

Article

Industrial Agroforestry—A Sustainable Value Chain Innovation through a Consortium Approach

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Abstract: Agroforestry has been practiced traditionally in India in the form of subsistence farming, but is being increasingly recognized from the economic point of view, in addition to its positive contribution to the wood-based industrial sector, which has recent origin. Low forest cover, poor productivity and legal restrictions coupled with an increasing demand for wood and wood products due to increasing population, industries and associated policy changes have ushered in a total mismatch between demand and supply. This has attracted increasing attention towards agroforestry. The National Forest Policy of India 1988 has directed all wood-based industries to generate their own raw material resources by linking farmers and extending technology and market support. However, these directives were not taken seriously, and consequently, the achievements that should have taken place in industrial agroforestry and plantation establishment are dismally modest for want of suitable institutional mechanism to resolve the research gaps that exist in the entire Production to Consumption System (PCS). Against this backdrop, Tamil Nadu Agricultural University (TNAU) has pioneered research by creating a value chain in industrial agroforestry which was initially demonstrated in 200 ha of farmlands through technological, organizational and marketing interventions. Incorporation of high yielding short rotation (HYSR) clones, precision silviculture technology, adoption of multifunctional agroforestry and value addition technology are the major technological interventions that attracted more farmers towards agroforestry development. Conceptualization and successful practice of the contract tree farming model, particularly the quadripartite contract farming model, ensured institutional linkage among the value chain players and facilitated technology transfer, assured buy back, price support system and also institutional credit and insurance. The provision of a market support system for a wide range of pulp wood, plywood, timber, and match wood exerted a significant influence among tree-growing farmers. In order to sustain these value chain innovations and interventions, an institutional mechanism, namely the Consortium of Industrial Agroforestry (CIAF), was established in 2015, which linked all value chain players and aided in resolving the issues in the entire production to consumption system (PCS) of agroforestry on a sustainable basis. Over the years, these innovative interventions have had a significant impact in terms of area increase, productivity and profitability improvement coupled with safeguarding the social and environmental concerns of agroforestry farmers from a holistic perspective. The Consortium-based Value Chain on Industrial Agroforestry model has a very good replication potential not only within India, but also elsewhere across the global landscape.

Keywords: industrial agroforestry; value chain; consortium; business incubator; sustainability

1. Introduction

India is one of the leading producers and consumers of wood and wood products in the Asian region. The growing population, industrialization and the associated science and

technological developments have created significant demand for a wide range of wood and wood products, which resulted in massive imports [1]. This is due to the low productivity ($0.7 \text{ m}^3/\text{ha}/\text{year}$) of India's forests coupled with legal restrictions in obtaining wood from natural forests, which in turn has necessitated increased attention towards establishment of agro- and farm forestry systems to meet the raw material requirements pertaining to domestic consumption and industrial utility [2]. Although the country possesses a wide range of wood-based industrial establishments, only fourteen major wood-based industries are considered as organized sectors, such as pulp, paper, veneer, plywood, match wood, sports goods, agricultural implements, construction and miscellaneous industries. The demand for timber in India is estimated to increase from 58 million cubic meters in 2005 to 153 million cubic meters in 2020, whereas its supply is projected to increase from 29 million cubic meters in 2000 to 60 million cubic meters in 2020 [1,3].

It is also indicated that the domestic supply of logs will witness a timber deficit of 20–70 million m^3 [4]. However, the actual demand is far higher, due to the fact that several wood-based industries are within unorganized sectors. With the enactment of National Forest Policy 1988 in India, the forest-based industry should produce the raw material needed for meeting its own requirements. Furthermore, the Hon'ble Supreme Court of India order 1996 led to a complete ban on the unregulated felling of trees or timber logging in government forests [5]. The growing demand coupled with restricted supply from organized forest resources has ushered in a total mismatch between the demand for and supply of wood and wood products [6]. Considering all these developments, the Tamil Nadu Agricultural University in 2008 created a value chain model in agroforestry after thoroughly investigating the existing constraints and issues in the agroforestry sector. The constraints were identified in the entire production to consumption system (PCS) and were categorized into production-, processing- and marketing-level issues. These issues and constraints in agroforestry are resolved through suitable technological, organizational and marketing interventions in a consortium mode, linking all the stakeholders in a single platform, not only to resolve the issues, but also to create self-reliance in raw material security besides safeguarding social, economic and environmental interests [7].

