuga*-T2 (131.67 cm). *Gmelina*-T7 (150.00 cm) also showed poor plant height in the first six months.

All the trees/shrubs except *Cassia*, *Gmelina* and *Garuga* were pruned at 1 m height after six months for harvesting green biomass and then allowed to regrowth. In the case of *Sesbania*, only side branches were pruned. At the end of the first year, *Sesbania*-T3 (426 cm) showed higher plant height compared to other species. Minimum plant height showed by Mulberry-T6 (136 cm). Gliricidia-T1 (217.33 cm) displayed satisfactory plant height by the end of the first year and this height is statistically equivalent to that of *Gmelina*-T7 (207.67 cm) and *Cassia*-T9 (203.33 cm). The plant height of Red gram-T8 at the end of the first year (second six months) declined compared to the first six months.

4.1.1.2 Number of branches/coppice shoots

The number of branches per tree/shrub was counted at the first six months of growth after planting (Table 1). The number of branches was significantly higher for Redgram-T8 (20.60) when compared to other tree species on wetland paddy bunds. Also, the *Sesbania*-T3 (15.47) showed a significant number of branches during this period. The minimum number of branches recorded in *Garuga*-T2 (4.67) is statistically equivalent to the Mulberry-T6 (4.90), *Cassia*-T9 (5.07), *Calliandra*-T4 (5.33) and *Gmelina*-T7 (5.60).

Well grown trees or shrubs like *Gliricidia*, *Sesbania*, *Calliandra*, *Terminalia*, red gram (perennial) and mulberry were subjected to pruning or lopping after six months and allowed to coppice. *Sesbania*-T3 (22.63) showed the maximum number of coppice branches compared to other species at the end of the first year. All species showed a higher number of coppice branches at the end of the first year than the number of branches during the first six months, excluding Redgram-T8. *Gmelina*-T7 (7.33), *Cassia*-T9 (11.07) and *Garuga*-T2 (5.33) were found to be comparatively slow growing during the first six months, so the harvest of these species was not taken during that period. So, they were not coppiced, but they had a higher number of branches when compared to the first six months. In the case of Red gram-T8 (16.87), the number of coppice branches was low compared to the number of branches during the first six months. Mulberry-T6 (4.33) showed the minimum number of coppice branches at the end of the first year.

4.1.1.3 Collar diameter

The data on the collar diameter of the selected trees/shrubs on wetland paddy bunds at intervals of six months are presented in Table 1. The collar diameters of different trees/shrubs on wetland paddy bunds varied significantly. Stem cuttings are used for the planting of *Gliricidia*-T1 and *Garuga*-T2 on wetland paddy bunds. So, the collar diameter of these species was not taken. During the first six months, *Sesbania*-T3 (43.08 mm) showed significantly the highest collar diameter compared to other species on the wetland paddy bunds. The lowest collar diameter was found in Mulberry-T6 (20.30 mm), which was shown statistically on par with *Cassia*-T9 (21.34 mm).

At the end of the first year, the highest collar diameter was shown in *Sesbania*-T3 (74.80 mm) and the lowest collar diameter was found in Mulberry-T6 (30.27 mm). Redgram-T8 (64.50 mm) showed good collar diameter growth at the end of the first year and *Terminalia*-T5 (58.83 mm) showed medium collar diameter growth compared to other species.

4.1.1.4 Survival percentage

The data in Table 1 indicate the significant variation in the survival percentage of selected trees/shrubs on the wetland paddy bunds at the end of the first year. Survival percentage was significantly higher in *Terminalia*-T5 (98%) and Red gram-T8 (98%), followed by *Sesbania*-T3 (95%) and *Cassia*-T9 (95%). The lowest survival percentage was observed in *Garuga*-T2 (10%) at the end of the experimental year.

4.1.1.5 Green biomass yield (Annual and seasonal)

The data on the green biomass yield of the selected trees/shrubs on the wetland paddy bunds at intervals of six months are presented in Table 2. These tree/shrub species showed significant variation in green biomass yield both annually and seasonally. Green biomass yield was significantly higher in Red gram-T8 (2.32 kg $plant^{-1}$) during the first harvest, which is statistically equivalent to *Sesbania*-T3 (2.06 kg $plant^{-1}$). *Gmelina*-T7, *Cassia*-T9 and *Garuga*-T2 were found to grow comparatively slowly during the first six months, so harvest of these species was not taken during that period. The remaining species gave statistically equivalent green biomass yield during the first harvest.

At the end of the first year, the second harvest, green biomass yields were significantly higher in *Sesbania*-T3 (3.39 kg plant^{-1}), followed by *Gliricidia*-T1 (2.34 kg plant^{-1}). Biomass of Red gram-T8 (1.78 kg plant^{-1}) declined in second harvest. The first harvest of *Gmelina*-T7 (1.16 kg plant^{-1}) and *Cassia*-T9 (1.30 kg plant^{-1}) was taken at the end of the first year. The yield of Mulberry-T6 (0.57 kg plant^{-1}) was comparatively lower than other species.

Data from Table 2 shows that *Sesbania*-T3 (5.45 kg plant^{-1}) annually produced significantly higher biomass than other species, followed by Red gram-T8 (4.10 kg plant^{-1}). Mulberry-T6 produced lesser green biomass during one year (1.08 kg plant^{-1}). Due to its poor growth and survival, *Garuga* could not yield any biomass in the first year.

4.1.1.7 Incidence of pest and diseases

No serious pest and disease incidence were noticed during the experimental period. A moderate attack of defoliators was found in *Sesbania* during the initial period. However, the plant survived and grew well without any plant protection measures.

Table 1. Growth parameters of bund grown trees and shrubs at intervals of six months in paddy field at State Seed Farm, Mannuthy

Treatments	Plant height (cm)		No. of branches at six months growth (Dec-22)	No. of branches/coppice shoots at the end of one year growth (Jun-23)	Collar diameter (mm)		Survival percentage (%) at the end of first year
	Six months after planting	One year after planting			Six months after planting	One year after planting	
Gliricidia-T1	197.33^{b}	217.33^{b}	8.33^{c}	10.40^{c}	-	-	60.00^{d}
Garuga-T2	131.67^{d}	150.00^{cd}	4.67^{d}	5.33^{d}	-	-	10.00^{f}
Sesbania-T3	303.67^{a}	426.00^{a}	15.47^{b}	22.63^{a}	43.08^{a}	74.80^{a}	95.00^{b}
Calliandra-T4	179.67^{bc}	187.33^{bc}	5.33^{d}	7.33^{cd}	24.88^{cd}	54.90^{c}	80.00^{c}
Terminalia-T5	178.00^{bc}	187.93^{bc}	6.47^{cd}	7.80^{cd}	32.78^{b}	58.83^{bc}	98.00^{a}
Mulberry-T6	121.33^{d}	136.00^{d}	4.90^{d}	4.33^{d}	20.30^{d}	30.27^{e}	80.00^{c}
Gmelina-T7	150.00^{cd}	207.67^{b}	5.60^{d}	7.33^{cd}	31.03^{bc}	51.95^{c}	50.00^{e}
Red gram-T8	195.60^{b}	183.60^{bc}	20.60^{a}	16.87^{b}	33.37^{b}	64.50^{b}	98.00^{a}
Cassia-T9	122.07^{d}	203.33^{b}	5.07^{d}	11.07^{c}	21.34^{d}	42.1^{d}	95.00^{b}
P value	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CD@0.05	43.42	43.98	2.72	3.88	6.32	9.16	2.68

Values with the same superscript in the column do not differ significantly.
$P<0.01$, significant @ 1 per cent level of significance

Table 2. Seasonal and annual green biomass yield of bund grown trees and shrubs in paddy field at State Seed Farm, Mannuthy

Treatments	Green biomass yield (kg plant^{-1})		
	Six months after planting	One year after planting	Annual
Gliricidia-T1	0.92^{b}	2.34^{b}	3.26^{bc}
Garuga-T2	0.00	0.00	0.00
Sesbania-T3	2.06^{a}	3.39^{a}	5.45^{a}
Calliandra-T4	0.90^{b}	0.87^{ef}	1.77^{de}
Terminalia-T5	1.12^{b}	1.42^{cd}	2.54^{cd}
Mulberry-T6	0.51^{b}	0.57^{f}	1.08^{e}
Gmelina-T7	0.00	1.16^{de}	1.16^{e}
Red gram-T8	2.32^{a}	1.78^{c}	4.10^{b}
Cassia-T9	0.00	1.30^{cde}	1.30^{e}
P value	0.0013	0.000	0.000
CD@0.05	0.73	0.53	0.98

Values with the same superscript in the column do not differ significantly.
P<0.01, significant @ 1 per cent level of significance

4.1.2 Growth and yield attributes of paddy

To study the interaction effect of bund grown trees/shrubs on paddy, data on the growth and yield parameters of paddy were collected from three positions from the tree/shrub base, *viz*, within 1 m radius, 1- 2 m radius and from the centre of the field beyond the reach of trees. For the measurements of paddy crop, sample plots of 1 m^2 were taken in a line running perpendicular to the tree line for each treatment. The growth and yield parameters of paddy are given below.

4.1.2.1 Plant height

The data on the plant height of the paddy from three positions from the tree/shrub base, within 1 m radius, 1- 2 m radius and from the centre of the field beyond the reach of trees/shrubs are presented in Table 3. Within 1 m radius, statistical analysis of the data revealed that significant differences existed among the plant height of paddy from the selected tree/shrub base. The plant height of the paddy from open paddy fields (104.19 cm) showed higher data than other treatment plots. The lowest plant height was shown by paddy from *Calliandra*-T4 (99.29 cm) plots, which is statistically equivalent to the plant height of paddy from Red gram-T8 (99.36 cm) and *Sesbania*-T3 (99.78 cm) plots. Between 1- 2 m radius, no significant difference was observed in the plant height of paddy from various treatments and open paddy fields.

4.1.2.2 Number of tillers/hills

The data on the number of tillers/hill of the paddy from three positions from the tree/shrub base, within 1 m radius, 1- 2 m radius and from the centre of the field beyond the reach of trees/shrubs are presented in Table 3. No significant difference was observed in the number of tillers/hill of paddy from various treatments and open paddy fields within 1 m radius, between 1- 2 m radius. In both cases, the highest number of tillers/hill showed by paddy from the open plots (20.54). Within 1 m radius, the lowest number of tillers/hill showed by paddy from the Red gram-T8 (17.29) plot. Between 1- 2 m radius, the lowest number of tillers/hill showed by paddy from the *Calliandra*-T4 (17.93) plot.

4.1.2.3 Number of panicles/m^2

The data on the number of panicles/m^2 of the paddy from three positions from the tree/shrub base, *viz*., within 1 m radius, 1- 2 m radius and from the centre of the field beyond the reach of trees/shrubs, are presented in Table 4. Within 1 m radius, statistical analysis of the data revealed that significant differences existed among the number of panicles/m^2 of paddy from the selected tree/shrub base. Paddy from open paddy fields (204) exhibited the highest number of panicles/m^2, which is statistically equivalent to the number of panicles/m^2 of paddy from the *Garuga*-T2 (202) and Mulberry-T6 (202) plots. The lowest number of panicles/m^2 was shown by paddy from *Calliandra*-T4 (191.33) plots, which is statistically equivalent to the number of panicles/m^2 of paddy from Red gram-T8 (193.33), *Gliricidia*-T1 (193.33) and *Sesbania*-T3 (194.67) plots.

Between 1- 2 m radius, no significant difference was observed in the number of panicles/m^2 of paddy from various treatments and open paddy fields. Except for *Calliandra*-T4, paddy from all treatment plots and open paddy fields showed more than 200 panicles/m^2.

4.1.2.4 Grain yield ha^{-1}

Table 4 shows the grain yield ha^{-1} of the paddy from three positions from the tree/shrub base *viz*., within 1 m radius, 1- 2 m radius and from the centre of the field beyond the reach of trees/shrubs. No significant difference was observed in the grain yield ha^{-1} of the paddy from different treatment plots and open paddy fields. The highest data showed by paddy from the open fields compared to treatment plots. In both cases, paddy from the *Calliandra*-T4 plot showed the lowest grain yield ha^{-1}. The grain yield of paddy cultivated beneath the trees/shrubs on the paddy bund varied between 2002.67 and 2606.67 kg ha^{-1}. A slight increase in yield was noticed in open paddy fields, where it reached 2633.33 kg ha^{-1}.

4.1.2.5 Straw yield ha^{-1}

Table 4 shows the straw yield ha^{-1} of the paddy from three positions from the tree/shrub base *viz*., within 1 m radius, 1- 2 m radius and from the centre of the field beyond the reach of trees. No significant difference was observed in the straw yield ha^{-1} of the paddy from different treatment plots and open paddy fields. The highest data showed by paddy from the open fields in compared to treatment plots. Within 1 m radius, paddy from the Red gram-T8 (6746.67 kg ha^{-1}) plot showed the lowest straw yield ha^{-1}. Between 1- 2 m radius, paddy from the *Calliandra*-T4 (7203.33 kg ha^{-1}) plot showed the lowest straw yield ha^{-1}.

4.1.2.6 Incidence of pest and diseases

No serious pest and disease incidence were noticed during the experimental period as timely plant protection measures have been adopted.

Table 3. Growth attributes of paddy (3 months after planting) under the shade of bund grown trees/shrubs and open fields with full sunlight at State Seed Farm, Mannuthy

Treatments	Within 1m tree/shrub base		Between 1- 2m from tree/shrub base	
	Plant height (cm)	Tillers/hill	Plant height (cm)	Tillers/hill
Gliricidia-T1	102.18[abc]	17.56	100.44	20.32
Garuga-T2	101.02[bcd]	18.18	101.67	19.54
Sesbania-T3	99.78[d]	18.05	100.33	18.77
Calliandra-T4	99.29[d]	17.42	102.11	17.93
Terminalia-T5	100.07[cd]	18.56	100.00	18.84
Mulberry-T6	100.12[cd]	18.49	103.79	19.65
Gmelina-T7	102.67[ab]	18.66	103.44	19.78
Red gram-T8	99.36[d]	17.29	100.46	18.57
Cassia-T9	100.93[cd]	18.45	102.79	18.78
Control (paddy in the open field beyond the reach of trees/shrubs)	104.19[a]	20.54	104.19	20.54
P value	0.005	0.19	0.51	0.58
CD@0.05	2.36	2.12	4.79	2.67

Values with the same superscript in the column do not differ significantly.
P<0.01, significant @ 1 per cent level of significance. P>0.05, non-significant.

Table 4. Yield attributes of paddy under the shade of bund grown trees/shrubs and open fields with full sunlight at State Seed Farm, Mannuthy

Treatments	Within 1m tree/shrub base			Between 1- 2m from tree/shrub base		
	Number of panicles/m^2	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Number of panicles/m^2	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
Gliricidia-T1	193.33[c]	2080.00	7332.67	204.00	2606.67	7506.67
Garuga-T2	202.00[a]	2526.67	7333.33	203.33	2573.33	7453.33
Sesbania-T3	194.67[c]	2126.67	7440.00	202.67	2386.67	7473.33
Calliandra-T4	191.33[c]	2002.67	6980.00	192.67	2143.33	7203.33
Terminalia-T5	200.67[ab]	2320.00	7186.67	202.67	2556.67	7450.00
Mulberry-T6	202.00[a]	2513.33	7446.67	203.33	2573.33	7504.67
Gmelina-T7	201.33[ab]	2486.67	7455.00	202.00	2320.00	7510.33
Red gram-T8	193.33[c]	2080.00	6746.67	202.67	2360.00	7453.33
Cassia-T9	196.00[bc]	2180.00	7186.67	203.33	2346.67	7497.33
Control (paddy in the open field beyond the reach of trees/shrubs)	204.00[a]	2633.33	7516.67	204.00	2633.33	7516.67
P value	0.0009	0.61	0.59	0.55	0.997	0.97
CD@0.05	5.71	755.80	790.12	10.55	1249.99	508.20

Values with the same superscript in the column do not differ significantly.
$P<0.01$, significant @ 1 per cent level of significance. $P>0.05$, non-significant.

4.1.4 Understorey Photosynthetically Active Radiation (PAR) Measurements

Understorey Photosynthetically Active Radiation (PAR) was measured above the paddy crop at three positions from the tree/shrub base, *viz*., within 1 m radius, 1- 2 m radius and from the centre of the field beyond the reach of trees/shrubs during the first year of growth. The data in Tables 5 and 6 show the understorey PAR measured within 1 m radius and between 1- 2 m radius, respectively. In all treatment plots, the highest PAR measurement was shown during mid-day (12.00-1.00 pm). Mean daily PAR within 1 m tree base ranged from 1205.07 to 1700.74 µmoles $m^{-2}s^{-1}$ and 1- 2 m tree base from 1154.85 to 1723.67 µmoles $m^{-2}s^{-1}$ whereas in open paddy, the PAR availability was 1731.93 µmoles $m^{-2}s^{-1}$. In all treatment plots, PAR measurement was slightly less than from the open paddy fields. The data in Table 7 shows the PAR transmittance from the treatment plots. Open paddy plots showed 100 per cent PAR transmittance, followed by Mulberry-T6 within 1 m radius (98.20%) and between 1- 2 m radius (99.52%). *Gmelina*-T7 also showed more than 90 per cent of the PAR transmittance within 1 m radius (92.78%) and between 1- 2 m radius (95.12%).

Table 5. Understorey Photosynthetically Active Radiation (PAR) measurements on paddy beneath bund grown trees and shrubs (within 1 m radius) (μmoles $m^{-2}s^{-1}$)

Treatments	Time (Hours)									Mean
	8.00- 9.00 AM	9.00-10.00 AM	10.00-11.00 AM	11.00 AM-12.00 PM	12.00-1.00 PM	1.00-2.00 PM	2.00-3.00 PM	3.00-4.00 PM	4.00-5.00 PM	
Gliricidia-T1	962.00	1062.33	1402.67	1576.67	1923.00	1746.33	1350.33	878.33	596.33	1277.56
Garuga-T2	859.00	1104.00	1337.67	1711.67	2085.33	1890.33	1247.33	1053.67	879.00	1352.00
Sesbania-T3	716.67	1186.33	1385.67	2058.67	2117.33	1679.00	1489.67	1180.00	1098.00	1434.59
Calliandra-T4	557.00	800.67	1099.33	1422.67	1958.67	1803.33	1420.67	1209.00	700.67	1219.11
Terminalia-T5	909.33	1358.33	1656.00	1859.00	1873.67	1804.67	1513.00	939.67	742.67	1406.26
Mulberry-T6	1224.33	1510.67	1792.33	2142.00	2200.00	1866.33	1684.00	1628.67	1258.33	1700.74
Gmelina-T7	1125.33	1286.00	1823.33	1929.00	2083.33	1816.33	1680.00	1545.00	1174.33	1606.96
Red gram-T8	800.67	1030.00	1380.33	1573.00	1753.33	1593.33	1317.33	868.00	529.67	1205.07
Cassia-T9	1070.00	1393.67	1555.33	1689.00	2009.67	1824.33	1472.67	1353.33	1059.67	1491.96
Open paddy	1232.67	1619.67	1845.00	2156.00	2214.00	1879.67	1703.00	1669.67	1267.67	1731.93

Table 6. Understorey Photosynthetically Active Radiation (PAR) measurements on paddy beneath bund grown trees and shrubs (between 1- 2 m radius) (µmoles $m^{-2}s^{-1}$)

Treatments	Time (Hours)									Mean
	8.00-9.00 AM	9.00-10.00 AM	10.00-11.00 AM	11.00 AM-12.00 PM	12.00-1.00 PM	1.00-2.00 PM	2.00-3.00 PM	3.00-4.00 PM	4.00-5.00 PM	
Gliricidia-T1	999.00	1296.00	1644.33	1903.33	1989.67	1818.67	1404.67	1538.00	1121.67	1523.93
Garuga-T2	1067.00	1123.33	1571.33	1849.00	2153.67	1924.00	1707.00	1428.00	1033.33	1539.63
Sesbania-T3	1112.00	1197.67	1529.00	2067.67	2199.33	1641.33	1665.33	1583.33	1242.33	1582.00
Calliandra-T4	540.00	758.33	986.67	1338.33	1939.33	1809.33	1421.67	998.67	601.33	1154.85
Terminalia-T5	1112.00	1613.33	1821.00	1918.33	1980.33	1895.00	1481.67	935.33	735.33	1499.15
Mulberry-T6	1226.00	1513.67	1793.67	2164.00	2202.33	1870.67	1694.67	1639.33	1408.67	1723.67
Gmelina-T7	1203.33	1301.00	1846.33	2032.67	2123.00	1830.67	1680.33	1586.67	1223.33	1647.48
Red gram-T8	980.00	1169.67	1612.33	1810.67	1961.67	1605.33	1374.00	932.67	790.00	1359.59
Cassia-T9	1172.00	1480.67	1733.33	1995.67	2099.00	1961.67	1607.67	1522.33	1247.33	1646.63
Open paddy	1232.67	1619.67	1845.00	2156.00	2214.00	1879.67	1703.00	1669.67	1267.67	1731.93

Table 7. PAR transmittance (%) to paddy near tree and shrub base and open field at State Seed Farm, Mannuthy

Treatments	Within 1m tree/shrub base	Between 1- 2m from tree/shrub base
Gliricidia-T1	73.77	87.99
Garuga-T2	78.06	88.90
Sesbania-T3	82.83	91.34
Calliandra-T4	70.39	66.68
Terminalia-T5	81.20	86.56
Mulberry-T6	98.20	99.52
Gmelina-T7	92.78	95.12
Red gram-T8	69.58	78.50
Cassia-T9	86.14	95.08
Open paddy	100	100

4.1.3 Soil parameters

4.1.3.1 Soil pH

Table 8 shows the soil pH in the paddy field from the tree/shrub base *viz*., within 1 m radius, 1- 2 m radius and from the centre of the field beyond the reach of trees/shrubs. No significant difference was observed in soil pH between various treatments and open paddy fields, even though all soil samples from the tree base within 1 m radius show slightly higher pH values than open plots, i.e., the centre of the fields. Within 1 m radius, soil samples from the Red gram-T8 (5.95) showed a high pH value, followed by *Sesbania*-T3 (5.55) and *Cassia*-T9 (5.52). Between 1-2 m radius, all soil samples showed statistically equivalent pH to the open fields. Red gram-T8 (5.58) showed the highest pH value, followed by *Sesbania*-T3 (5.40) and *Gmelina*-T7 (5.39).

In all treatment plots, soil samples from within 1 m radius showed slightly higher pH values than soil samples from 1- 2 m radius.

4.1.3.2 Available nitrogen

Table 8 shows the available nitrogen content in the paddy field from the tree/shrub base, *viz*., within 1 m radius, 1- 2 m radius and from the centre of the field beyond the reach of trees/shrubs. The available nitrogen content of all soil samples from both 1 m radius and between 1- 2 m radius with open fields showed significant differences throughout the study period. Significantly higher available nitrogen content was in soil samples from the open paddy fields (158.89 kg ha^{-1}), which is found statistically on par with the available nitrogen content of soil samples from *Cassia*-T9 treatment within 1 m radius, followed by *Gmelina*-T7 (146.35 kg ha^{-1}), *Terminalia*-T5 (142.17 kg ha^{-1}) *Gliricidia*-T1 (142.17 kg ha^{-1}) *Sesbania*-T3 (133.80 kg ha^{-1}) and Red gram-T8 (133.80 kg ha^{-1}) within 1 m radius, which was found to be statistically equivalent. Soil samples within 1 m radius of Mulberry-T6 (62.72 kg ha^{-1}) showed significantly the lowest available nitrogen content.

In 1- 2 m radius, *Terminalia*-T5 (158.40 kg ha^{-1}) showed statistically equal available nitrogen content with open paddy fields. Followed by *Cassia*-T9 (154.71 kg ha^{-1}), *Gliricidia*-T1 (150.53 kg ha^{-1}) and Red gram-T8 (150.53 kg ha^{-1}), which were statistically equivalent to each other. Soil samples of 1- 2 m radius in Mulberry-T6 (108.71 kg ha^{-1}) showed significantly the lowest available nitrogen content, which is found to be statistically equivalent to *Sesbania*-T3 (121.26 kg ha^{-1}) and *Calliandra*-T4 (121.26 kg ha^{-1}).

4.1.3.3 Available phosphorous

Table 8 shows the available phosphorous content in the paddy field from the tree/shrubs base, *viz*., within 1 m radius, 1- 2 m radius and from the centre of the field beyond the reach of trees/shrubs. The available phosphorous content of all soil samples from the treatment plots was statistically on par with the available phosphorous content of open fields. No significant difference was observed in available phosphorous content in soil samples from both 1 m radius and 1- 2 m radius with open fields. In all treatment plots, soil samples from within 1 m radius showed lower available phosphorous content than soil samples from 1- 2 m radius. But no significant difference between them.

Within 1 m radius, soil samples from all treatment plots showed slightly lesser available phosphorous content than open fields. The lowest available phosphorous content was observed in *Gmelina*-T7 (26.91 kg ha^{-1}), followed by *Gliricidia*-T1 (27.55 kg ha^{-1}). Soil samples from the remaining treatment plots showed available phosphorous within the range of 31 to 36 kg ha^{-1}. Between 1- 2 m radius, soil samples from *Gmelina*-T7 (28.73 kg ha^{-1}) showed minimum available phosphorus content compared to other treatments, followed by *Gliricidia*-T1 (29.27 kg ha^{-1}).

4.1.3.4 Available potassium

Table 8 shows the available potassium content in the paddy field from the tree/shrub base, *viz*., within 1 m radius, 1- 2 m radius and from the centre of the field beyond the reach of trees/shrubs. No significant difference was observed in available potassium content in soil samples of both 1 m radius and between 1- 2 m radius with open fields. In all treatment plots, excluding *Sesbania*-T3 and *Gmelina*-T7, soil samples within 1 m radius showed slightly lesser available potassium content than soil samples from 1- 2 m radius.

Comparing soil samples from within 1 m radius, Mulberry-T6 (52.08 kg ha^{-1}) showed the lowest available potassium content, followed by *Cassia*-T9 (52.91 kg ha^{-1}). *Terminalia*-T5 (65.11 kg ha^{-1}) showed the highest available potassium content among treatment plots. Comparing soil samples between 1- 2 m radius, *Cassia*-T9 (55.63 kg ha^{-1}) showed the lowest available potassium content.

4.1.3.5 Organic carbon

Table 8 shows the organic carbon in the paddy field from the tree/shrub base *viz*., within 1 m radius, 1- 2 m radius and from the centre of the field beyond the reach of trees/shrubs. No significant difference was observed in organic carbon in soil samples from both 1 m radius and between 1- 2 m radius with open fields. Most treatment plots showed slightly higher organic carbon within 1 m radius than between 1- 2 m radius, excluding *Garuga*-T2 and *Calliandra*-T4. Comparing soil samples within 1 m radius, *Calliandra*-T4 (0.44%) showed the minimum organic carbon, followed by *Garuga*-T2 (0.45%). *Cassia*-T9 (0.57%) showed the highest organic carbon content within 1 m radius. Among soil samples from between 1- 2 radius, *Cassia*-T9 (0.56%) showed the highest value, which is slightly less than organic carbon within 1 m radius.

Table 8. Soil parameters of paddy field underneath bund grown trees/shrubs and open field at State Seed Farm, Mannuthy

Treatments	Within 1m tree/shrub base					Between 1- 2m from tree/shrub base				
	pH	Available N (Kg ha^{-1})	Available P (Kg ha^{-1})	Available K (Kg ha^{-1})	Organic Carbon content (%)	pH	Available N (Kg ha^{-1})	Available P (Kg ha^{-1})	Available K (Kg ha^{-1})	Organic Carbon content (%)
Gliricidia-T1	5.42	142.17^{ab}	27.55	59.70	0.56	5.40	150.53^{ab}	29.27	61.57	0.55
Garuga-T2	5.30	100.35^{c}	35.82	64.82	0.45	5.27	129.62^{bc}	36.26	64.50	0.51
Sesbania-T3	5.55	133.80^{ab}	31.60	62.72	0.55	5.40	121.26^{c}	35.06	58.99	0.49
Calliandra-T4	5.39	125.44^{b}	29.53	61.51	0.44	5.33	121.26^{c}	35.21	63.27	0.48
Terminalia-T5	5.46	142.17^{ab}	34.91	65.11	0.51	5.34	158.40^{a}	36.75	65.81	0.50
Mulberry-T6	5.32	62.72^{d}	35.27	52.08	0.48	5.24	108.71^{c}	37.51	64.96	0.46
Gmelina-T7	5.40	146.35^{ab}	26.91	64.85	0.57	5.39	133.80^{abc}	28.73	63.84	0.54
Red gram-T8	5.95	133.80^{ab}	33.44	58.52	0.56	5.58	150.53^{ab}	36.01	66.52	0.55
Cassia-T9	5.52	157.61^{a}	32.14	52.91	0.57	5.35	154.71^{ab}	38.14	55.63	0.56
Control	5.22	158.89^{a}	38.97	66.83	0.53	5.22	158.89^{a}	38.97	66.83	0.53
P value	0.15	0.000	0.15	0.26	0.19	0.11	0.004	0.36	0.96	0.42
CD@0.05	0.45	25.16	8.68	12.87	0.12	0.22	25.85	9.49	19.31	0.10

Values with the same superscript in the column do not differ significantly. $P<0.01$, significant @ 1 per cent level of significance. $P<0.05$, significant @ 5 per cent level of significance. $P>0.05$, non-significant.

Experiment II Survey and documentation of green manuring practices in Ollukkara and Wadakkanchery block

Traditional and existing green manuring practices in the paddy fields of Ollukkara and Wadakkanchery blocks were documented through the questionnaire survey with the help of the Padashekharasamithi of local government bodies. The collected data about green manuring practices are given below.

4.2.1 Existing manuring practices in paddy fields

Existing manuring practices in the paddy fields of the Ollukkara and Wadakkanchery blocks were displayed in Table 9. Most of the farmers are dependent on chemical fertilizer for paddy cultivation. However, they used manures as supplementary in paddy fields. The primary choice of manure among surveyed farmers was cow dung, employed by 95 per cent of participants. Additionally, goat manure (65%) and chicken manure (75%) were preferred in these paddy fields. In contrast, neem cake (25%) and ash (30%) were the less favoured options. Green manure was the preference for 40 per cent of the farmers and 70 per cent opted for green leaf manure in their paddy fields. Green manure is typically incorporated during the periods between paddy cultivation. Table 10 illustrates the most commonly cultivated green manures in the paddy fields of Ollukkara and Wadakkanchery blocks, with 62.5 per cent of green manure enthusiasts opting for Dhaincha and 25 per cent choosing cowpea.

4.2.2 Choice of tree species used for green manuring in paddy field

Table 11 presents data regarding the types of tree species employed for green manuring in the paddy fields of the Ollukkara and Wadakkanchery blocks. *Gliricidia sepium* emerged as the dominant species used by most of the farmers who participated in the questionnaire survey. While *Gliricidia sepium* was utilized seasonally, specifically during the mundakan (Kharif) and puncha (Summer) periods, the remaining species were employed annually during the mundakan season.

Table 12 depicts the sources of tree species utilized for green leaf manuring in the paddy fields of the Ollukkara and Wadakkanchery blocks. A significant proportion of these species (62.5%) were cultivated in farmers' home gardens, with the remaining 37.5 per cent being grown in field boundaries. *Cleistanthus collinus* and *Gliricidia sepium* naturally occur in home gardens and field boundaries, while other species were intentionally planted for various purposes (Table 11).

4.2.3 Indigenous knowledge of green manuring practices

Table 13 provides insights into the traditional knowledge of green manuring practices and past green leaf manuring species employed in the paddy fields of the Ollukkara and Wadakkanchery blocks. *Terminalia paniculate*, *Terminalia bellirica* and *Mangifera indica* emerged as the most favoured species and were considered the optimal choices for green leaf manuring in paddy fields. During the earlier period, it was sufficient to use 1000-1500 kg of green leaves from these species per hectare. Except for *Gliricidia*, all these species were used annually, primarily during the mundakan season. The utilization of green leaves from more than 15 species was noted, with the majority (97.5%) of these species sourced from nearby forest areas. Only 50 per cent of the farmers who participated in the questionnaire survey collected green leaves from their home gardens for small purposes (Table 14).

4.2.4 Type and source of supplementary fertilizers used in paddy fields

Table 15 depicts the source of additional fertilizers and manures employed in the paddy fields within the Ollukkara and Wadakkanchery blocks. Of the farmers participating in the questionnaire survey, 60 per cent sourced supplementary fertilizers and manures from local markets. A smaller proportion, 40 per cent of farmers, collected manures in smaller quantities from their households, while the remaining larger quantities (45%) of fertilizers were imported from other states. In addition, 50 per cent of the surveyed farmers acquired fertilizers from the Department of Agriculture Development and Farmer’s Welfares, as detailed in Table 9, which explains supplementary manures in the paddy fields.

The majority of the farmers who took part in the questionnaire survey primarily utilized chemical fertilizers. As outlined in Table 16, this reliance on chemical fertilizers had drawbacks. All 100 per cent of the surveyed farmers reported that the use of chemical fertilizers led to a decline in soil fertility and productivity. Moreover, 75 per cent of them noted that chemical fertilizers provided only immediate yields and necessitated continuous use to maintain such yields. Furthermore, 40 per cent of farmers experienced a decline in the quality of rice associated with the use of chemical fertilizers.

4.2.5 Constraints in the adoption of green manuring

Table 17 presents the constraints encountered in implementing green leaf manuring within the paddy fields of the Ollukkara and Wadakkanchery blocks. A comprehensive survey of participating farmers revealed that the availability of labour and associated costs were the primary challenges, affecting 100 per cent of them. Additionally, the availability of land (75%) and issues related to land ownership (50%) were significant factors influencing the adoption of green leaf manuring in paddy fields. In specific regions, climatic conditions (7.5%) also played a role in determining the choice between different types of manures or fertilizers. Furthermore, transportation concerns (40%) were identified as a factor influencing the adoption of green leaf manuring in certain areas.

4.2.6 Adoption of green leaf manuring in paddy fields

Table 18 illustrates the strategies to improve the use of green manures, as per the opinions of farmers who participated in a questionnaire survey. The survey revealed that 75 per cent of the participating farmers recommended planting trees in vacant areas. Additionally, 60 per cent of respondents suggested the practice of boundary planting in paddy fields and planting trees along the banks of streams.

Table 19 elaborates on the survey findings regarding the preferred locations for planting green manure trees, in paddy fields or other areas. A majority of the farmers expressed a willingness to incorporate green leaf manures into their paddy fields. Specifically, 90 per cent of the surveyed farmers indicated their readiness to plant trees or shrubs in vacant spaces within paddy fields. Furthermore, 85 per cent of the farmers were open to cultivating trees in their home gardens, while 60 per cent expressed willingness to engage in boundary planting and tree planting along stream banks. Notably, 80 per cent of the participating farmers expressed interest in planting green manure trees in their paddy fields, whereas 15 per cent were not interested in this practice (Table 20).

Table 9. Current manuring practices adopted by farmers in paddy fields of Ollukkara and Wadakkanchery blocks

Sl No	Type of manure used	Percentage of farmers who adopted manuring practice (%)
1	Cow dung	95
2	Goat dung manure	65
3	Chicken manure	75
4	Green manure	40
5	Green leaf manure	70
6	Neem cake	25
7	Ash	30

Table 10. Farmers perception about cultivation of green manure crops in paddy fields of Ollukkara and Wadakkanchery blocks

Sl No	Green manure crops	Common name	Percentage of farmers who adopted green manuring practice
1	*Sesbania bispinosa*	Dhaincha	62.5
2	*Vigna unguiculata*	Cow Pea	25
3	*Plectranthus rotundifolius*	Koorkka	12.5
4	*Tephrosia purpurea*	Kozhinjil	12.5

Table 11. Type of tree/shrub species used for current practices of green leaf manuring in paddy fields of Ollukkara and Wadakkanchery blocks

Sl No	Tree/Shrub species	Common name	Seasonal/annual	Season
1	*Gliricidia sepium*	Sheema konna	Seasonal	Mundakan, puncha
2	*Mangifera indica*	Maavu	Annual	Mundakan
3	*Macaranga peltata*	Podunni/vatta	Annual	Mundakan
4	*Cleistanthus collinus*	Oduk	Annual	Mundakan
5	*Xylia xylocarpa*	Irumull/irul	Annual	Mundakan
6	*Terminalia paniculata*	Maruth	Annual	Mundakan
7	*Bridelia retusa*	Mullan kayni	Annual	Mundakan

Table 12. Source of tree/shrub species used for current green leaf manuring practices in paddy fields of Ollukkara and Wadakkanchery blocks

Sl No	Source	Percentage (%)
1	Home gardens	62.5
2	Field boundary	37.5
3	Others	18.75

Table 13. Type of tree/shrub species and quantity (kg per ha) used for traditional green leaf manuring practices in the paddy fields of Ollukkara and Wadakkanchery blocks

Sl No	Tree/Shrub species	Common name	Quantity (kg per ha)	Seasonal/ annual	Season
1	*Terminalia paniculata*	Maruth	1000-1200	Annual	Mundakan
2	*Terminalia bellirica*	Thanni	1000-1300	Annual	Mundakan
3	*Mangifera indica*	Maavu	1000-1500	Annual	Mundakan
4	*Bridelia retusa*	Mullan kayni	1800	Annual	Mundakan
5	*Terminalia arjuna*	Neermaruth	2000	Annual	Mundakan
5	*Tephrosia purpurea*	Kozhinjil	2000	Annual	Mundakan
6	*Calycopteris floribunda*	Pullani	1800-2000	Annual	Mundakan
7	*Albizia lebbeck*	Karimthakara.	1800	Annual	Mundakan
8	*Cleistanthus collinus*	Oduk	2000	Annual	Mundakan
9	*Lagerstroemia microcarpa*	Venthekku	2000-2100	Annual	Mundakan
10	*Calophyllum inophyllum*	Punna	1800-2000	Annual	Mundakan
11	*Xylia xylocarpa*	Irumull/irul	1800-2000	Annual	Mundakan
12	*Dalbergia latifolia*	Veetti	2000-2200	Annual	Mundakan
13	*Grewia tiliaefolia*	Chadachi	2000-2300	Annual	Mundakan
14	*Chromolaena odorata*	Communist pacha	2000-2500	Annual	Mundakan
15	*Glycosmis pentaphylla*	Panel	2000-2300	Annual	Mundakan
16	*Gliricidia sepium*	Sheema konna	1500-1800	Seasonal	Mundakan, puncha
17	*Macaranga peltata*	Podunni/vatta	2000-2500	Annual	Mundakan
18	Others	Others	2500-3000	Annual	Mundakan

Table 14. Source of tree/shrub species used for traditional green leaf manuring practices in paddy fields of Ollukkara and Wadakkanchery blocks

Sl No	Source	Percentage (%)
1	Forest	97.5
2	Home garden	50
3	Field boundary	12.5
4	Others	20

Table 15. Source of other manures and fertilizers currently used in paddy fields of Ollukkara and Wadakkanchery blocks

Sl No.	Source	Percentage (%)
1	Households	40
2	Local markets	60
3	Agriculture Dept.	50
4	Other states	45

Table 16. Disadvantages of chemical fertilizers in paddy fields as informed by farmers in Ollukkara and Wadakkanchery blocks

Sl No.	Disadvantage	Percentage (%)
1	Only get instant yield	75
2	To be used continuously	75
3	Soil fertility is lost, the soil becomes characterless, the soil is less and non-productive	100
4	The quality of rice decreases	40

Table 17. Constraints experienced by farmers in the adoption of green leaf manuring in the paddy fields of Ollukkara and Wadakkanchery blocks

Sl No	Constraints	Percentage (%)
1	Scarcity of labours	100
2	Cost	100
3	Transport	45
4	Climate problems	7.5
5	Ownership	50
6	Land availability	75
7	Other constraints	5

Table 18. Strategies for enhancing cultivation and utilization of green manures as proposed by farmers in Ollukkara and Wadakkanchery blocks

Sl No	Strategies	Percentage (%)
1	Cultivation of Kozhinjil/Cowpea or pulses in intervals of paddy cultivation	25
2	Planting trees in vacant places	75
3	Boundary planting	60
4	Planting trees in banks of streams	60
5	Promoting green leaf manuring through agriculture dept	50
6	Compost	10

Table 19. Preferred location for planting green manure trees in paddy field or elsewhere as suggested by farmers in Olllukkara and Wadakkanchery blocks

Sl No	Preferred location	Percentage (%)
1	Boundary planting	60
2	Vacant places in the field	90
3	Home gardens	85
4	Planting trees in banks of streams	60
5	Wide paddy bunds	30

Table 20. Farmers' opinion for adopting green manuring practices via planting tree species in their paddy fields of Ollukkara and Wadakkanchery blocks

Sl No	Opinion	Percentage (%)
1	Interested	80
2	Not interested	15
3	No reply	5

DISCUSSION

5. DISCUSSION

A one-year-long field study has assessed the green biomass production and crop interaction of selected trees/shrubs on wetland paddy bunds. The study also evaluated the survey and documentation of the indigenous knowledge, the current practices and the farmer's perspective on green manuring in paddy fields of Ollukkara and Wadakkanchery blocks in Thrissur district. The results of the experiment titled "Growth, green biomass production and crop interaction of selected trees and shrubs on wetland paddy bunds" are discussed here concerning the published literature on the subject.