During the journey spanning over a decade, value chain-based agroforestry promotion has witnessed the establishment of over 80,000 ha of organized agroforestry plantations in association with a wide range of wood-based industries and other consortium-member institutions, which resulted in the sourcing of more than 10 lakh tons of wood from the farmers to wood-based industries and ensured sustainable mechanisms in raw material availability and agroforestry promotion. This manuscript elaborates the various innovations made in the entire production to consumption system (PCS) in agroforestry along with the achievements made in industrial agroforestry development.

2. Research and Knowledge Gap

Since India's independence, promotion of forestry and agroforestry has been attempted by various agencies, institutions and organizations, both in natural forests and in agricultural land use systems. This has been witnessed by the role played by Indian forests and agroforestry plantations in meeting the domestic and industrial wood requirements [8]. The Government of India, as early in 1952, enunciated independent India's first National Forest Policy, which mandated the presence of one third of the total geographic area of the country being under forests and tree cover [9]. Simultaneously, increased importance was given to establishment of new wood-based industries, and the industries depended primarily on natural forests for their raw material requirement.

However, after the enunciation of the 1988 National Forest Policy [9], there was a paradigm shift in forest management, which encouraged participatory forest management involving local people in all decision-making processes. Production-oriented management of natural forests has been dispensed with, and conservation-oriented forest management has been introduced across the country after 1990s.

Forestry and agroforestry policy directives on promotion of agroforestry with increased participation of wood-based industries [10] along with the complete ban on felling in natural forests by the Honorable Supreme court of India have ushered in a total mismatch between demand and supply [5]. The demand for timber in India has increased to 153 million cubic meters in 2020 [3,5]. However, several unorganized and small scale industries are also available in the country for which the quantity of wood requirement is not available. Particularly, India's furniture and handicraft sector is highly unorganized, and the demand data is not available [11]. Similarly, match industries, catamaran, music instruments, agricultural implements, etc., are the major wood-based industries for which the supply chain is highly unorganized. The country's demand for energy requirement by domestic and other industrial establishments is estimated at more than 380 million m³ [12], and the demand is also growing at an alarming rate.

In a holistic perspective, the existing database on wood demand and supply is highly unorganized and extends a greater scope of agroforestry promotion, as most natural forests are closed for felling. Considering these developments in India, Tamil Nadu Agricultural University has mandated industrial agroforestry as a major focal area for research, and the state of Tamil Nadu has been approached to implement an innovative agroforestry model to promote industry-based agroforestry. Before implementation, a thorough baseline study was conducted to identify the existing research and knowledge gap in the entire process of the production to consumption system in agroforestry. The research team has identified a wide range of problems and knowledge constraints, which are categorized as production, processing and consumption related [6] as indicated in Figure 1.

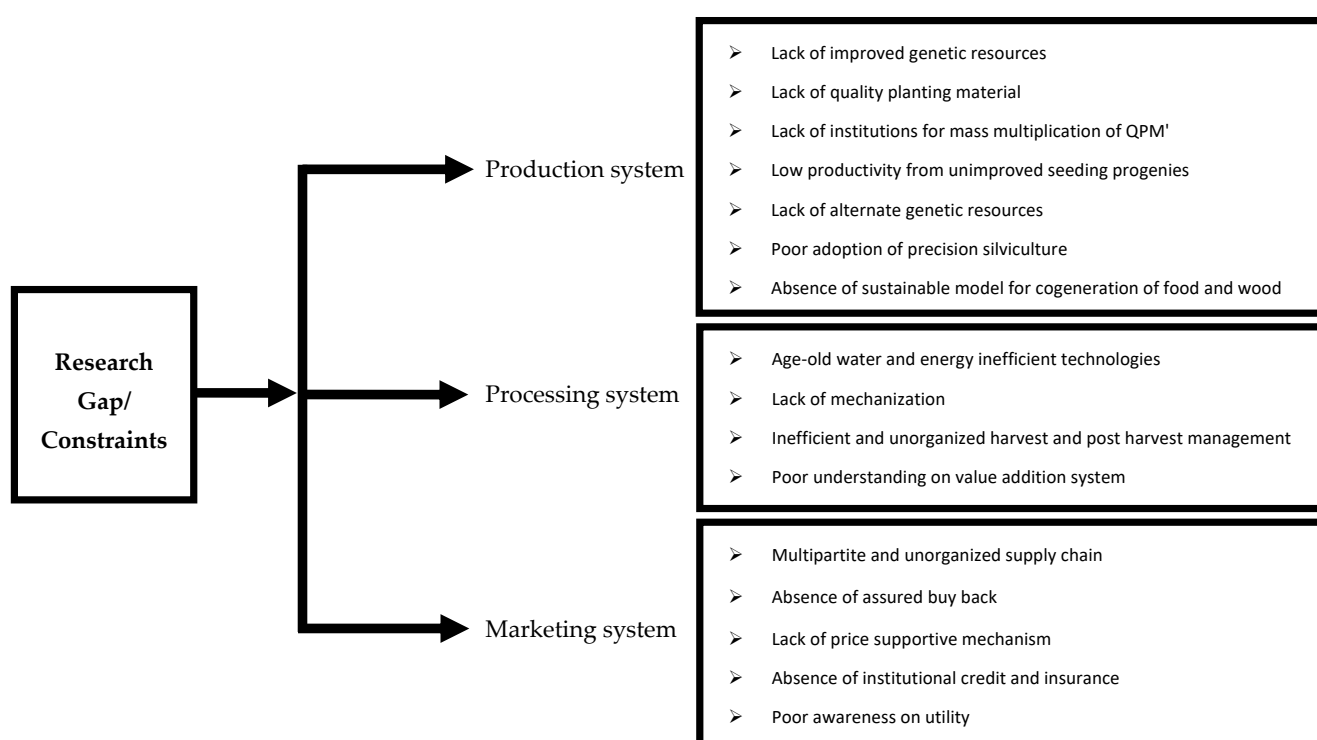


Figure 1. Research and knowledge gaps.

3. Innovations and Interventions

The identified research gaps and the associated issues and constraints that existed in agroforestry were resolved through innovative technology development. These innovations included technological, organizational and marketing strategies. Traditionally, forestry and agroforestry developments were done using unimproved genetic resources which resulted in poor productivity coupled with long felling duration. Similarly, the practice of management technology and agroforestry were done with traditional knowledge. In the

case of supply chain, it was predominantly multipartite and highly unorganized in nature. All these issues were resolved through leveraging innovative technological approaches.

3.1. Technological Innovations

3.1.1. Development and Deployment of High Yielding Short Rotation (HYSR) Clones

The incorporation of clone-based superior genetic stocks has made a significant impact in productivity, which has increased from less than 10 m³/ha/annum to the tune of over 25 m³/ha/annum. These high yielding clones are also amenable for harvesting between 16–18 months for pulp and paper utility to over 48 months for plywood utility depending on the technical specifications required by the respective wood-based industries. The following are the prioritized high yielding short rotation clones amenable for varied industrial utility incorporated in agroforestry promotion and development (Table 1).

Table 1. HYSR clones for industrial utility.

Sl. No	Species	Improved Varieties	Productivity (MT/ha)	Duration (Years)	Industrial Utility
1.	Casuarina	MTP-1 MTP-2 CJ-01	150	3–5	Pulp, paper, biomass power, construction industries
2.	Eucalyptus	MTP-1	130	5	Paper
		EH LBT 01	150	5	Plywood, pulp
		EG-01	150	5	Plywood core, face veneer
3.	Melia	MTP-1	175–200	5	Plywood
		MTP-2	200–250	2 for pulp, 6 for ply	Pulp, ply
		MTP-3	100	8 ply	Face veneer
4.	Kadam	MTP-1	100	6	Plywood
5.	<i>Dalbergia sisoo</i>	DS-18	150	6–8	Pulp, energy, timber
6.	<i>Toona ciliata</i>	TC-02	150	6	Plywood
7.	<i>Gmelina arborea</i>	FCRI GA-08/09	500 kg/tree	6	Packing case, timber
8.	Teak	MTP TK-07	150 Cubic Feet/tree	15	Timber
9.	Red Sanders	TNRS-01	100 kg heartwood/tree	16–18	Timber

3.1.2. Miniclonal Technology

Traditionally agroforestry plantation development was done using seed-based progenies which exhibited wide variation and resulted in uneven productivity. This issue has been resolved by developing miniclonal technology for a wide range of species. This miniclonal technology has ensured mass multiplication coupled with genetic uniformity. The significant advantage of this technology over the traditional mass multiplication technology is compared and presented (Table 2).

3.1.3. Design and Development of Multifunctional Agroforestry Model

Unlike other countries in the North American and European continents where the average farm size increased [13], the farm holdings in India are very small. Hence, a suitable agroforestry model is very important not only to attract the farmers, but also to enhance the productivity levels. Hence, an innovative multifunctional agroforestry model has been designed and demonstrated in various agro-climatic zones that ensures daily income to the farmers (Figure 2).