5.1 Experiment I. Green biomass production and crop response of selected trees/shrubs on wetland paddy bunds

5.1.1 Growth and biomass of trees/shrubs

Environmental factors like light intensity temperature and soil parameters like moisture and nutrient content impact on plant growth and development. Specific minimum, optimal and maximum light levels are required in a given region for plant species' effective growth and development. The relative growth of these plant species can vary greatly, often due to changes in abiotic elements such as temperature, water availability, light exposure and nutrient availability associated with the habitat. These factors play a crucial role in determining the suitability of different plant species for a particular area.

5.1.1.1 Plant height

The height of trees/shrubs on wetland paddy bunds can vary significantly depending on several factors, including the tree species, local climate, soil conditions and management practices. In the present study, cultivated trees/shrubs on wetland paddy bunds show significantly different plant heights (Table 1 and Fig 2). As sesbania suffers mortality due to topping, only side branches were pruned and growing tips were kept intact. So, it was not feasible to control its height as 1 m hedges on wetland paddy bunds by using topping. Other species were maintained as 1 m hedges through lopping.

During the initial period, sesbania outpaced others, reaching a plant height of 303.67 cm, followed by *Gliricidia* (197.33 cm) and red gram (195.60 cm). *Sesbania*'s rapid growth, especially in the first year, is attributed to its species' characteristics, making it suitable as an annual green manure crop (Duke, 1983). Karmakar *et al.* (2016) noted sesbania's potential to grow 5-6 meters in nine months in fertile sites. *Gliricidia* also showed quick initial growth, reaching 3 m in the first year (Elevitch and Francis, 2006). Red gram, when part of an intercropping system under rainfed conditions, achieved a height of over 1.5 m within a year (Sharma *et al.*, 2010), showcasing its rapid growth alongside other crops. Collectively, these studies underscore the adaptability and ability of *Sesbania*, red gram and *Gliricidia* to thrive in diverse cropping conditions, including ill drained paddy fields.

Calliandra-T4 (179.67 cm) and *Terminalia*-T5 (178.00 cm) showed statistically equivalent plant height on wetland paddy bunds. Previous research has shown that *Calliandra* seedlings exhibit rapid growth, reaching 2.5-3.5 meters in just 180 days and expanding to 3-5 meters within their first year of growth (Sebuliba *et al*., 2012). However, in contrast, *Calliandra* displayed limited height when cultivated on wetland paddy bunds. Earlier studies found that, generally, *Terminalia* showed 1.5-2 meters plant height in the initial years. The same plant height was observed on wetland paddy bunds. *Gmelina*-T7, when grown on wetland paddy bunds, attained a height of 150 cm within six months and reached a height of 207.67 cm within one year. This growth rate is slightly below the typical growth characteristics of the *Gmelina* species, known for its fast growth and ability to achieve heights exceeding 2.5 meters (Swamy *et al.*, 2003). *Garuga*-T2 (131.67 cm), *Cassia*-T9 (122.07 cm) and Mulberry-T6 (121.33 cm) were found to be comparatively shorter. Raj *et al.* (2016) documented a slow growth pattern of mulberry during its initial year of planting. *Cassia* generally showed 123 cm plant height in the first six months and 360 cm in the first fifteen months (Nyadzi1a *et al.*, 2002).

All trees/shrubs except *Garuga*, *Cassia* and *Gmelina* were harvested and allowed to regrow and the plant height was measured at the end of the first year.

Lopping was performed for all species except *Sesbania*. At the end of the first year, *Sesbania* (426 cm) showed significantly higher plant height than other species. The consistent pattern of plant height observed during the sixth month was also evident at the end of the first year. All species except red gram (183.60 cm) showed an increasing trend in plant height after harvesting. The Red gram exhibited slightly reduced plant growth at the end of the first year, which could be attributed to the prevailing weather conditions during that period. Following the harvesting, all the species experienced the onset of summer. Fabunmi *et al.* (2010) found that red gram showed a poor response to pruning. *Cassia* and *Gmelina* showed more than 2 m in height at the end of the first year. Mulberry and *Garuga* displayed limited plant height by the end of the first year, which could be attributed to the waterlogged conditions in the paddy field, potentially impacting the growth of these species. Likewise, the general growth characteristics of *Calliandra*, as expected, didn't exhibit on wetland paddy bunds. This variation in growth might be associated with the specific soil and water conditions in the study area.

5.1.1.2 Number of branches

In general, the number of branches plays a significant role in determining the overall growth and development of plants and trees. The data on the number of branches of the selected trees/shrubs on the wetland paddy bunds at intervals of six months are presented in Table 1 and Fig 2. In the present study, trees/shrubs growing on the wetland paddy bunds showed significant differences in number of branches throughout the study period. Redgram-T8 (20.60) showed a significantly higher number of branches compared to other species. Kumawat *et al.* (2013) reported that red gram (perennial) showed around 20 branches per plant when growing under rainfed conditions. *Sesbania* (15.47) showed better number of branches after six months. In most cases, *Sesbania* plants tend to develop more than ten branches within 100 days after being planted (Ginting and Mirwandhono, 2021). *Gliricidia* (8.33) and *Terminalia* (6.47) showed a medium number of branching. *Gliricidia* plants typically produce more than 20 branches within one year of growth because they are known for their prolific branching habit (Sukanten *et al.*, 1995). During the initial six months, *Gliricidia* plants exhibited a lower number of branches and this observation could likely be attributed to the soil and water conditions prevalent in that particular area. *Gmelina* (5.60), *Calliandra* (5.33), *Cassia* (5.07) and *Garuga* (4.67) showed poor branching, which is statistically equivalent to mulberry (4.90). *Gmelina* and *Garuga* showed poor branching habits on wetland paddy bunds. In the initial period, *Gmelina* generally showed poor branching habits (Swamy *et al.*, 2003).

5.1.1.3 Collar diameter

The collar diameter of a tree, also known as the root collar diameter or basal diameter, refers to the width of the tree's trunk at the base, typically measured at ground level. This measurement is significant for several reasons when it comes to understanding tree growth and overall tree health. The data on the collar diameter of the selected trees/shrubs on the wetland paddy bunds at intervals of six months are presented in Table 1 (Fig 3). In the present study, trees/shrubs growing on the wetland paddy bunds showed significant differences in collar diameter throughout the study period. Stem cuttings are employed for the establishment of *Gliricidia*-T1 and *Garuga*-T2 on the bunds of wetland paddy fields. Consequently, the measurement of the collar diameter for these species was omitted. In the initial half-year period, *Sesbania*-T3 (43.08 mm) exhibited notably greater collar diameter when compared to the other species present on the paddy bunds in the wetland. Typically, *Sesbania* is known for its rapid growth, so it displayed the largest collar diameter within a relatively brief timeframe (Williams *et al*., 2014). *Terminalia* (32.78 mm) and red gram (perennial) (33.37 mm) demonstrated robust collar diameter growth on the paddy bunds in the wetland area, indicating their successful adaptation to the prevailing climate and soil conditions. However, Mulberry-T6 (20.30 mm) and *Cassia*-T9 (21.34 mm) were observed to have the smallest collar diameter among the species planted on the wetland paddy bunds.

A consistent pattern in collar diameter was evident by the end of the first year. *Sesbania*-T3 (74.80 mm) displayed the greatest collar diameter, while Mulberry-T6 (30.27 mm) exhibited the smallest. Redgram-T8 (64.50 mm) demonstrated good collar diameter growth by the end of the first year and *Terminalia*-T5 (58.83 mm) displayed moderate collar diameter growth in comparison to the other species.

5.1.1.4 Number of coppice shoots

The data on the number of branches/coppice shoots of the selected trees/shrubs on the wetland paddy bunds at the end of the first year are presented in Table 1 (Fig 2). All tree/shrub species, except *Cassia*, *Gmelina* and *Garuga*, exhibited rapid growth and one harvest of these species was done after six months. So, the number of coppice shoots recorded for six species at the end of the first year. Among the selected trees/shrubs, *Sesbania*-T3 (22.63) showed a significantly higher number of coppice shoots. According to Karmakar *et al.* (2016), *Sesbania* was recommended as suitable for the process of pruning. Numerous research studies have consistently noted that *Sesbania* exhibited enhanced coppicing capabilities across various conditions (Yantasath, 1988; Duguma and Tonye, 1994; Ella, *et al.,* 1991). Redgram-T8 (20.60) showed a significantly higher number of branches than other species, but after harvesting, they showed fewer coppice shoots (16.87) than in the earlier season. Tenakwa, *et al.* (2022) reported that the variations observed in the initial establishment and subsequent regrowth of plants, in relation to factors like plant height, number of branches and stem diameter, can be attributed to various elements. These factors may include the season and prevailing climatic conditions post-harvest, the presence of meristems and the allocation of stored soluble carbohydrates for regrowth. According to Chairiello and Gulmon (1991), perennial plants tend to employ a stress-tolerance strategy when faced with unfavourable conditions. This strategy involves maintaining a shorter stature and directing a higher proportion of resources belowground. This adaptation may provide an explanation for the generally lower plant height observed during the regrowth phase compared to the initial establishment. *Gliricidia*-T1 (10.40) coppice well after first cut. Many research studies have indicated that *Gliricidia* is the most favourable option for agroforestry practices because of its remarkable coppicing capabilities (Kwesiga, 1994; Harrington and Fownes, 1993; Sileshi *et al.,* 2020). Waddington (2003) noted that species like *Gliricidia* exhibit strong coppicing capabilities and yield a significant quantity of top-notch biomass. *Calliandra*-T4 (7.33) and *Terminalia*-T5 (7.80) showed statistically equivalent coppice shoots. Generally, *Calliandra* and *Terminalia* showed a moderate number of coppice shoots. Mulberry-T6 (4.33) had the least number of coppice shoots. Overall, *Sesbania* and *Gliricidia* demonstrated superior coppicing characteristics, followed by red gram (perennial) and *Terminalia*, while *Calliandra* and mulberry exhibited subpar performance.

Gmelina and *Cassia* were formed to be comparatively slow growing and harvest was taken at the end of the first year. *Garuga* was formed to be very slow-growing and was not ready for harvest at the end of the first year. So, the number of coppice shoots for these species is not recorded. But the number of branches is higher at the end of the first year compared to the first six months.

5.1.1.5 Survival percentage

The term "survival percentage of trees" refers to the proportion or percentage of trees that have successfully survived a specific period or event. The number of trees that survived one year after planting was recorded, revealing notable differences among the various tree/shrub species (Table 1 and Fig 4). Among the selected trees/shrubs on wetland paddy bunds, *Terminalia*-T5 (98%) and red gram-T8 (98%) showed significantly higher survival percentages, followed by *Sesbania*-T3 (95%) and *Cassia*-T9 (95%). Jain and Singh (1998) found that *Terminalia* was a promising species in waterlogged areas as it survives well even in sodic soils also. Manasa *et al*. (2022) reported that *Cassia* was the most suitable tree species for planting on rice bunds and *Cassia* became the predominant tree species in both dryland and irrigated fields. Numerous studies reported that red gram (perennial) cultivation was a common practice in India. Red gram (perennial) is also widely cultivated in the paddy bund of the Palghat region of Kerala, mainly for serving as windbreaks (Joshi *et al*., 2005; Soyam *et al*., 2022; Bankar *et al.,* 2016). Karmakar *et al.* (2016) observed that *Sesbania* exhibits strong resilience to waterlogging, making it a suitable choice for regions prone to seasonal flooding. It thrives in wetter, humid environments and can prosper in diverse soil types, including poor, waterlogged, saline, alkaline and heavy clay soils. *Calliandra* (80%) and mulberry (80%) showed good survival on wetland paddy bunds. Sagaran (2017) documented that *Calliandra* demonstrated superior establishment, growth and survival, with a success rate of 98 per cent, even when subjected to repeated pruning during the first year after planting. However, the survival rate of *Calliandra* on wetland paddy bunds was lower compared to uplands. Raj *et al.* (2016) observed superior establishment and survival of mulberry plants in coconut gardens. They achieved a 100 per cent survival rate even when harvested frequently during the initial year of planting. But on wetland paddy bunds, it was slightly low. *Gliricidia* (60%) exhibited a moderate level of survival and growth on the wetland paddy bunds, with its performance being influenced by the height of the bunds. In general, the use of 1.2 m cuttings of *Gliricidia* resulted in notably elevated survival rates (Yamoah *et al.,* 1987), but here the water logged condition affects the survival of *Gliricidia*. *Gmelina* exhibited an average survival rate (50%) on wetland paddy bunds. It is due to *Gmelina* having a poor survival rate in paddy conditions (MacLean *et al.,* 2003; Panwar *et al.,* 2013*)*. The least survival percentage was observed in *Garuga*-T2 (10%) at the end of the experimental year. This study found that *Garuga* is not a suitable choice for planting on wetland paddy bunds.

5.1.1.6 Green biomass yield (Annual and seasonal)

The green biomass yield of a tree refers to the quantity of living plant material (leaves, branches and stems) that a tree produces. This measurement is often used to assess the productivity and growth of trees, especially in forestry and ecological studies. It's an essential parameter for understanding a tree's capacity for photosynthesis, carbon sequestration and overall ecosystem contribution. The yield can vary significantly depending on the tree species, environmental conditions and management practices. Annual and seasonal green biomass yield of selected trees/shrubs on wetland paddy bunds are represented in Table 2 and Fig 5. The data given in Table 2 indicate the significant difference in annual and seasonal green biomass yield produced by selected trees/shrubs on wetland paddy bunds. In the present study, green biomass yield was significantly higher in red gram-T8 (2.32

kg plant^{-1}) during the first harvest, which is statistically equivalent to *Sesbania*-T3 (2.06 kg plant^{-1}). Generally, red gram (perennial) produces more biomass seasonally (Tenakwa *et al.,* 2022) and Fabunmi *et al.* (2010) found that red gram produced 13 t/ha biomass in normal conditions. *Terminalia*-T5 (1.12 kg plant^{-1}), *Gliricidia*-T1 (0.92 kg plant^{-1}), *Calliandra*-T4 (0.90 kg plant^{-1}) and Mulberry-T6 (0.51 kg plant^{-1}) produced statistically equivalent biomass. Following the pruning or lopping process, *Sesbania*-T5 (3.39 kg plant^{-1}) generated more biomass than the other species. Gutteridge and Shelton (1993) stated that *Sesbania* yielded 55 t/ha of green material in just 6.5 months. In the instance of red gram-T8 (1.78 kg plant^{-1}), the biomass from coppicing was lower than the initial biomass, although it was relatively higher than the biomass of other species, except for *Sesbania* and *Gliricidia*. *Gliricidia*-T1 (2.34 kg plant^{-1}) yielded a good amount of coppice biomass. Because of its abundant biomass production, *Gliricidia* is widely used as both green manure and fodder crop in nearly every household in Kerala (KAU, 2016). Likewise, reports indicate that *Calliandra*, when intercropped in coconut gardens in Kerala, shows superior establishment, faster growth and increased yield during the first year of planting (Sagaran, 2017). However, *Calliandra*-T4 (0.87 kg plant^{-1}) exhibited low coppice biomass production by the end of the first year following lopping. In both seasons, Mulberry-T6 gave the lowest green biomass. The lower yields of mulberry in the first year of planting were attributed to its slow initial growth, as reported by Raj *et al.* (2016), but it performed better in the following years.

Gmelina and *Cassia* were observed to have relatively slow growth and were harvested at the end of the first year. *Garuga*, on the other hand, was found to be extremely slow-growing and was not mature enough for harvesting by the end of the first year.

In the case of annual biomass, *Sesbania*-T5 (5.45 kg plant^{-1}) produced a significantly higher quantity of green biomass, followed by Red gram-T8 (4.10 kg plant^{-1}), *Gliricidia*-T1 (3.26 kg plant^{-1}) and *Terminalia*-T5 (2.54 kg plant^{-1}). The lowest biomass was produced by Mulberry-T6 (1.08 kg plant^{-1}).

The study indicates that large quantity of green leaf manure can be produced by hedge row planting of trees and shrubs like *Sesbania*, red gram (perennial), *Gliricidia* and *Terminalia* in paddy bunds even in the initial year of planting. As a common practice, the internal bunds in paddy fields are spaced at 20-30 meters (feedback from farmers). If the bunds are placed at 20 m intervals, the total length of bunds in one direction (either E-W or N-S) would be 500 meters per hectare. When scaled to a hectare basis, around 2 to 2.5 t/ha/year green leaf can be harvested from 500 plants of *Sesbania*/red gram (perennial) accommodated on bund length of 500 m/ha, which can satisfy half of the recommended green leaf manure doses in paddy (5 t/ha/year as per POP of KAU).

Calliandra, mulberry and *Terminalia* are heavily grazed by goats and cows. In spite of the heavy grazing, the trees fully survived the onset of monsoon. These trees cannot be planted in bunds for green manuring purposes without providing protection. These trees also can be planted for fodder for animals during the lean period.