Table 2. Efficiency of miniclonal technology.

Sl. No	Traditional Technology	Mini Clonal Technology
1.	Reduced rooting %	Increased rooting %
2.	Poor quality root system	High quality root system
3.	Variation in field growth	Uniform growth in the field
4.	More gestation period for propagation	Less gestation period almost half
5.	Larger area are required	Less area is required
6.	Root promoting hormones required	No growth hormones required

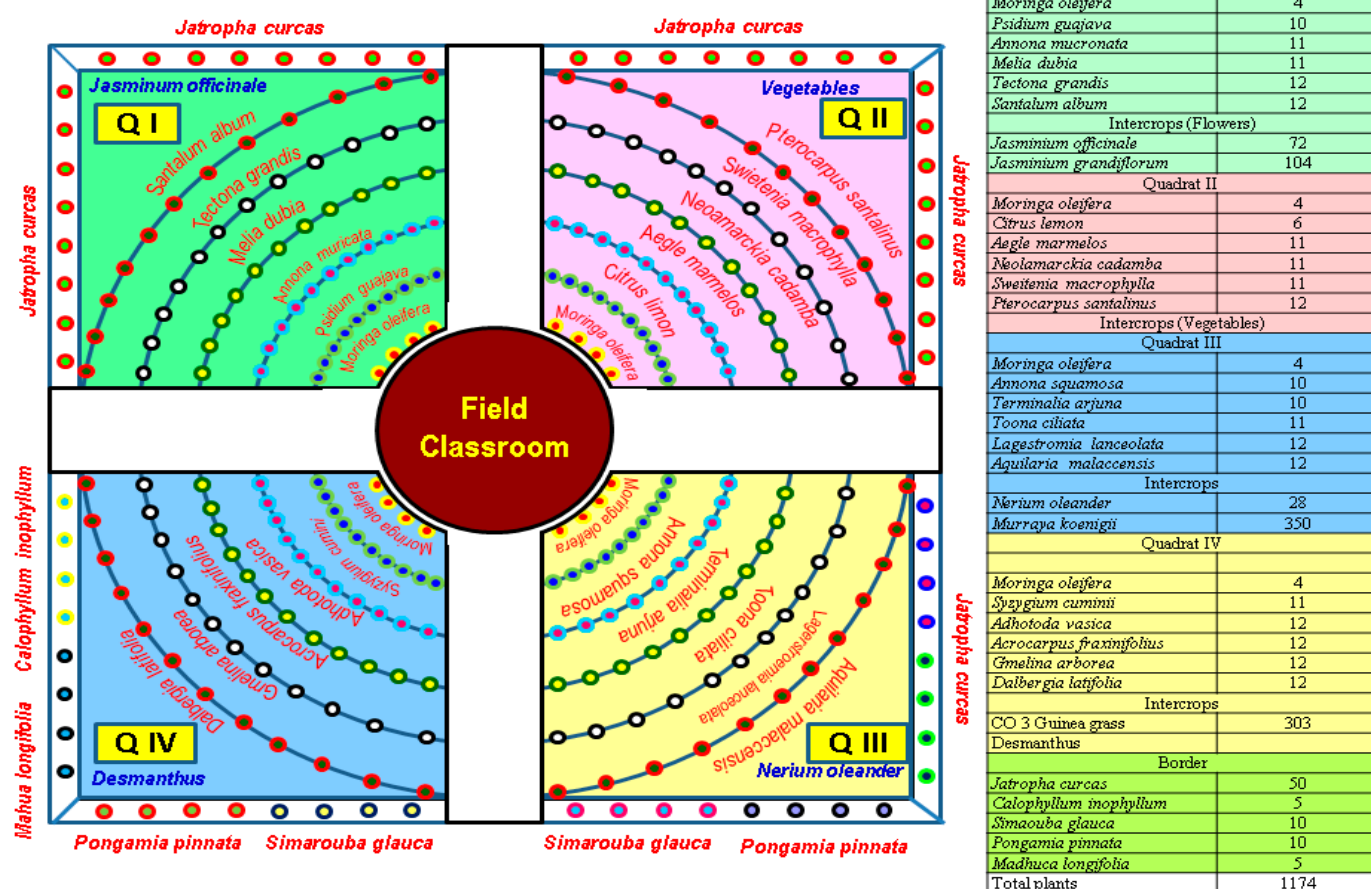


Figure 2. Design and development of multifunctional agroforestry models.