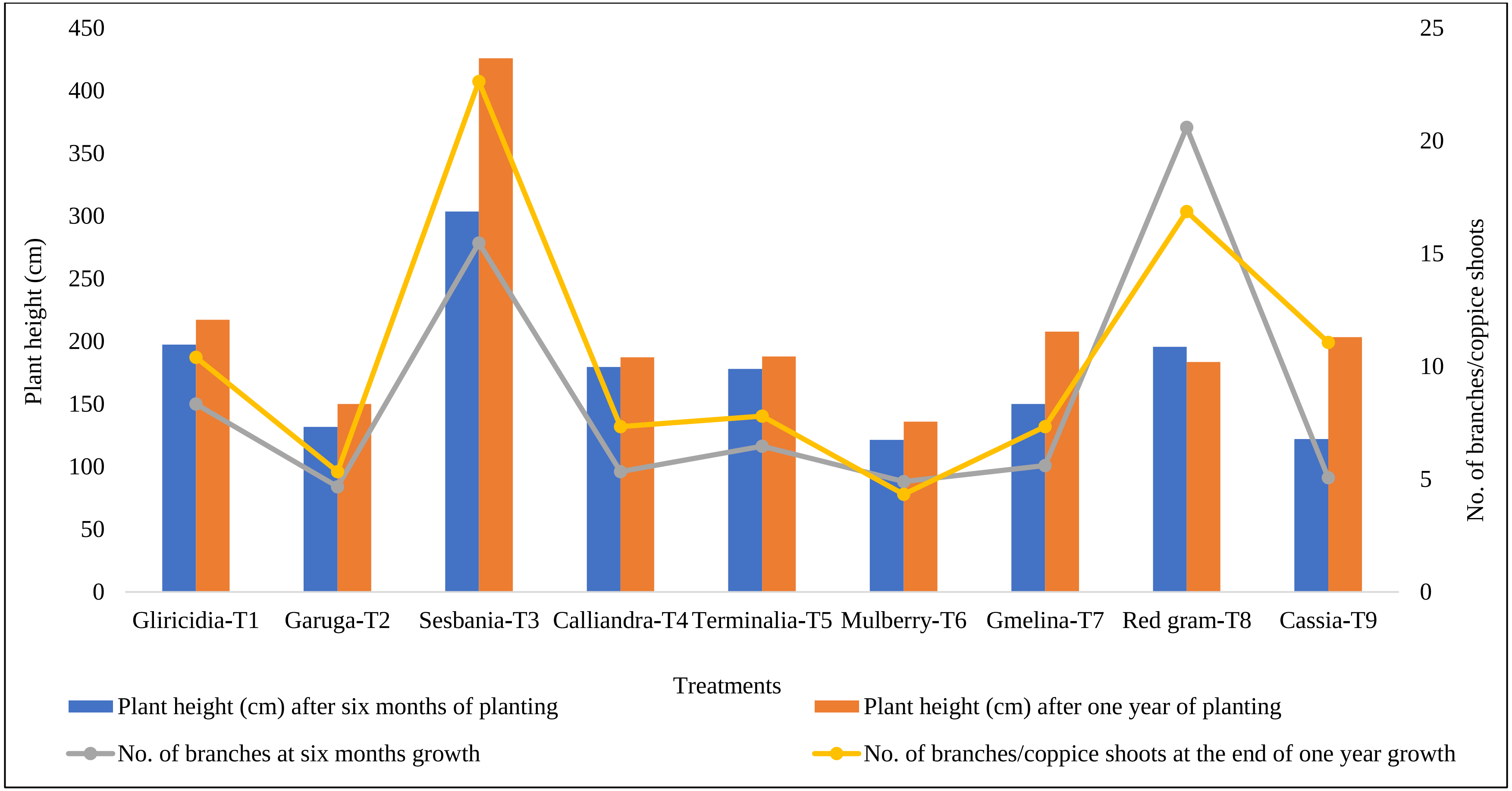

Fig 2. Growth parameters of bund grown trees and shrubs at intervals of six months in paddy field at State Seed Farm, Mannuthy

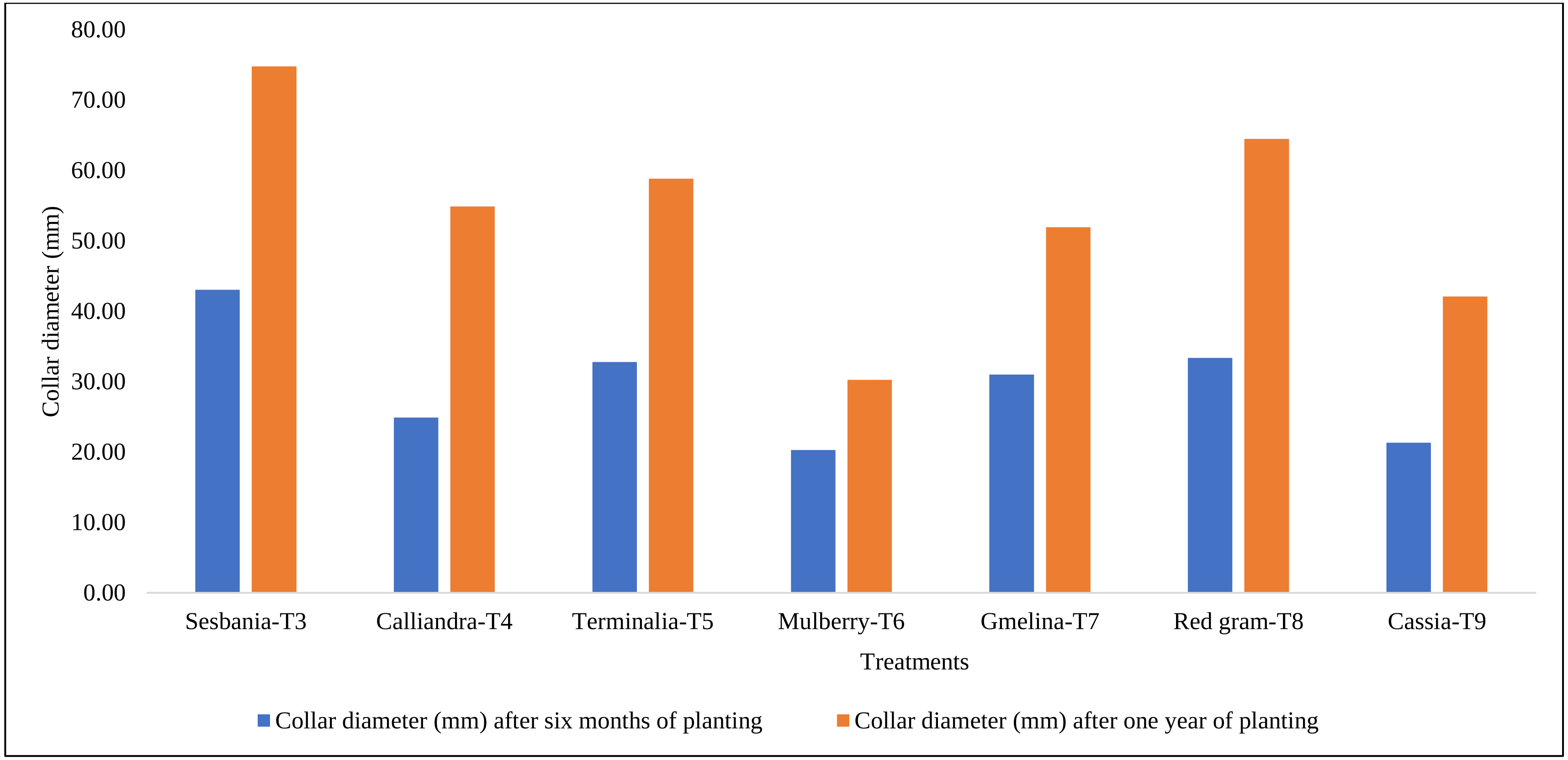

Fig 3. Collar diameter of bund grown trees and shrubs at intervals of six months in paddy field at State Seed Farm, Mannuthy

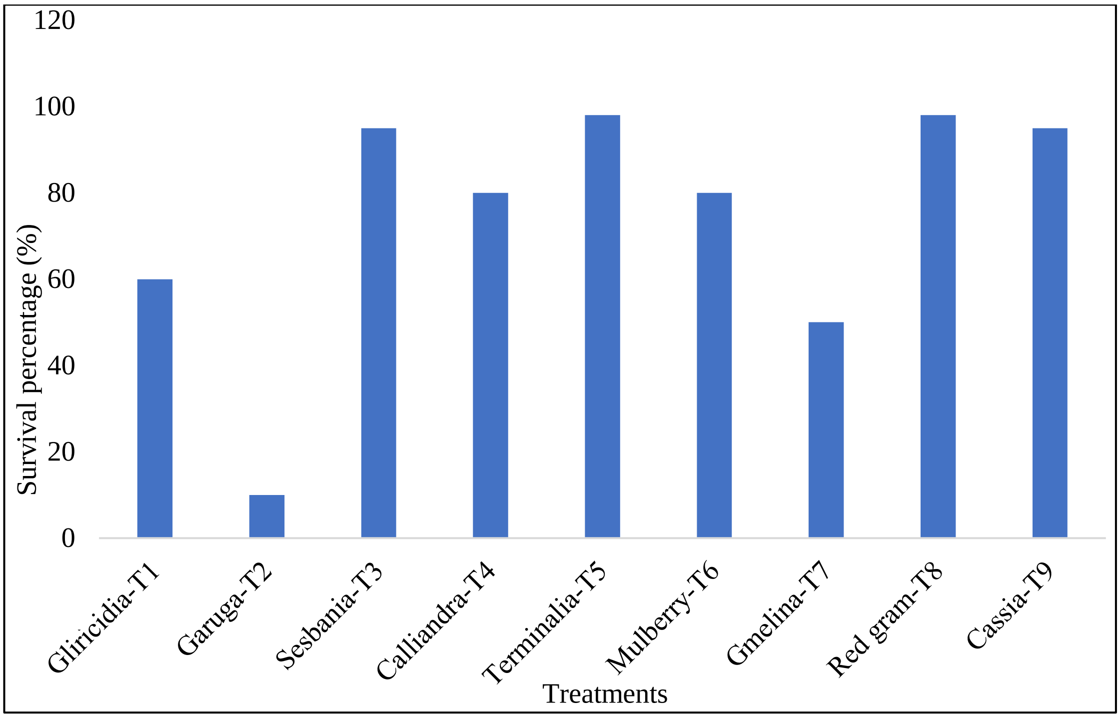

Fig 4. Survival percentage of bund grown trees and shrubs in paddy field after one year at State Seed Farm, Mannuthy

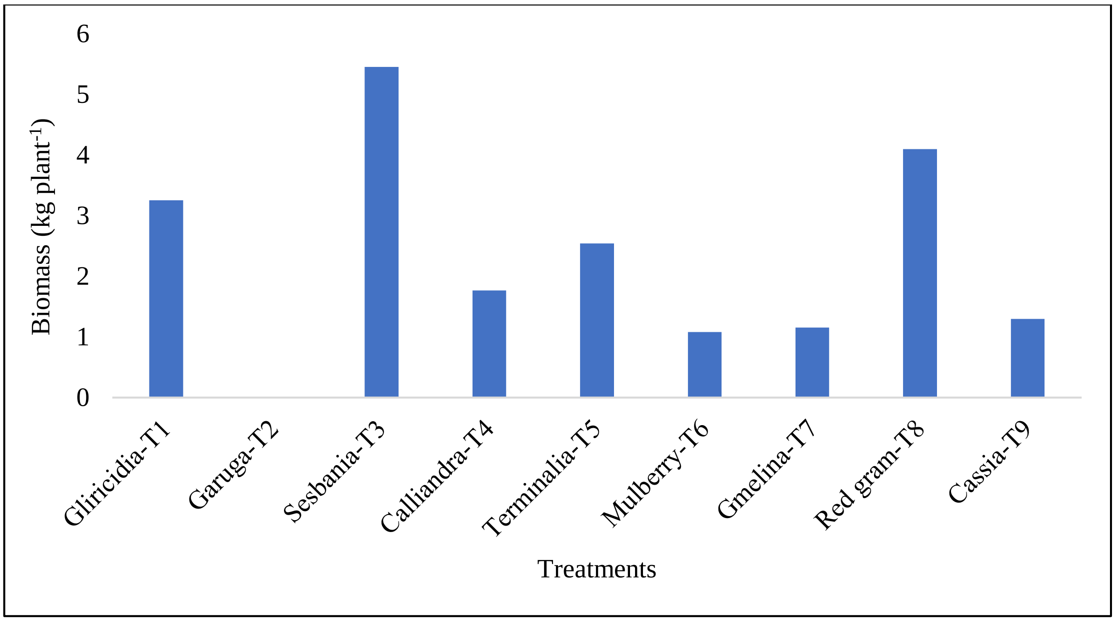

Fig 5. Annual green biomass yield of bund grown trees and shrubs in paddy field State Seed Farm, Mannuthy

5.1.2 Growth and yield attributes of paddy

The growth and yield attributes of paddy encompass the characteristics and factors that play a pivotal role in influencing the development and productivity of rice crops. These attributes encompass a variety of factors, such as plant height, tiller number, panicle count, grain weight and overall crop yield, among others. A comprehensive understanding and effective management of these growth and yield attributes are fundamental for successful rice cultivation and the optimization of agricultural practices.

The data presented in Table 3 and Fig 6 shed light on the growth attributes of paddy in three distinct positions relative to the base of trees/shrubs: within a 1 m radius, within a 1- 2 m radius and beyond the reach of trees in the centre of the field. Notably, a significant difference was observed only in the plant height of the paddy within a 1 m radius when compared to the control plot (centre of the field), which recorded better plant height. Sinha and Prajapathi (2022) reported that the tallest plant height (113.88 cm) was observed in transplanted rice fields within the control plot, compared to paddy grown under the canopy of trees/shrubs. Conversely, some studies found that paddy plant height generally tends to be greater when cultivated under the shade of trees (Sae-lee *et al.*, 1992). However, no significant differences were observed in the remaining growth attributes during the study period. The trees and shrubs were planted just a year ago, so their impact on the paddy crops was not significant. The noteworthy variation in plant height within a 1 m radius can be attributed to the shading effect or root interaction of the growing trees on the paddy bunds. The number of tillers/hill ranged between 17 and 20, which was not statistically significant.

The data presented in Table 4 and Fig 7 offers insights into the yield attributes of paddy across three distinct positions relative to the base of trees/shrubs: within 1 m radius, within 1- 2 m radius and in the central region of the field, away from the trees. Notably, a significant difference was observed in the number of panicles/m^2 of paddy within 1 m radius. Conversely, no statistically significant differences were detected in the remaining yield parameters of paddy in the experimental plots. Within the 1 m radius, the control plots exhibited the highest number of panicles/m^2.

The growth and yield parameters for paddy in both the *Calliandra*-T4 and Red gram-T8 plots were slightly lower when compared to the other plots. This decrease can be attributed to the wider canopies of these two species, which cast more shade and, consequently, had an impact on the growth and yield of the paddy crop. Boundary plantations had a negative impact on rice crop growth and yield. Shade from these trees, influenced by factors like tree diameter and crown width, significantly affects crop performance in farmers' fields. The adverse effects were most pronounced near the tree base, resulting in decreased growth and rice yield. However, moving away from the tree line leads to improved yield and characteristics. Wider tree crowns had a more detrimental impact on rice yield, while narrower crowns had a milder effect (Sinha and Prajapathi, 2022). Mankur *et al.* (2022) found that teak (*Tectona grandis*) boundary plantations negatively affect rice growth and yield, primarily due to shading from these trees. This impact varies based on factors like tree diameter at breast height (dbh), crown width and distance from the tree line. In particular, the adverse effects on rice growth and yield are most significant in the presence of teak shading. As one moves away from the tree line, rice yield and its characteristics improve. Notably, wider tree crowns have a more pronounced negative impact on rice yield and its attributes, while narrower crowns have a milder effect. Miyagawa *et al.* (2017) reported that the presence of trees on levees had a discernible impact on the rice yields in their proximity, although the specific effects were influenced by both the tree species and the overall field conditions.

The experimental period lasted for only one year and as a result, the interaction between the crops and trees did not exhibit significant effects. However, it is crucial to acknowledge that the growth and yield parameters of paddy in the experimental plot showed a decline, likely attributed to the influence of fluctuating weather conditions. Throughout the study period, there were continuous shifts in weather patterns, which had a detrimental impact on the paddy yield. Typically, the average grain yield in Kerala is 3105 kg/ha, with Thrissur averaging 3667 kg/ha (GOK, 2023). Nonetheless, data from Table 4 indicates that the grain yield ranged from 2000 to 2700 kg/ha, while the straw yield fell within the range of 6700 to 7600 kg/ha, indicating a significant decrease in paddy yield over the whole region.

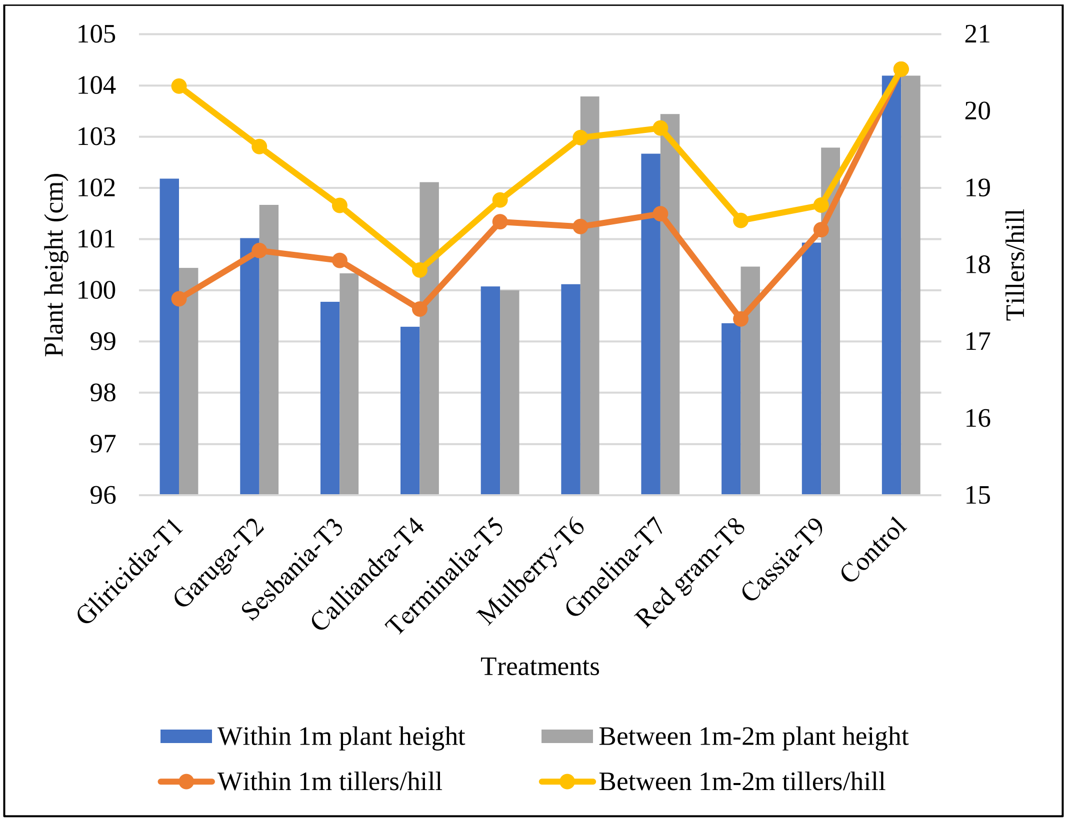

Fig 6. Growth attributes of paddy (3 months after planting) under the shade of bund grown trees/shrubs and open fields with full sunlight at State Seed Farm, Mannuthy