This model has incorporated tree, agriculture, horticulture and animal components, which ensure sustainable income generation activities.

3.1.4. Value Addition Technology

During the implementation process of industrial agroforestry, it was observed that 5–10 tons of plantation residues and huge volume of agricultural crop residues were generated per hectare, which are either unutilized or underutilized. Hence, a suitable value addition technology has been developed, and the agroforestry residues are successfully value added into briquettes, which find major utility as an energy source for the industries. This value addition technology has extended additional income besides creating a new business enterprise development in agroforestry sector.

3.1.5. Design and Development of Machineries for Agroforestry

Though machines are deployed for several land development activities, deploying machines for other activities is dismally modest. Hence, design and deployment of machineries for pitting and debarking were successfully done. Auger machines are designed with an efficiency of 120–150 pits/hr of 60 cm³ size, which helps to resolve the issue of labor unavailability and also to reduce human drudgery. Similarly, design and deployment of debarking and chipping machines at the decentralized level are the major technological innovations which help to accelerate the agroforestry plantation development process and add value to the supply chain process.

3.2. Organizational Innovations

3.2.1. Design and Deployment of Contract Tree Farming

Before implementation of the value chain based agroforestry, the agroforestry supply chain was highly unorganized. The supply chain players, from farmers to industries, existed, although they never interacted, which exhibited a multipartite and highly unorganized supply chain. This was resolved by designing an organized value chain model to replace the multipartite supply chain. Accordingly, the following three contract tree farming models were designed (Figure 3) and implemented in association with the pulp and paper (2009), energy (2011), match wood (2012), plywood (2013) and timber industries (2019).

In all the contract tree farming processes, the concept is to introduce a quadripartite model at the beginning stage, and over a period this has to be translated into tripartite and bipartite models for ensuring sustainability of the model. In the quadripartite model, the value chain stakeholders directly play a vital role in creating organizational linkages and the associated agroforestry supply chain process. The roles and responsibilities of each player are furnished in Figure 3.

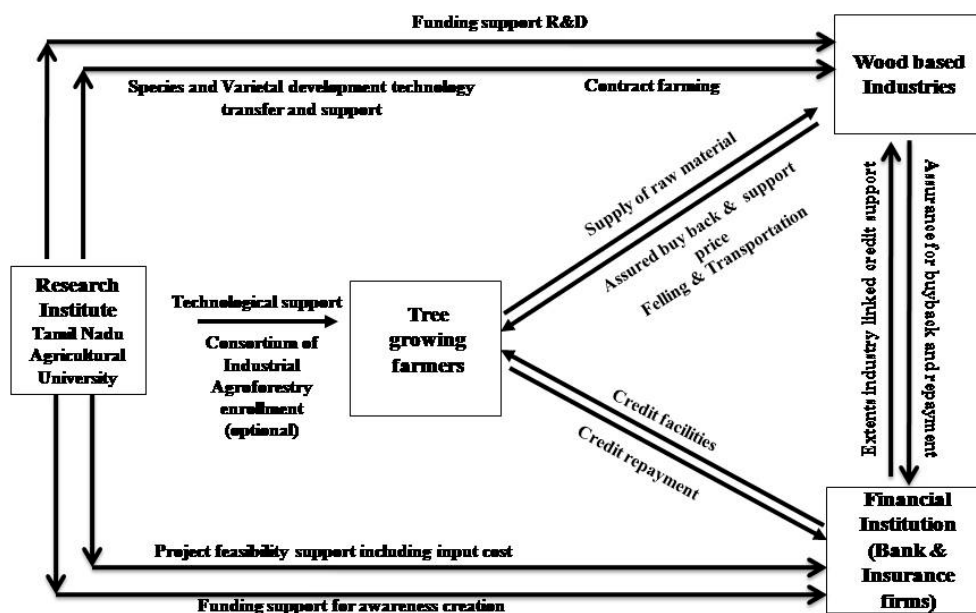
3.2.2. Consortium of Industrial Agroforestry

To further strengthen the organizational linkages and to create institutional mechanisms, the current research group has pioneered in conceptualization and establishment of an exclusive institution called Consortium of Industrial Agroforestry (CIAF) to sustain the organizational structure and resolve the issues from the entire production to consumption system in agroforestry [14]. The consortium is designed on a self-sustainability model and incorporates all supply and value chain players of various wood-based industries in order to strengthen and facilitate organized agroforestry promotion and development. As of the time of preparing this manuscript, CIAF has enrolled 310 members, and the pedigree of the members are depicted in Figure 4.