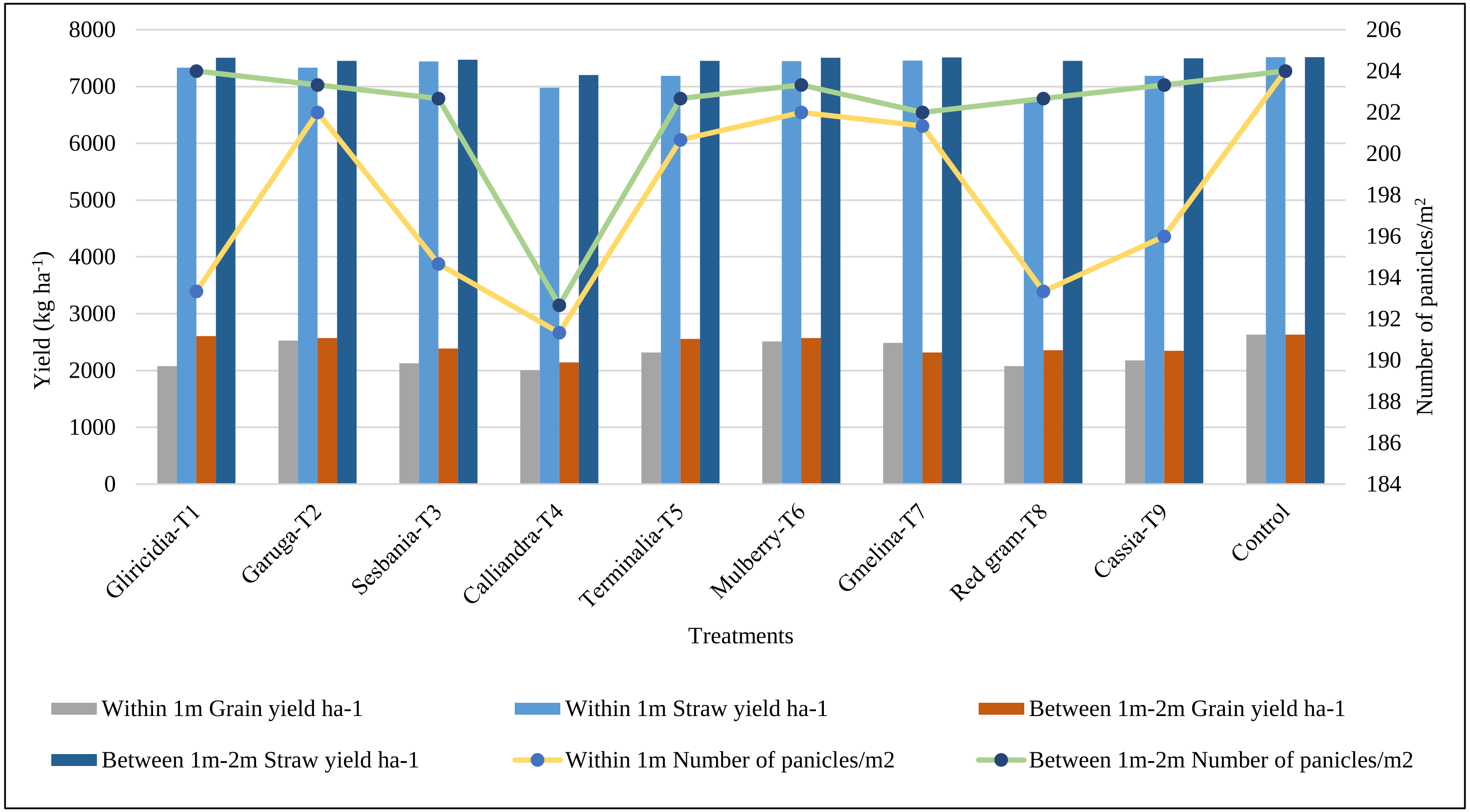

Fig 7. Yield attributes of paddy growing underneath bund grown trees/shrubs and open fields with full sunlight at State Seed Farm, Mannuthy

5.1.4 Understorey Photosynthetically Active Radiation (PAR) Measurements

Diurnal variations in understorey Photosynthetically Active Radiation (PAR) were measured above the paddy crop at three positions from the tree/shrub base, *viz*., within 1 m radius, 1- 2 m radius and from the centre of the field beyond the reach of trees and represented in Table 7 and Fig 8. PAR transmittance ranged from 69.58 per cent to 98.20 per cent within a 1 m radius in various treatment plots and from 66.68 per cent to 99.52 per cent between 1- 2 m beyond the reach of trees/shrubs. At the centre of the paddy field, PAR transmittance reached 100 per cent. Across all treatment plots, slightly higher PAR transmittance was found between 1- 2 m beyond the trees, except for the *Calliandra*-T4 treatment. *Calliandra* exhibited a wider crown above 1 m in height, resulting in a more pronounced shade effect within the 1- 2 m radius. Conversely, other species, particularly red gram (perennial), had wider crowns closer to the ground, leading to a greater shade effect within a 1-m radius.

In general, light availability, its interception and the efficiency with which this intercepted light is converted to biomass play a critical role in determining the understorey's biomass yield (Gao *et al.*, 2013). Sinha and Prajapathi (2022) discovered that broader tree crowns had a more detrimental impact on rice yield, while narrower crowns had a milder effect. The competition between trees and crops is heavily influenced by light availability, which is affected by the tree canopy. Mankur *et al.* (2022) reported that the shade from boundary plantations had a negative impact on paddy cultivation. Conversely, Manasa *et al.* (2022) found that the presence of *Gliricidia* trees did not adversely affect cultivated crops due to their shading effect and the light shade from the *Sesbania* canopy did not hinder companion plant growth.

Throughout the study period, the trees/shrubs were pruned or lopped to a height of 1 m from the ground for all harvests. After the harvest, the trees/shrubs were maintained as hedges. Consequently, the shade from the trees/shrubs and shrubs along the wetland paddy bunds did not significantly impact the growth and yield of paddy. During the study period, a pruning or lopping height of 1 m from the ground was maintained for all the harvests.

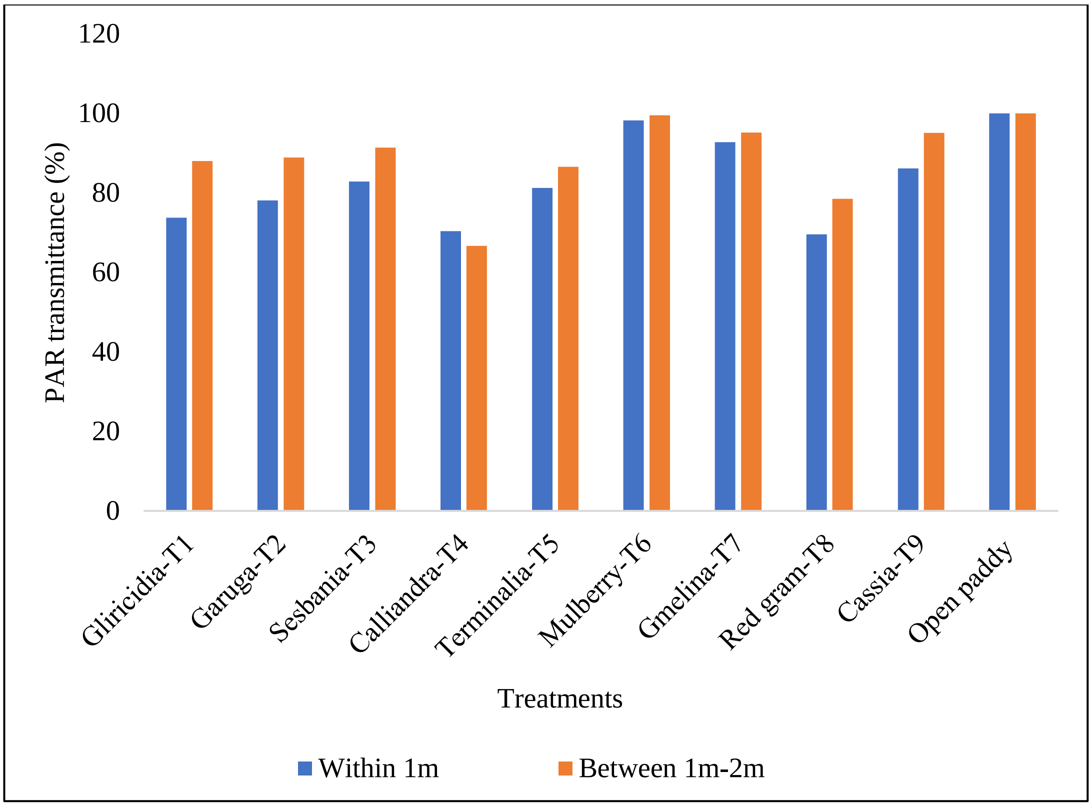

Fig 8. PAR transmittance (%) to paddy near tree and shrub base and open field at State Seed Farm, Mannuthy

5.1.3 Soil parameters

The soil parameters (Table 8) in the paddy field from the tree/shrub base, *viz*., within 1 m radius, 1- 2 m radius and from the centre of the field beyond the reach of trees/shrubs. With the exception of available nitrogen content, no significant differences were observed in the soil pH, organic carbon, available phosphorus and available potassium content across the various treatment plots. These findings were consistent with earlier soil data collected from the study area, indicating that these soil characteristics remained relatively stable over the study period. The pH levels of soils in both the treatment plots and open paddy fields fell within the range of 5.22 to 5.95 (Fig 9), with a slight pH increase noted in the treatment plots compared to the open paddy fields. Notably, the red gram plots exhibited higher soil pH levels. Russell *et al.* (2018) noted that trees can influence soil pH, which might explain this variation. It's important to mention that the study area had a history of continuous cultivation, with long-term application of NPK fertilizers, resulting in generally high available phosphorus content, ranging from 26.91 to 38.97 kg ha^{-1} (Fig 11). Moreover, soils in Thrissur, Kozhikode, Ernakulam and Alappuzha districts of Kerala have been reported as rich in available phosphorus content (Bastin *et al.*, 2014). Contrary to the general trend in Kerala, the study area exhibited a deficiency in the available potassium content, with values ranging from 52.08 to 66.83 kg ha^{-1} (Fig 12). In terms of organic carbon content, the observed range was 0.44% to 0.57% (Fig 13).

The study detected significant differences in the available nitrogen content of the soil when comparing various treatment plots to open paddy fields. Notably, soil samples taken from within 1 m radius and 1- 2 m radius beyond the reach of trees exhibited marked disparities in available nitrogen content (Fig 10).

Numerous studies have emphasized the nitrogen-fixing ability of legumes in soil (Peoples and Baldock, 2001; Yuvaraj *et al.*, 2020; LaRue and Patterson, 1981). Consequently, leguminous plants such as *Cassia*, red gram, *Calliandra*, *Sesbania* and *Gliricidia* displayed significant variations in available nitrogen content. Interestingly, only *Cassia* exhibited similar levels of available nitrogen content when compared to the open paddy fields. Additionally, outside of the legume category, *Terminalia* and *Gmelina* showcased comparable available nitrogen content to that of *Gliricidia*.

Within the 1- 2 m radius, a decline in available nitrogen content was observed, specifically in *Sesbania*. In both scenarios, soil samples obtained from the mulberry plot exhibited the lowest levels of available nitrogen content, registering at 62.72 kg/ha and 108.71 kg/ha, respectively. Mulberry is a non leguminous tree without nitrogen fixing ability and its nutrient requirement is very high (Acsah,2018). Further research will be necessary to thoroughly examine the root distribution of mulberry and *Sesbania* plants growing on the wetland paddy bunds.

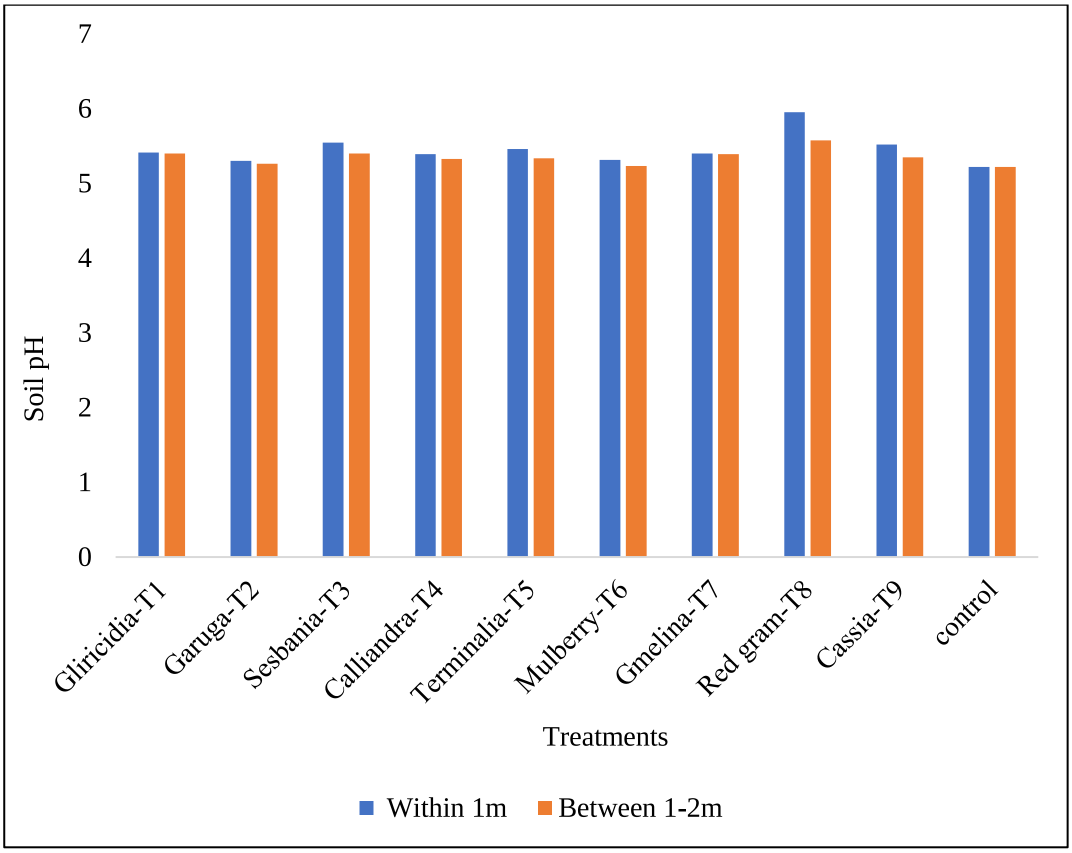

Fig 9. pH of the paddy soil near the tree and shrub base and in open control plots at State Seed Farm, Mannuthy

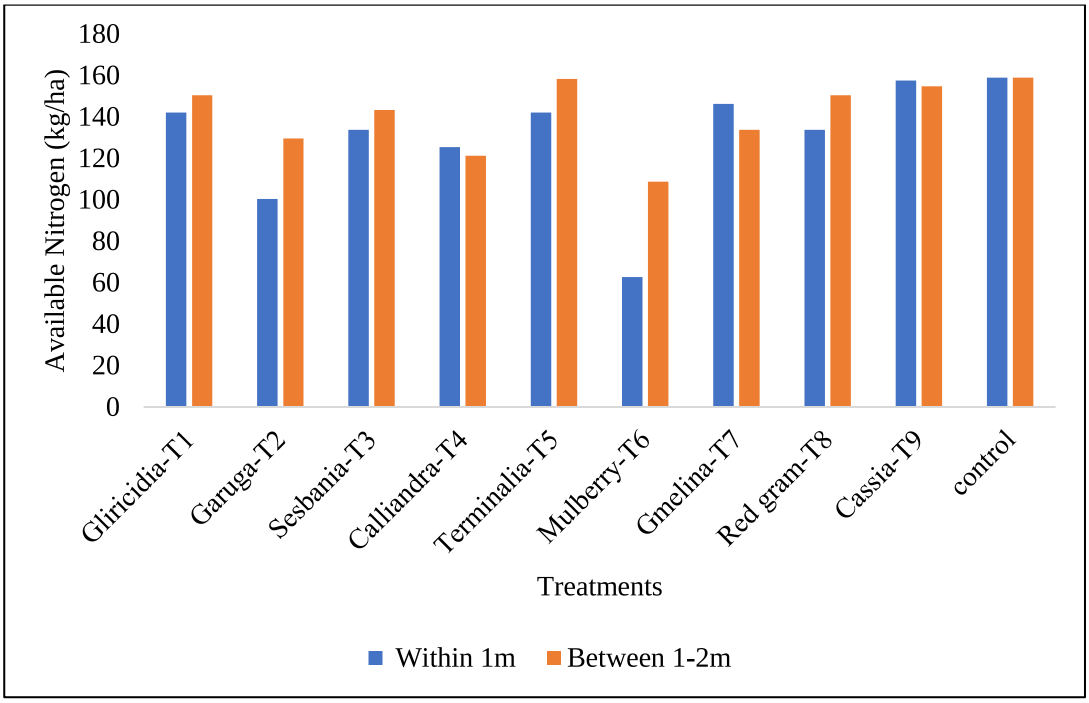

Fig 10. Available nitrogen content in the paddy soil near tree and shrub base and control open plots at State Seed Farm, Mannuthy

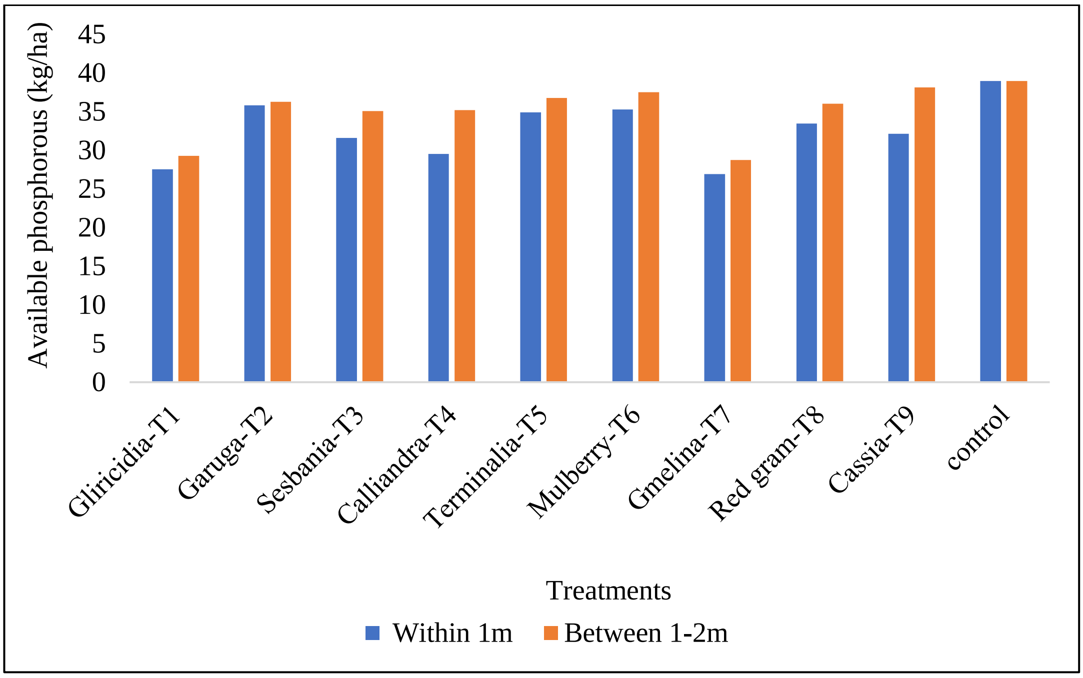

Fig 11. Available phosphorous content in the paddy soil near the tree and shrub bases and control open plots at State Seed Farm, Mannuthy

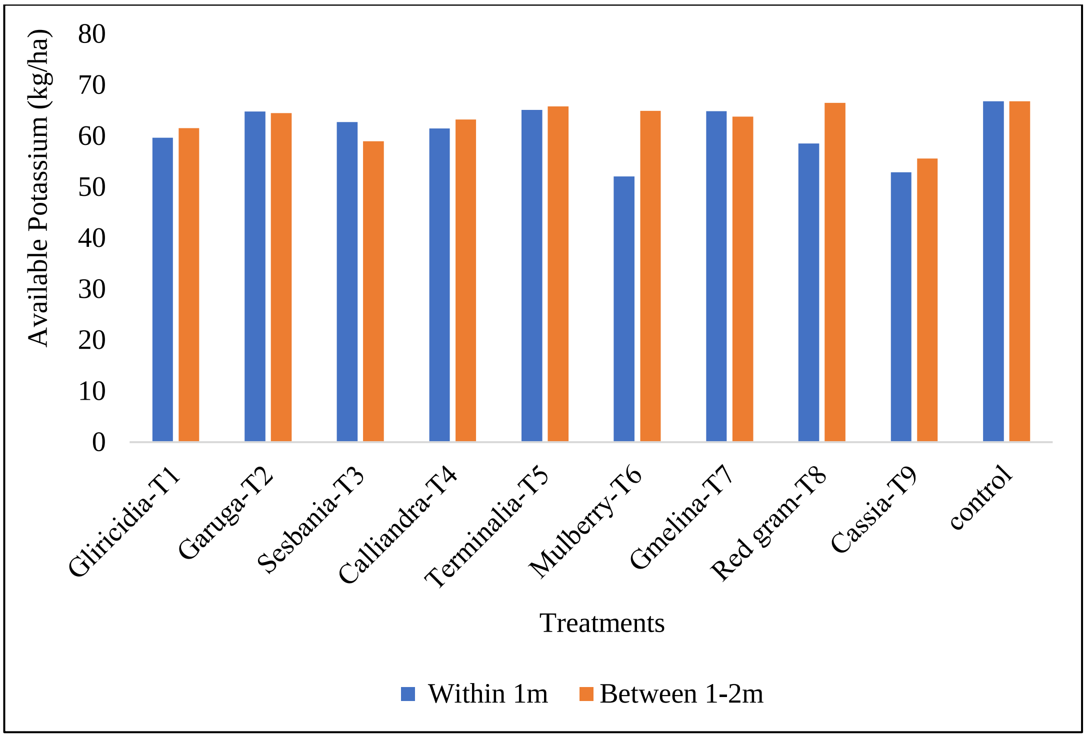

Fig 12. Available potassium content in the paddy soil near tree and shrub base and control open plots at State Seed Farm, Mannuthy

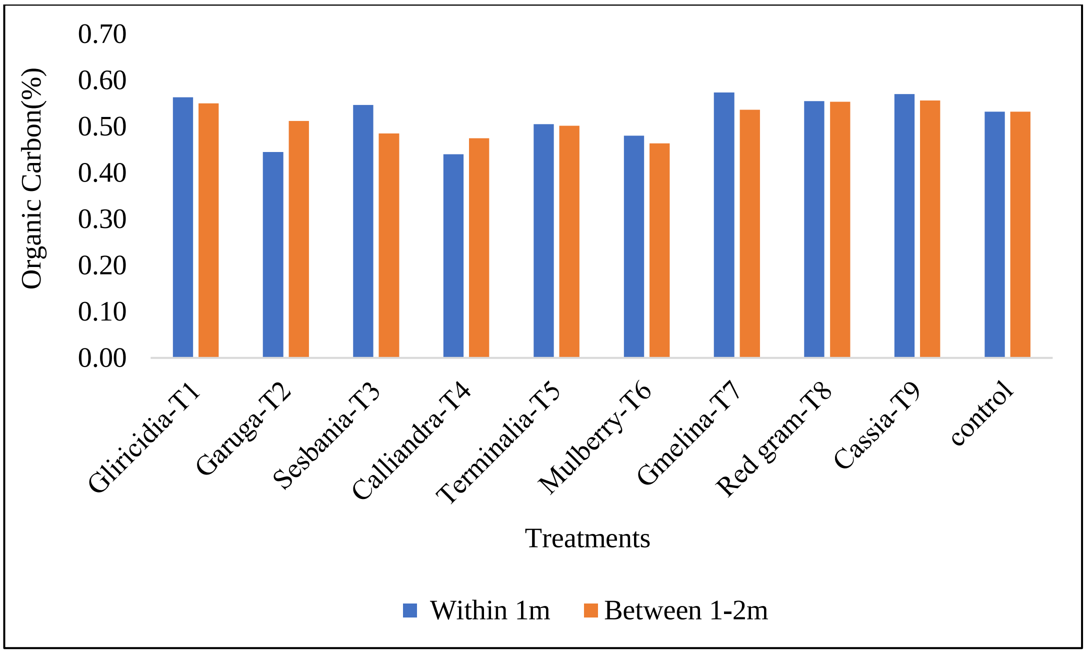

Fig 13. Organic carbon content in the paddy soil near tree and shrub base and control open plots at State Seed Farm, Mannuthy

5.2 Experiment II. Survey and documentation of green manuring practices in Ollukkara and Wadakkanchery block

5.2.1 Existing manuring practices in paddy fields

Existing manuring practices in the paddy fields of the Ollukkara and Wadakkanchery blocks were displayed in Table 9. The data reveals the choices made by local farmers to enrich their fields with manures (Fig 14). The majority of farmers rely on chemical fertilizers for growing rice, but they also incorporate organic manures as a supplement in their paddy fields. The primary choice of manure among the surveyed farmers was cow dung, with a significant 95 per cent of participants opting for this traditional organic fertilizer. Cow dung, known for its nutrient-rich composition, is a readily available resource in many agricultural communities, making it a popular choice. In addition to cow dung, the survey observed that goat manure is also fairly well-liked, with 65 per cent of farmers incorporating it into their paddy fields. Goat manure, while similar to cow dung in its nutrient value, may be more accessible for certain farmers and can be a valuable addition to soil health. Chicken manure, known for its high nitrogen content, is another favoured option, with 75 per cent of farmers utilizing it to bolster their paddy fields.

Conversely, neem cake and ash appear to be less favoured options among the surveyed farmers, chosen by only 25 per cent and 30 per cent of participants. Neem cake, derived from neem tree seeds, is prized for its natural pest-repellent properties and soil enrichment benefits. Ash, typically from crop residue burning, can serve as a source of potassium.

Green manure is a practice embraced by 40 per cent of the surveyed farmers. Green manure typically involves planting cover crops, which are later incorporated into the soil to enhance its organic matter content. This method aids in improving soil structure and fertility during fallow periods between paddy cultivation. Moreover, 70 per cent of the farmers prefer green leaf manure, another organic matter source. Green leaf manure, often composed of plant residues, is known for its role in enriching soil with essential nutrients.

Table 10 illustrates the most commonly cultivated green manures in the paddy fields of Ollukkara and Wadakkanchery blocks. Green manures are an integral part of sustainable agriculture, as they contribute to soil health and nutrient replenishment. The survey revealed that 62.5 per cent of those who opt for green manure prefer Dhaincha, while 25 per cent choose cowpeas or pulses as their preferred green manure crop. Dhaincha, with its ability to fix atmospheric nitrogen, is highly regarded for enhancing soil fertility and nitrogen availability for subsequent crops. Cowpea, a leguminous crop, also adds nitrogen to the soil, making it a valuable choice for crop rotation and soil improvement (Fig 15). These data collectively shed light on the organic farming practices in these regions, showcasing the significance of organic matter and green manure in maintaining and enhancing soil quality for sustainable paddy cultivation.

5.2.2 Type of tree species used for green manuring in paddy field

Table 11 displays valuable insights into the selection of tree species as adopted by farmers in the paddy fields of the Ollukkara and Wadakkanchery blocks for green manuring. The dominant species selected for green manuring in this region was *Gliricidia sepium,* chosen by a majority of participating farmers. *Gliricidia sepium* is known for its nitrogen-fixing abilities, which enrich the soil with essential nutrients, particularly used during the mundakan and puncha periods. Apart from *Gliricidia sepium*, the other tree species were employed annually, primarily during the mundakan season. The use of different tree species for green manuring aligns with crop rotation practices and contributes to the overall health and fertility of the soil.

Numerous studies consistently highlighted the prominent use of green leaves from *Gliricidia* in paddy fields as a highly effective form of organic manure. *Gliricidia*, a nitrogen-fixing tree species, had gained recognition for its remarkable ability to enrich the soil with a wide range of essential nutrients. The green leaves of *Gliricidia,* when incorporated into paddy fields, played a pivotal role in enhancing soil fertility and supporting healthy crop growth. The nutrients contributed by *Gliricidia* leaves include nitrogen, phosphorus, potassium and various micronutrients. These organic additions aided in improving soil structure, increasing nutrient availability to the crops and fostering a favourable environment for beneficial soil microorganisms (Kang *et al*., 1985; Agboola *et al*., 1982; Gohl, 1981; Kidd and Taogaga, 1985).

Farmers who participated in the survey were informed that the utilization of *Gliricidia* leaves as green manure was a sustainable and eco-friendly practice. This approach not only reduced their reliance on synthetic fertilizers but also promoted soil health and long-term agricultural sustainability. The versatility and efficacy of using *Gliricidia* leaves had made it a preferred choice among these farmers and it played a significant role in contributing to the success of paddy cultivation and the establishment of sustainable farming systems.

Table 12 complements the information presented in Table 11 by highlighting the sources of these tree species used for green leaf manuring in the paddy fields of the Ollukkara and Wadakkanchery blocks. It's noteworthy that the origin of these species significantly influences their availability and use. Fig 16 illustrates that a substantial portion of these tree species (62.5%) is cultivated in farmers' home gardens. Home gardens often serve as a valuable resource for various tree species that can be used for green manuring. These trees can be strategically planted and maintained by farmers to provide organic matter for paddy fields, demonstrating the sustainable nature of this agricultural practice. Additionally, 37.5 per cent of these tree species are grown in field boundaries. Notably, *Cleistanthus collinus* and *Gliricidia sepium* were naturally occurring in both home gardens and field boundaries. These species can thrive in these environments, making them readily available for use in green leaf manuring without extensive cultivation efforts. These species were not purposefully planted with the specific intention of green manuring. Instead, their utilization as manure in paddy fields depended on their natural availability. Farmers made use of these tree species for green manuring based on their accessibility and suitability for enhancing soil fertility in the paddy fields.

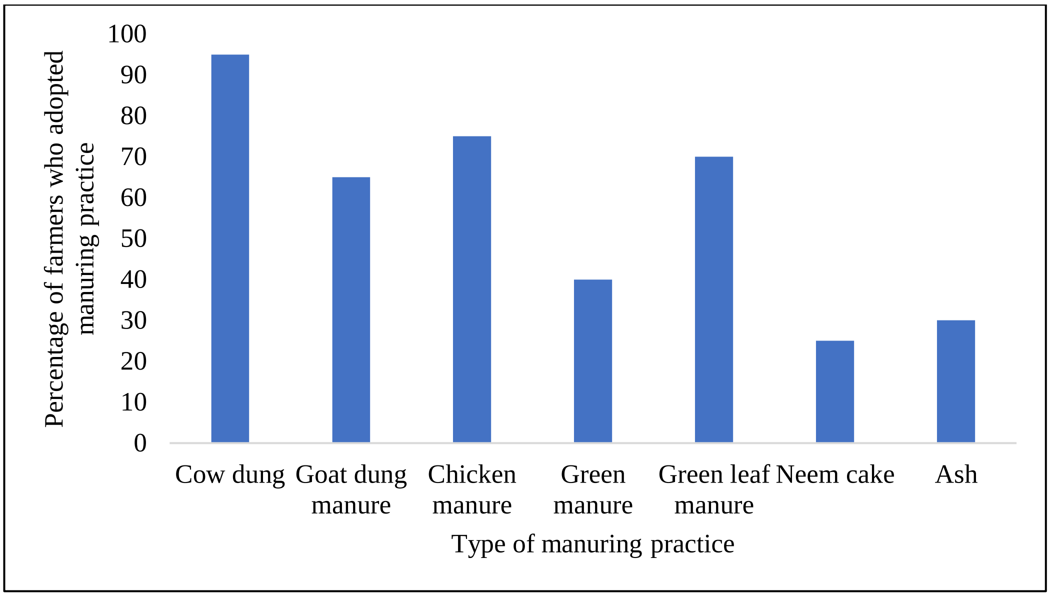

Fig 14. Current manuring practices adopted by farmers in paddy fields of Ollukkara and Wadakkanchery blocks

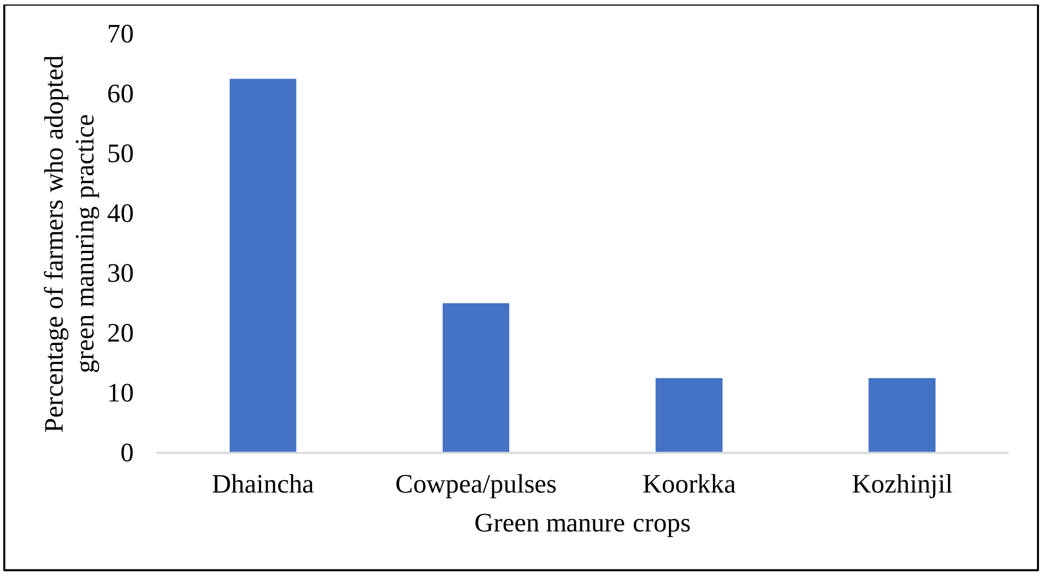

Fig 15. Farmers perception about cultivation of green manure crops in paddy fields of Ollukkara and Wadakkanchery blocks

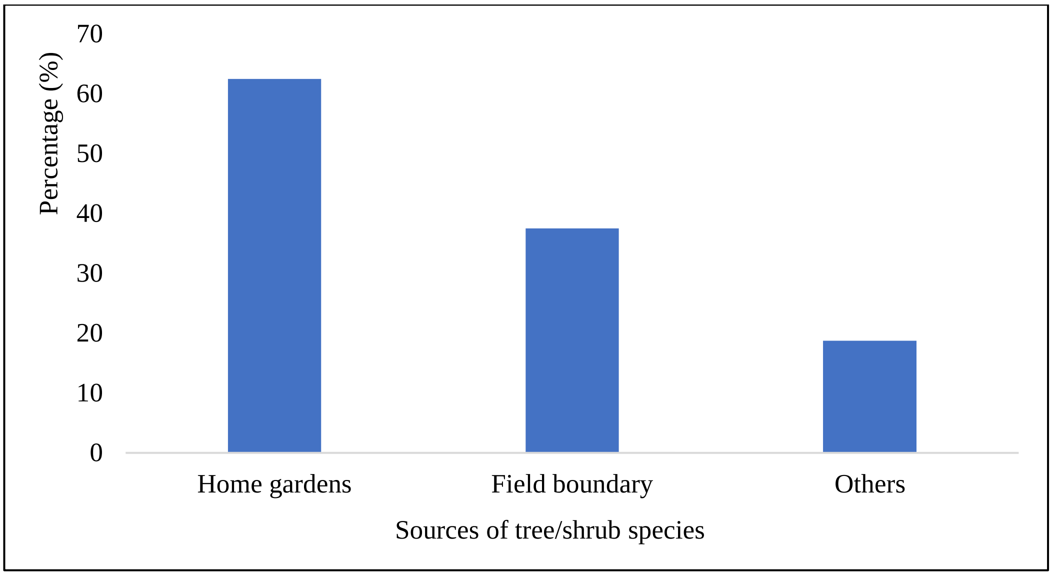

Fig 16. Source of tree/shrub species used for current green leaf manuring practices in paddy fields of Ollukkara and Wadakkanchery blocks

5.2.3 Indigenous Knowledge of green manuring practices

Table 13 provides insights into the traditional knowledge of green manuring practices and past green leaf manuring species employed in the paddy fields of the Ollukkara and Wadakkanchery blocks. This data provides a historical perspective on sustainable agricultural practices in the region. The most favoured and optimal choices for green leaf manuring in paddy fields were *Terminalia paniculata*, *Terminalia bellirica* and *Mangifera indica.* These tree species were considered highly effective for enhancing soil fertility. During earlier periods, it was common practice to use 1000-1500 kg of green leaves from these species per hectare. These leaves, when incorporated into the soil, contributed vital organic matter and essential nutrients, supporting robust paddy crop growth. With the exception of *Gliricidia*, all these preferred species were employed on an annual basis, primarily during the mundakan season. This aligns with traditional agricultural practices where green manure is applied during fallow periods to enhance soil quality and nutrient availability for the subsequent paddy crops. It's noteworthy that the utilization of green leaves extended beyond these prominent species. The survey revealed that farmers employed green leaves from over 15 different species for manuring. This diversity in species selection showcases the rich traditional knowledge and practices of the local farming community, emphasizing the importance of organic matter in sustainable agriculture. An intriguing aspect of this practice was the sourcing of these green leaves. A significant majority (97.5%) of the green leaf manuring species were obtained from nearby forest areas. This highlights the sustainable approach of the farmers, who relied on naturally occurring resources to enrich their paddy fields. Moreover, 50 per cent of the surveyed farmers collected green leaves from their home gardens for smaller-scale purposes. This practice showcased the integration of home gardening into traditional agricultural systems, where farmers made efficient use of available resources to support their agricultural endeavours (Table 14 and Fig 17).

Jayanarayanan (2001) reported that in Kerala, the practice of using green leaf manures to enrich the soil and promote sustainable rice cultivation has a rich and enduring tradition. Kumar *et al*. (1992) explained that within Kerala, it was customary to find living fences constructed using small trees and shrubs. These live fences often featured species like *Vitex negundo, Gliricidia sepium, Manihot glaziovii and* others. Furthermore, in numerous upland agricultural production systems, multipurpose trees such as *Gliricidia sepium, Macaranga peltata, Leucaena leucocephala* and the like served as sources of green leaf manure and fodder. To meet their green leaf manure requirements, farmers primarily turned to fast-growing tree species that were strategically planted along their field boundaries. The declining ratio of forests-to-agricultural lands and the increased intensity of land use increased the pressure on remaining forests due to the illicit cutting of trees (for firewood, charcoal and for making agricultural implements), overgrazing and collection of fodder, green leaf manure, litter and non-wood forest products (Amruth, 2004; KFRI, 2005).

5.2.4 Type and source of supplementary fertilizers used in paddy fields

Table 15 depicts the source of additional fertilizers and manures employed in the paddy fields within the Ollukkara and Wadakkanchery blocks. The data reveals the diverse sources of these agricultural inputs, shedding light on the practices of local farmers (Fig 18). Among the farmers who participated in the questionnaire survey, 60 per cent procured supplementary fertilizers and manures from local markets. These local markets served as convenient hubs for acquiring agricultural inputs, catering the needs of the farming community. In contrast, 40 per cent of the farmers opted for a more self-reliant approach by collecting smaller quantities of manures from their own households. This practice reflects the resourcefulness of these farmers who utilize organic materials from their immediate surroundings. Interestingly, a significant proportion (45%) of the fertilizers used in these paddy fields were imported from other states. This demonstrates the diverse geographic sourcing of agricultural inputs and the regional exchange of resources to support farming activities. Additionally, 50 per cent of the surveyed farmers accessed fertilizers from the Department of Agriculture Development and Farmer's Welfares, as elaborated in Table 9, which provides a comprehensive overview of supplementary manures in the paddy fields.

Table 16 highlights a critical aspect of the farmers' practices, particularly their reliance on chemical fertilizers. While many farmers relied on these fertilizers, it's essential to recognize the associated challenges. Notably, all 100 per cent of the surveyed farmers reported that the use of chemical fertilizers had detrimental effects on soil fertility and productivity. This emphasizes the long-term consequences of chemical fertilizer use on the health of the soil. Furthermore, 75 per cent of these farmers noted that chemical fertilizers provided only immediate yields and necessitated continuous use to maintain such yields. This highlights the need for regular and sustained application of these fertilizers, which can be a costly and environmentally impactful practice. Additionally, 40 per cent of farmers experienced a decline in the quality of rice associated with the use of chemical fertilizers (Fig.19). This indicates that while chemical fertilizers may boost yields, they can have adverse effects on the quality of the harvested crops.

The disadvantages of chemical fertilizers highlight the importance of considering the long-term impacts on soil health and agricultural sustainability. Sustainable and balanced approaches to soil management, such as organic farming practices and soil conservation, aim to address these drawbacks while promoting the long-term health of both soil and crops.