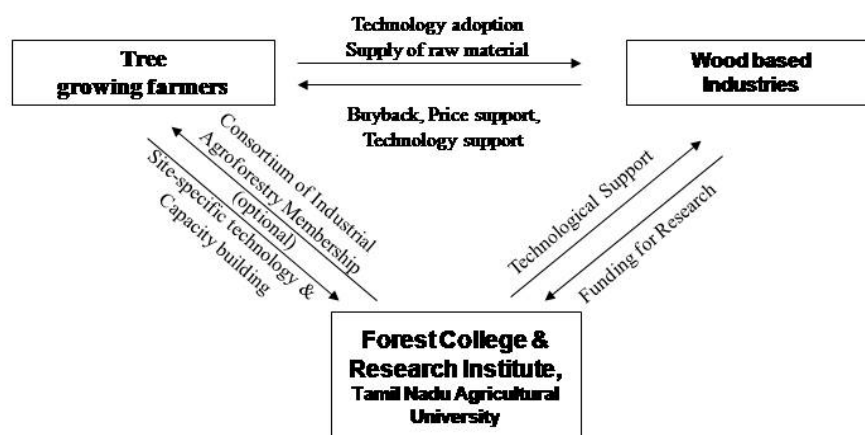
The National Agroforestry Policy (2014) of India, which was the first of its kind in the world, has identified several strategies to promote agroforestry in India [10]. Establishment of the Consortium is one the various strategies stipulated in the policy to leverage technology-based agroforestry promotion and satisfy the policy directives of both the forestry and agroforestry sectors. Availability of quality seedlings, organized institutions for plantation establishment, creation of felling institutions, loading, transportation and provision for a wide range of market outlets are the major organizational innovations that have attracted more stakeholders towards organized agroforestry development.

The Consortium of Industrial Agroforestry is a self-sustaining institution and generates financial resources through various activities. Funding support for continuous research and development is extended by Consortium wood-based industries. The CIAF has also created a corpus fund through membership fees, capacity building, consultancy and testing charges. The fund is deposited as a fixed deposit, and the interest accrued annually is used for research and outreach activities. As of the time of preparation of this manuscript, the Consortium has generated corpus money of USD 62,371. The revenue generated along with funding support, extended by the member industries are furnished in Figures 4–6.

(a) Quad-partite contract tree farming model.



(b) Tripartite contract tree farming model.



(c) Bipartite contract tree farming model.

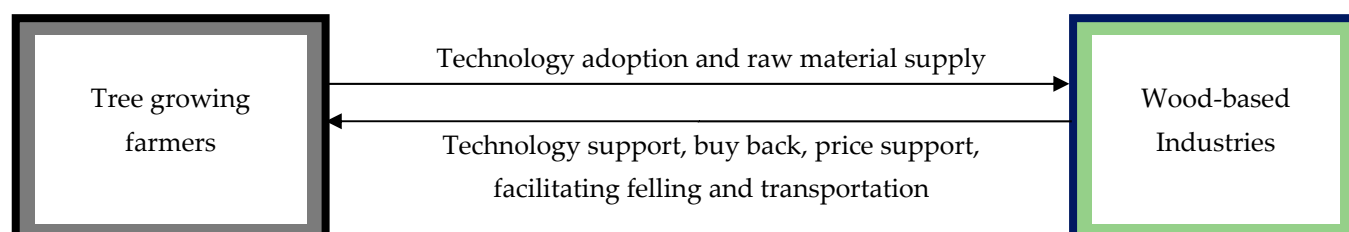


Figure 3. Contract tree farming models implemented in Tamil Nadu, India: (a) Quadripartite contract tree farming model; (b) tripartite contract tree farming model; (c) bipartite contract tree farming model.

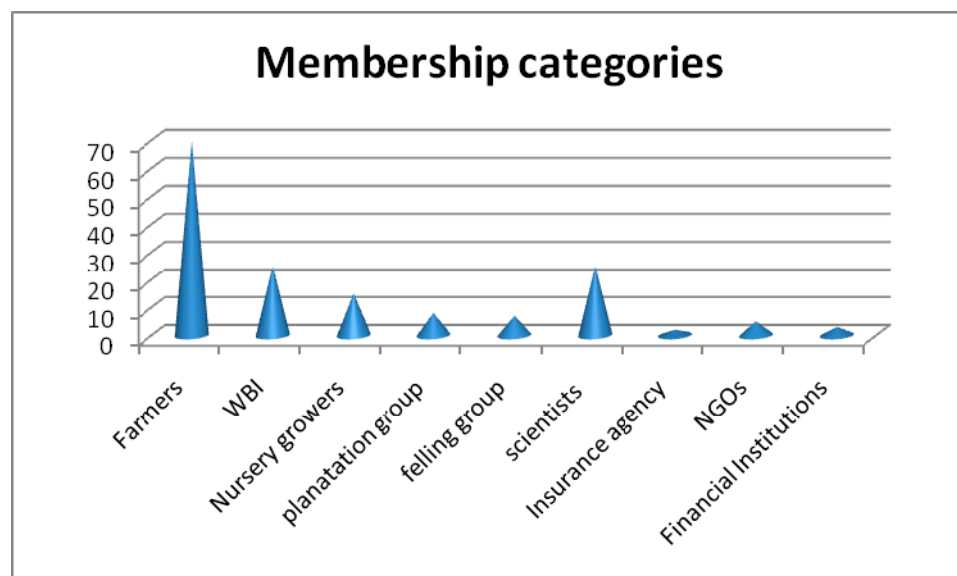


Figure 4. Membership categories.

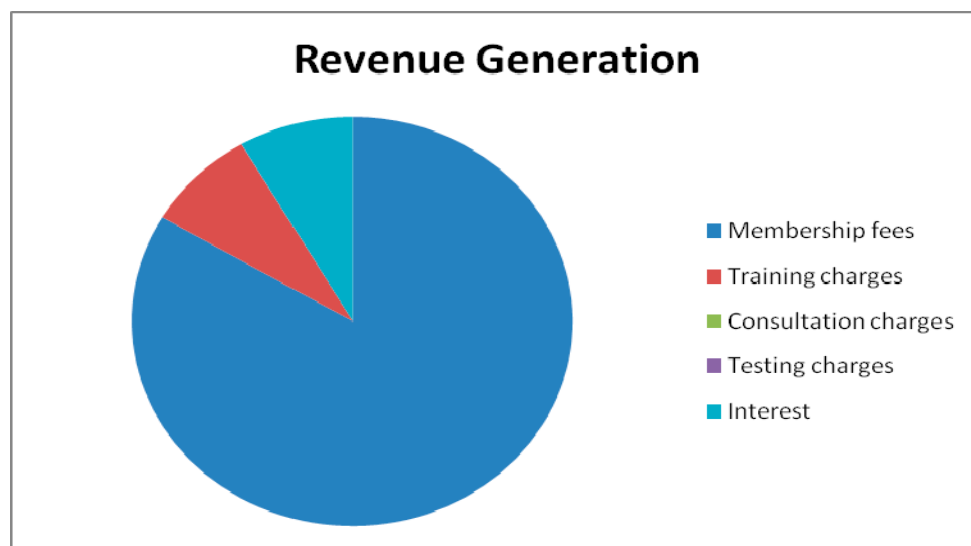


Figure 5. Revenue generation from 2015–2021.

3.3. Marketing Innovations

One of the major problems faced by the tree growing farmers is the lack of assured buy back and price support. This issue has been resolved by establishment of a market support system coupled with assured buy back by the Consortium industries. The last decade of agroforestry promotion has extended greater confidence both on the part of farmers and industries due to the price support system established and extended to the farmers. Originally, the price support system was extended only for pulpwood species, but has now been extended to plywood, matchwood, energy and timber species. The price support system has been established through mutual consultations with all stakeholders involved in the entire production to consumption system coupled with continuous price and market analysis. The price support system designed and extended to various tree species is furnished in Table 3.