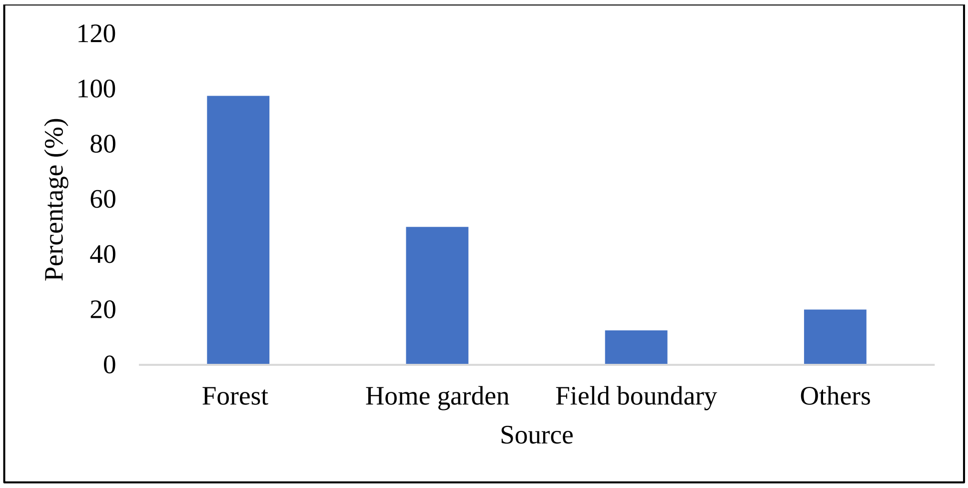

Fig 17. Source of tree/shrub species used for traditional green leaf manuring practices in paddy fields of Ollukkara and Wadakkanchery blocks

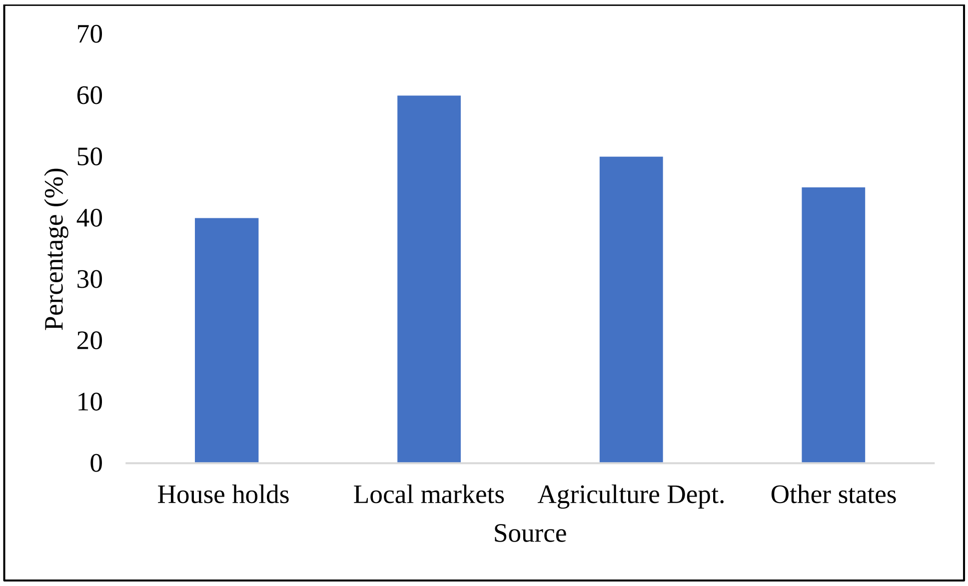

Fig 18. Source of other manures and fertilizers currently used in paddy fields of Ollukkara and Wadakkanchery blocks

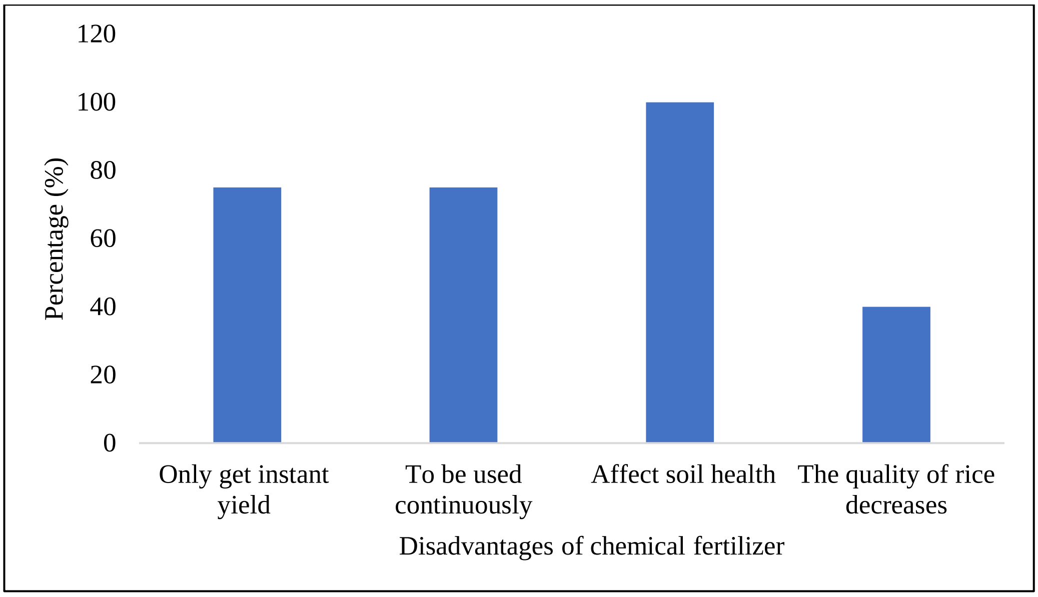

Fig 19. Disadvantages of chemical fertilizers in paddy fields as informed by farmers of Ollukkara and Wadakkanchery blocks

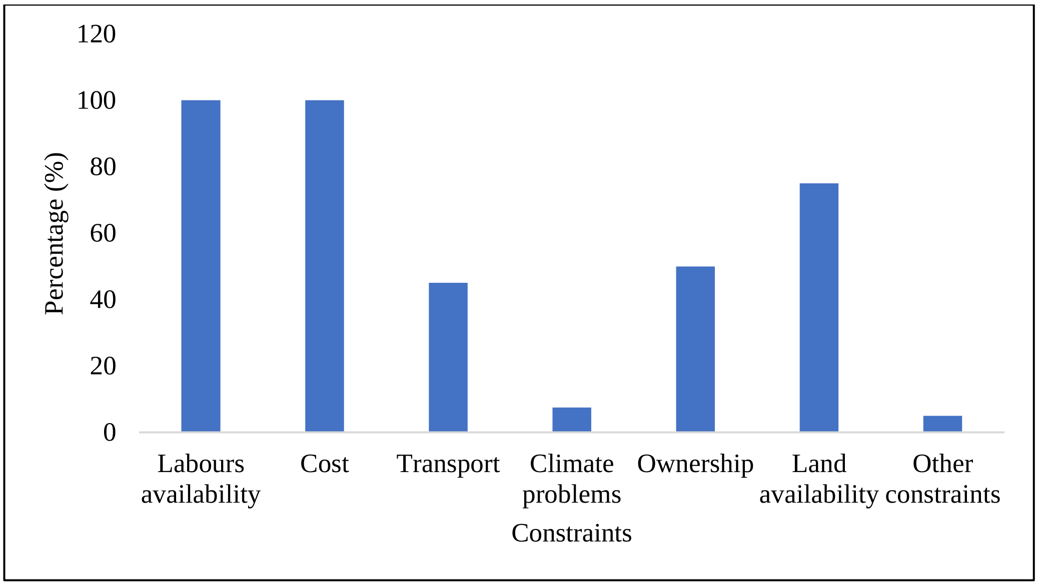

Fig 20. Constraints experienced by farmers in the adoption of green leaf manuring in the paddy fields of Ollukkara and Wadakkanchery blocks

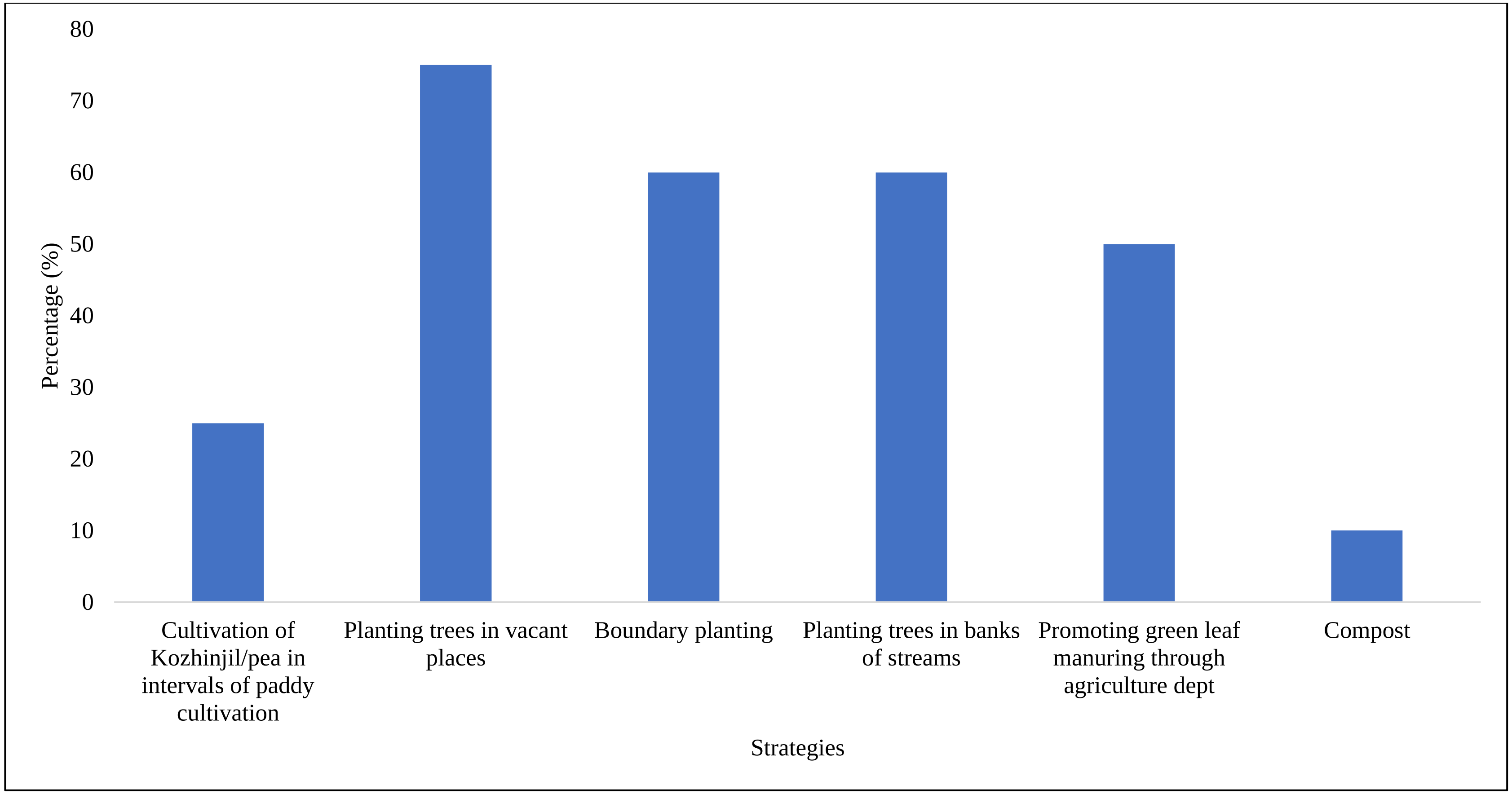

Fig 21. Strategies for enhancing cultivation and utilization of green manures as proposed by farmers in Ollukkara and Wadakkanchery blocks

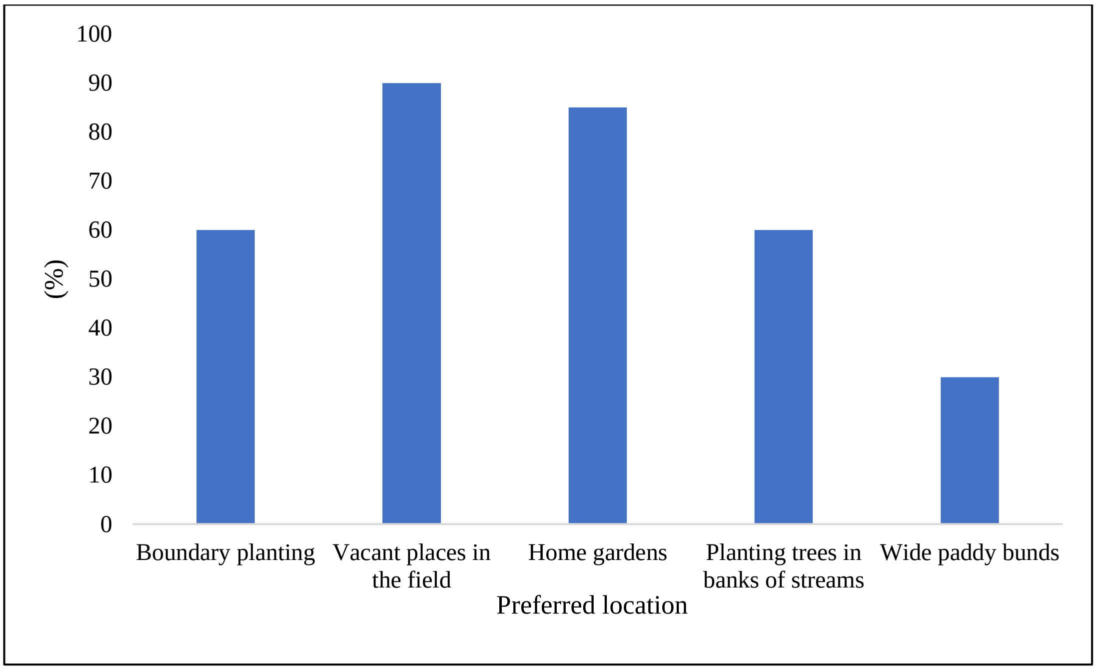

Fig 22. Preferred location for planting green manure trees in a paddy field or elsewhere as suggested by farmers in Olllukkara and Wadakkanchery blocks

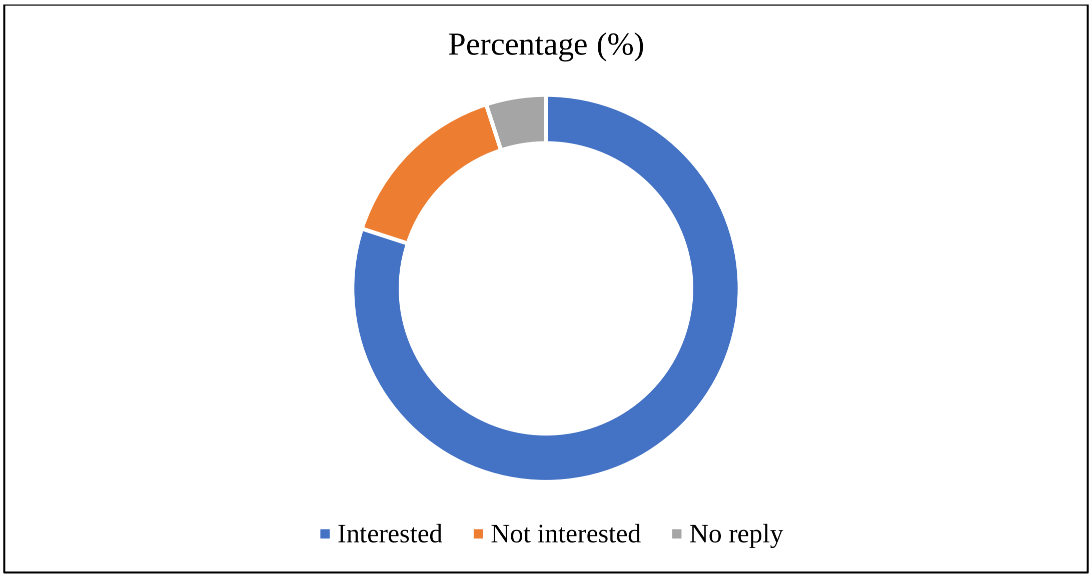

Fig 23. Farmers' opinion for adopting green manuring practices via planting tree species in their paddy fields of Ollukkara and Wadakkanchery blocks

5.2.5 Constraints in the adoption of green manuring

Table 17 and Fig 20 present the constraints encountered in implementing green leaf manuring within the paddy fields of the Ollukkara and Wadakkanchery blocks. The primary constraint reported by all surveyed farmers was the availability of labour and the associated costs. Implementing green leaf manuring requires a significant amount of labor, from collecting green leaves to incorporating them into the fields. The expenses related to labor can be a substantial burden for farmers. Approximately 75 per cent of the participating farmers faced challenges related to the availability of land. Adequate land is necessary for growing green manure species, such as *Gliricidia* or other nitrogen-fixing trees. Limited land availability can hinder the cultivation of these supplementary crops. Land ownership complexities were a significant constraint for half of the surveyed farmers. Leased land ownership can make it difficult for farmers to commit to planting trees or shrubs for green manuring, as they may not have full control over the land.

In certain specific regions, climatic conditions were reported as a constraint, albeit by a smaller percentage of farmers (7.5%). Climatic factors, such as rainfall patterns and temperature, can influence the choice of manure or fertilizers. In some areas, adverse climatic conditions may impact the effectiveness of green leaf manuring. In certain regions within the Wadakkanchery blocks, the paddy fields frequently experienced complete inundation during the rainy seasons. This inundation significantly impacted paddy cultivation in these areas. Transportation challenges were identified as a constraint by 40 per cent of the surveyed farmers. This relates to the logistics of collecting green leaves from trees planted in various locations. Transportation costs and logistical issues can add complexity to the process of incorporating green manure into paddy fields.

These constraints are multifaceted and vary from labour and land availability to climatic conditions and transportation issues. Addressing these challenges is essential for promoting the adoption of sustainable agricultural practices like green leaf manuring and enhancing overall crop productivity.

5.2.6 Adoption of green leaf manuring in paddy fields

Table 18 illustrates the strategies to improve the use of green manures, as per the opinions of farmers who took part in a questionnaire survey. This data stems from the perspectives of participating farmers who contributed to a questionnaire survey. A significant majority of farmers, constituting 75 per cent of the respondents, recommended the practice of planting trees in vacant areas. This strategy involves utilizing unused land for planting green manure trees, thereby enhancing soil fertility and supporting sustainable agricultural practices. Approximately 60 per cent of the surveyed farmers proposed the practice of boundary planting in paddy fields. This approach involves planting green manure trees along the boundaries of paddy fields, effectively making use of the field perimeters. An equal proportion, 60 per cent of respondents, suggested planting trees along the banks of streams. This practice contributes to soil enrichment and aids in stream bank stabilization and the prevention of soil erosion. Approximately 50 per cent of the surveyed farmers have proposed promoting green leaf manuring through the Department of Agriculture Development and Farmer’s Welfare. It underscores the importance of government support and institutional collaboration in advancing such practices within the agricultural sector. 10 per cent of the surveyed farmers suggested the utilization of green leaves as compost in paddy fields (Fig 21).

Table 19 elaborates on the survey findings regarding the preferred locations for planting green manure trees in paddy fields or other areas. It provides an overview of their willingness to incorporate green leaf manures into various settings (Fig 22). A significant 90 per cent of the participating farmers expressed their readiness to plant trees or shrubs in vacant spaces within paddy fields. This demonstrates a strong inclination toward enhancing soil fertility within the fields where paddy is cultivated. A large majority, 85 per cent of the farmers, were open to the idea of cultivating green manure trees within their home gardens. This reflects the integration of home gardening into sustainable agricultural practices. A notable 60 per cent of respondents expressed their willingness to engage in boundary planting, emphasizing the importance of utilizing field boundaries for green manure tree cultivation. The same percentage, 60 per cent, indicated their readiness to plant green manure trees along stream banks, recognizing the potential benefits for both soil and water resources.

Table 20 provides insights into the level of interest among participating farmers regarding the planting of green manure trees, specifically in paddy fields. A significant 80 per cent of the surveyed farmers expressed a strong interest in planting green manure trees directly within their paddy fields. This underscores the relevance and popularity of the practice among paddy cultivators. A smaller fraction, 15 per cent, reported a lack of interest in incorporating green manure trees into their paddy fields (Fig 23). This could be due to various reasons, including resource limitations or alternative agricultural practices.

Tables 18,19 and 20 collectively reflect the willingness and preferences of farmers in terms of adopting and enhancing the use of green manures. The majority of farmers are open to various strategies and locations for planting green manure trees, indicating a positive attitude toward sustainable agricultural practices and soil enrichment.

SUMMARY

6. SUMMARY

The research work entitled "Growth, green biomass production and crop interaction of selected trees and shrubs on wetland paddy bunds" was undertaken during 2022-23 at State Seed Farm, Mannuthy, Thrissur, Kerala, to assess the growth and green biomass production of selected fast-growing trees/shrubs on wetland paddy bunds of Kerala and the impact of bund-grown trees on paddy growth and yield and soil properties. The study also examined the current and past green manuring practices in the paddy fields of Ollukkara and Wadakkanchery blocks in the Thrissur district. The salient findings of the study are summarised as follows:

6.1 Experiment I. Green biomass production and crop response of selected trees/shrubs on wetland paddy bunds

1. All the selected trees/shrubs established well on wetland paddy bunds except *Garuga*.
2. In the initial period, *Sesbania* (303.67 cm) grew fast, becoming the tallest species, followed by *Gliricidia* (197.33 cm) and red gram (perennial) (195.60cm). *Calliandra* and *Terminalia* had similar heights, while *Gmelina* grew slowly and *Garuga*, *Cassia* and mulberry were relatively short, likely due to local conditions.
3. After one year, most species underwent pruning and lopping, except for *Cassia*, *Gmelina* and *Garuga*. *Sesbania* remained the tallest. *Cassia* and *Gmelina* reached over 2 meters in height, while mulberry and *Garuga* stayed short, possibly due to waterlogged conditions. *Calliandra*'s growth was moderate.
4. Redgram (20.60) had the most branches, followed by *Sesbania* (15.47), *Gliricidia* and *Terminalia*, while *Gmelina*, *Calliandra*, *Cassia* and *Garuga* had had few branches at the end of the first year.
5. Initially, *Sesbania* (43.08 mm) had the largest collar diameter due to its rapid growth, while *Terminalia* (32.78 mm) and red gram (33.37 mm) also grew well. Mulberry (20.30 mm) and *Cassia* (21.34 mm) had the smallest

collar diameter. By the end of the first year, *Sesbania* (74.80 mm) still had the largest collar diameter, mulberry (30.27 mm) remained the smallest and red gram (64.50 mm) and *Terminalia* (58.83 mm) showed moderate growth, respectively.

6. The survival rates of trees/shrubs on wetland paddy bunds varied with species. *Terminalia* (98%) and red gram (98%) had the highest survival rates, followed by *Sesbania* (95%) and *Cassia* (95%), which are suited for waterlogged conditions. *Calliandra* (80%) and mulberry (80%) also survived well, though *Calliandra*'s survival was slightly lower than expected. *Gliricidia* (60%) had moderate survival, while *Gmelina* (50%) had an average survival rate. *Garuga* (10%) had the lowest survival percentage, making it unsuitable for planting on wetland paddy bunds.
7. *Sesbania* (22.63) had the highest number of coppice shoots, followed by red gram (16.87), which showed fewer after harvesting. *Gliricidia* exhibited good coppicing capabilities, while *Calliandra* and *Terminalia* had a moderate number of coppice shoots. Mulberry had the least number of coppice shoots. *Gmelina* and *Cassia* were slow-growing and were harvested at the end of the first year, while *Garuga* was very slow-growing and not ready for harvest. Overall, *Sesbania* and *Gliricidia* demonstrated superior coppicing characteristics, followed by red gram and *Terminalia*, while *Calliandra* and mulberry exhibited subpar performance.
8. The green biomass yield from trees and shrubs on wetland paddy bunds varied significantly. Red gram (perennial) (2.32 kg plant^{-1}) and *Sesbania* (2.06 kg plant^{-1}) had the highest green biomass yield in the initial harvest, with red gram (perennial) generally producing more seasonal biomass. After pruning, *Sesbania* (3.39 kg plant^{-1}) excelled in green biomass production. *Gliricidia* also yielded a good amount of biomass and *Calliandra* showed good establishment and growth in the first year but had lower coppice biomass production. Mulberry had the lowest green biomass yield in both seasons. *Gmelina* and *Cassia*, harvested at the end of the first

year, grew relatively slowly, while *Garuga* was extremely slow-growing and not ready for harvest.

9. In terms of annual biomass, *Sesbania* (5.45 kg plant^{-1}) produced the most, followed by red gram (perennial) (4.10 kg plant^{-1}), *Gliricidia* (3.26 kg plant^{-1}) and *Terminalia* (2.54 kg plant^{-1}), with mulberry (1.08 kg plant^{-1}) having the lowest biomass yield. When scaled to a hectare basis, around 2 to 2.5 t/ha/year green leaf can be harvested from 500 plants of *Sesbania*/red gram (perennial) accommodated on bund length of 500 m/ha (bunds spaced at 20m intervals in E-W direction), which can satisfy half of the recommended green leaf manure doses in paddy.
10. In the study, plant height of paddy was significantly affected within 1 m radius of trees/shrubs, with taller plants observed in control plots beyond the reach of trees/shrubs. No significant differences were observed in other paddy growth attributes. Similarly, yield attributes were affected within a 1 m radius, with control plots having the highest number of panicles/m^2. No significant differences were observed in other paddy yield attributes. Wider canopies, such as those from *Calliandra* and red gram (perennial), negatively impacted growth and yield even though the effect was marginal.
11. PAR transmittance varied from 69.58 per cent to 98.20 per cent within a 1 m radius, 66.68 per cent to 99.52 per cent between 1- 2 m beyond the trees/shrubs and reached 100 per cent in the centre of the paddy field. The shading effect of trees like *Gliricidia* and *Sesbania* did not significantly hinder crop growth. The maintenance of 1 m pruning or lopping height for all harvests ensured that the shade from the trees and shrubs along the wetland paddy bunds did not substantially impact paddy growth and yield.
12. In the current study, Soil pH, organic carbon, available phosphorus and available potassium content remained stable across treatment plots and open paddy fields, with pH ranging from 5.22 to 5.95. Slight pH variations were observed, particularly higher in red gram (perennial) plots, likely influenced by tree/shrub presence.

13. Available phosphorus content was generally high, ranging from 26.91 to 38.97 kg ha^{-1}, consistent with local soil characteristics. However, available potassium content in the study area was deficient, ranging from 52.08 to 66.83 kg ha^{-1}. Organic carbon content ranged from 0.44 per cent to 0.57 per cent in the soil.
14. Notable disparities in available nitrogen content were observed between treatment plots and open paddy fields, with significant variations in samples within 1 m and 1- 2 m radii from trees/shrubs. Plants belonging to the legume family, like *Cassia*, red gram (perennial), *Calliandra*, *Sesbania* and *Gliricidia*, showed notable differences in the amount of available nitrogen in the soil. Remarkably, only *Cassia* (157.63 kg ha^{-1}) had nitrogen levels in line with those found in the open paddy fields (158.89 kg ha^{-1}). Within the 1- 2 m radius, *Sesbania* displayed a decline in available nitrogen content. Mulberry had the lowest available nitrogen content (62.72 kg ha^{-1} and 108.71 kg ha^{-1} within 1 m radius and between 1- 2 m radius, respectively). Further research on the root distribution and nutrient uptake of mulberry and *Sesbania* in wetland paddy bunds is warranted.

Experiment II Survey and documentation of green manuring practices in Ollukkara and Wadakkanchery block

1. The predominant preference among the surveyed farmers is cow dung, with a substantial 95 per cent of participants favouring this conventional and nutrient-rich organic fertilizer. Farmers prefer goat and chicken manure (65% and 75% adoption, respectively) rich in nutrients. Neem cake and ash are less favoured (25% and 30% adoption) despite their soil-enriching potential. Green manuring is practiced by 40 per cent of farmers, while green leaf manure is used by 70 per cent to enrich the soil with essential nutrients.
2. The data from the current study indicates that 62.5 per cent of those opting for green manure prefer dhaincha. Additionally, 25 per cent of the respondents favour cowpeas or pulses as their green manure crop of choice.

3. Information from the farmers underscores that *Gliricidia* is the dominant selection for green leaf manure due to its nitrogen-fixing abilities, mainly used during the mundakan and puncha seasons. Other tree species are employed annually, typically during mundakan. Notably, 62.5 per cent of these species are cultivated in farmers' home gardens, serving as a valuable resource for organic matter in paddy fields. The remaining 37.5 per cent grow in field boundaries, with *Cleistanthus collinus* and *Gliricidia* naturally occurring in both settings, readily available for green leaf manuring without extensive cultivation.
4. Currently, farmers do not engage in deliberate tree cultivation for the specific purpose of green leaf manuring. Instead, their practices rely on the presence and accessibility of certain tree species, utilizing the leaves of these trees as sources of green leaf manure.
5. The current study provides historical insights into the traditional green manuring practices and the use of specific green leaf manuring tree species in the paddy fields of the Ollukkara and Wadakkanchery blocks. The most preferred species for green leaf manuring were *Terminalia paniculata, Terminalia bellirica,* and *Mangifera indica,* with farmers historically applying 1000-1500 kg of green leaves from these trees per hectare. Except for *Gliricidia*, these species were used annually during the mundakan season, aligning with the traditional wisdom of using green manure during fallow periods to enhance soil quality for subsequent crops.
6. It's noteworthy that farmers employed green leaves from over 15 tree species for manuring, showcasing their rich traditional knowledge and the importance of organic matter in sustainable agriculture. Most of these leaves (97.5%) were sourced from nearby forests, reflecting sustainable farming practices. Additionally, 50 per cent of farmers collected green leaves from their home gardens, integrating home garden into traditional agriculture.
7. The study found that the diverse sources of fertilizers and manures used in the paddy fields of Ollukkara and Wadakkanchery. Most farmers (60%)

obtain these inputs from local markets, while 40 per cent collect them from their own surroundings. Notably, 45 per cent import fertilizers from other states. Additionally, all farmers recognize the negative impact of chemical fertilizers on soil fertility. Most (75%) believe chemical fertilizers provide only short-term gains and 40 per cent observed a decline in rice quality. This underscores the need for sustainable soil management practices to ensure long-term agricultural viability.

8. Most of the farmers faced challenges when implementing green leaf manuring in the Ollukkara and Wadakkanchery paddy fields. Labour costs and availability were a universal concern, as a substantial workforce is needed for collecting and using green leaves. Land availability (75% of farmers) was another issue for growing green manure species. Half the farmers faced complexities due to land ownership arrangements, while a smaller percentage (7.5%) dealt with climatic factors. Transportation challenges were reported by 40 per cent of farmers, affecting the collection of green leaves.
9. In the current study, farmers proposed some strategies to enhance green manuring in paddy fields. 75 per cent propose planting trees in vacant areas, while 60 per cent recommend boundary planting and planting along stream banks. About 50 per cent suggest promoting green leaf manuring through the Department of Agriculture Development and Farmer's Welfare and 10 per cent advise using green leaves as compost.
10. The study found that 90 per cent are ready to plant trees in vacant paddy fields, 85 per cent in home gardens and 60 per cent in field boundaries and along stream banks.
11. 80 per cent of surveyed farmers are highly interested in planting green manure trees in their paddy fields, demonstrating a positive attitude towards sustainable agricultural practices. Fifteen per cent expressed less interest, possibly due to resource constraints or alternative practices.

In conclusion, tree/shrub species like *Sesbania*, red gram (perennial), *Cassia*, *Terminalia* and *Gliricidia*, which exhibit strong yield and resilience, prove to be excellent choices for hedge row planting along bunds in wetland paddy fields. Conversely, species like *Calliandra* exhibited moderate performance, followed by *Gmelina* and mulberry. *Garuga* is totally unsuitable for waterlogged conditions. *Calliandra*, mulberry and *Terminalia* are prone to grazing and need protection from cattle. Regular lopping and pruning to generate green biomass do not hinder paddy growth. Although the nutrient uptake of these bund-growing trees/shrubs has not been recorded, further research on their root distribution and nutrient uptake in wetland paddy bunds is advisable.

The study highlights the challenges faced by farmers due to excessive chemical fertilizer use, negatively impacting soil conditions. Consequently, farmers are interested in embracing green leaf manuring in paddy fields as a sustainable agricultural practice.

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GROWTH, GREEN BIOMASS PRODUCTION AND CROP INTERACTION OF SELECTED TREES AND SHRUBS ON WETLAND PADDY BUNDS

By

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ABSTRACT OF THE THESIS

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8. ABSTRACT

Rice, the staple food in Kerala, is experiencing a significant production deficit, with only one-fifth of the annual requirement being met. The key to enhancing rice production is improving the productivity of existing agricultural lands. Green leaf manuring offers a promising, cost-effective, and eco-friendly solution to enhance productivity. Traditional green leaf manuring practices have been abandoned in Kerala, primarily due to the scarcity of conventional green leaves and various constraints, including labour and transportation. However, a potential approach to rejuvenate this eco-friendly practice involves cultivating green manuring trees and shrubs in rice bunds and maintaining them as hedges through regular lopping.

This study entitled "Growth, green biomass production and crop interaction of selected trees and shrubs on wetland paddy bunds" was carried out as two separate experiments: a field experiment in State Seed Farm, Mannuthi, Thrissur; and Survey and documentation in Ollukkara and Wadakkanchery blocks, Thrissur, Kerala, during 2022-23. The study aimed to evaluate the survival, growth and biomass production of green manuring trees and shrubs under ill-drained conditions of wetland paddy bunds and their effects on paddy. The study also envisaged surveying and documenting the indigenous knowledge, the current practices and the farmer's perspective on green leaf manuring in paddy fields of Ollukkara and Wadakkanchery blocks in Thrissur district.

In the first experiment, different tree species like *Gliricidia*, *Garuga*, *Sesbania*, *Calliandra*, *Terminalia*, mulberry, *Gmelina*, red gram and *Cassia* were planted in paddy bunds at spacing of 1m in Randomized Block Design with three replications. The results indicated that most species established well initially, with some species showing exceptional growth and biomass production. Notably, *Sesbania* (5.45 kg plant^{-1}), red gram (perennial) (4.10 kg plant^{-1}), *Gliricidia* (3.26 kg plant^{-1}), and *Terminalia* (2.54 kg plant^{-1}) emerged as top performers in terms of annual biomass yield in the initial year of planting. At the same time, some species

had slower growth rates (*Cassia* and *Gmelina*) and lower survival rates (*Garuga* and *Gmelina*). *Garuga* had only 10% survival rate, hence found unsuitable for bund planting in paddy. Interaction studies of trees on paddy indicate that paddy growth and yield were not significantly influenced by bund planting in the initial year of tree growth. Soil properties of paddy, like pH and nutrient content, except the available nitrogen content, didn't vary across various treatments. However, a noticeable decline in available nitrogen content was observed in paddy soils beneath mulberry, indicating its competitive nature. Tree species like *Sesbania*, red gram, *Cassia*, *Terminalia* and *Gliricidia*, which demonstrate robust productivity and resilience, are excellent choices for planting on wetland paddy field bunds. When scaled to hectare basis, around 2 to 2.5 t/ha/year green leaf can be harvested from 500 plants of *Sesbania*/red gram accommodated on bund length of 500 m/ha (bunds spaced at 20 m intervals in E-W direction), which can satisfy half of the recommended green leaf manure doses in paddy.

The study also explored local farmers' preferences and practices regarding green leaf manuring. Traditionally, more than 15 tree species were utilized for green leaf manure, primarily collected from forests (97.5% of farmers surveyed), with species like *Terminalia paniculata*, *Terminalia bellirica* and *Mangifera indica* being commonly employed. However, in the present scenario, the predominant supplementary manures include cow dung (95%), green manure (40%), and green leaf manure (preferably *Gliricidia sepium* and *Mangifera indica*) (70%). These green leaf manures are often sourced from home gardens (62.5%) and field boundaries (37.5%). Farmers have recognized the adverse impacts of chemical fertilizers and demonstrated a strong interest in sustainable soil management. Despite this interest, several challenges like labour scarcity, high cost, land availability constraints, and transportation issues, hinder the widespread adoption of green leaf manuring practices. Encouragingly, approximately 80 per cent of farmers are interested in adopting green leaf manuring practices by planting green manuring trees in unused areas, boundaries, and bunds. To support this transition, farmers actively seek technical support and subsidies from the Department of Agriculture Development and Farmer’s Welfares.

APPENDICES

Appendix I

Mean monthly weather parameters during April 2022 to September 2023 of the study area (Experiment I) recorded by Department of Agricultural Meteorology, College of Agriculture, Vellanikkara, Kerala

Months	Maximum temperature (°C)	Minimum temperature (°C)	Rainfall (mm)	Relative humidity (%)
April 2022	34.2	25.1	84.3	77
May 2022	31.1	23.9	422	85
June 2022	31.3	23.5	391.8	84
July 2022	29.3	23.5	628.8	88
August 2022	29.9	23.6	563.7	84
September 2022	31.1	23.7	167.5	81
October 2022	32	23.6	69.6	77
November 2022	32.4	23	75.4	73
December 2022	32.2	22.6	91.7	67
January 2023	32.7	21.9	0	56
February 2023	35.4	21.9	0	49
March 2023	36.1	24.2	1.7	57
April 2023	36.8	25.5	108.3	67
May 2023	34.7	25.7	23.4	74
June 2023	31.8	24.4	276.3	83
July 2023	29.6	23.7	667.3	88
August 2023	32.5	24.4	25.3	77
September 2023	30.7	23.7	516.7	87

Appendix II

Questionnaire used for the survey in Ollukkara and Wadakkanchery blocks

Survey and documentation of green manuring practices in Ollukkara and Wadakkancheri blocks in Thrissur District

1. Name of the farm owner :
2. Address :
3. Ward No. and Name :
4. Gram Panchayat :
5. Block panchayat :
6. Locality :
7. Extent of land (paddy field) owned (ha):
8. Current manuring practices in paddy fields:

1	
2	
3	
4	

9. Type of tree/shrub species and quantity (per ha) used for green manuring

Sl No	Tree/Shrub species	Quantity (per ha)	Planted/ natural
1			
2			
3			
4			
5			

10. Lopping/pruning period of tree/shrub species

Sl No	Tree/Shrub species	Seasonal/ annual	Quantity (kg)
1			
2			
3			
4			
5			

11. Name of tree/shrub species used in the summer period

Sl No.	Tree / Shrub species	Quantity
1		
2		
3		
4		

12. Indigenous knowledge of green manuring practices (suitability of green manure tree/shrub species with respect to the crop, variety or season)

Sl No.	Tree / Shrub species	Variety	Season
1			
2			
3			
4			

i. Past green manuring practices in the field:

13. Type and source of supplementary fertilizers /organic manures used in paddy field

Sl No.	Type	Source	Advantage	Disadvantage
1				
2				
3				
4				

14. Type and source of supplementary fertilizers /organic manures used in paddy field

Sl No.	Type	Source	Advantage	Disadvantage
1				
2				
3				
4				

15. Benefits of green manuring

16. Relevance of green manuring in paddy field

17. Constraints in the adoption of green manuring

18. Strategies for enhancing cultivation and utilization of green manures

19. Your preferred location for planting green manure trees in a paddy field or elsewhere

20. Is interested in planting green manuring trees in your paddy fields?

21. Additional information