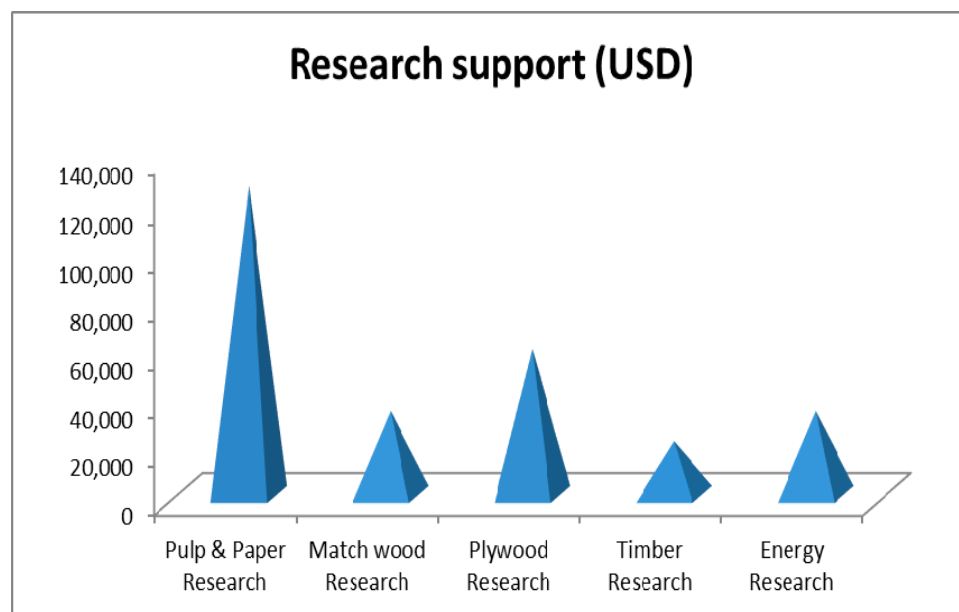


Figure 6. Research grant support by Consortium industries in USD.

Table 3. Price support system for various tree species.

S.No.	Species and Clone	Specifications (GBH) (Meters)	Rate/MT USD
A		Plywood Utility	
1.	<i>Melia dubia</i> (MTP-1, MTP-2 and MTP-3)	0.45 and Above	117
		0.30 to 0.43	68
		<0.30	41
2.	<i>Eucalyptus</i> (EH-LBT-01)	0.45 and Above	82
		0.30 to 0.43	48
		<0.30	41
3.	<i>Toona ciliata</i> (MTPTC-02)	0.45 and Above	110
4.	<i>Swietenia macrophylla</i> (MTPSM-20)	0.45 and Above	96
5.	<i>Neolamarckia cadamba</i> (MTP-1)	0.45 and Above	89
6.	<i>Acrocarpus fraxinifolius</i> (FCRIAF-07)	0.45 and Above	82
B		Timber Utility	
1.	Teak (MTPTK-07, MTPTK-21, MTPTK-16)	0.60 to 0.73	220
		0.76 to 0.88	247
		0.91 to 1.21	344
		1.21 and Above	516
2.	<i>Gmelina arborea</i> (FCRIGA-08)	0.60 to 1.06	110
		1.06 and Above	165
3.	Acacia hybrid	0.91 to 1.19	123
		1.21 and Above	165

Table 3. Cont.

S.No.	Species and Clone	Specifications (GBH) (Meters)	Rate/MT USD
C	Matchwood Utility		
1.	<i>Ailanthus excelsa</i> (MTPSS-07)	0.60 and Above	82
D	Pulpwood Utility		
1.	Casuarina (MTP-1, MTP-2)	0.12 to 0.20	75
2.	Eucalyptus (MTP-1, EG-1& 2)	0.12 to 0.40	75
E	Biomass Energy		
1.	Subabul (FCRI LL15)	0.05 to 0.40	48
2.	Other Species	0.05 to 0.40	48

3.4. Business Innovations

Unlike agriculture and other land use systems, forestry and agroforestry land use systems need to be addressed sustainably, taking into consideration the nature and type of growth and development. The innovations made through technological, organizational and marketing strategies were institutionalized through the Consortium of Industrial Agroforestry. However, this demanded creating business development opportunities to sustain the income and further employment generation activities. Accordingly, TNAU pioneered in establishing India's first agroforestry business incubator in 2018 and leveraged technology-based business development activities in the agroforestry sector and created significant attention among the value chain players [15]. The various support and services extended by the business incubator are presented in Figure 7.

This incubator has enrolled 70 incubatees, out of which 15 are physically stationed in the incubator and are involved in technology development, validation and commercialization. The incubation establishment has attracted more farmers and unemployed youth to create new startups and enterprises leveraging agroforestry technologies. Establishment of 14 nurseries with clonal licensing support has facilitated the production of 0.1 million clonal plants annually in the state of Tamil Nadu and satisfies the demands of agroforestry policy directives in addition to creating significant income and employment generation activities for the society.

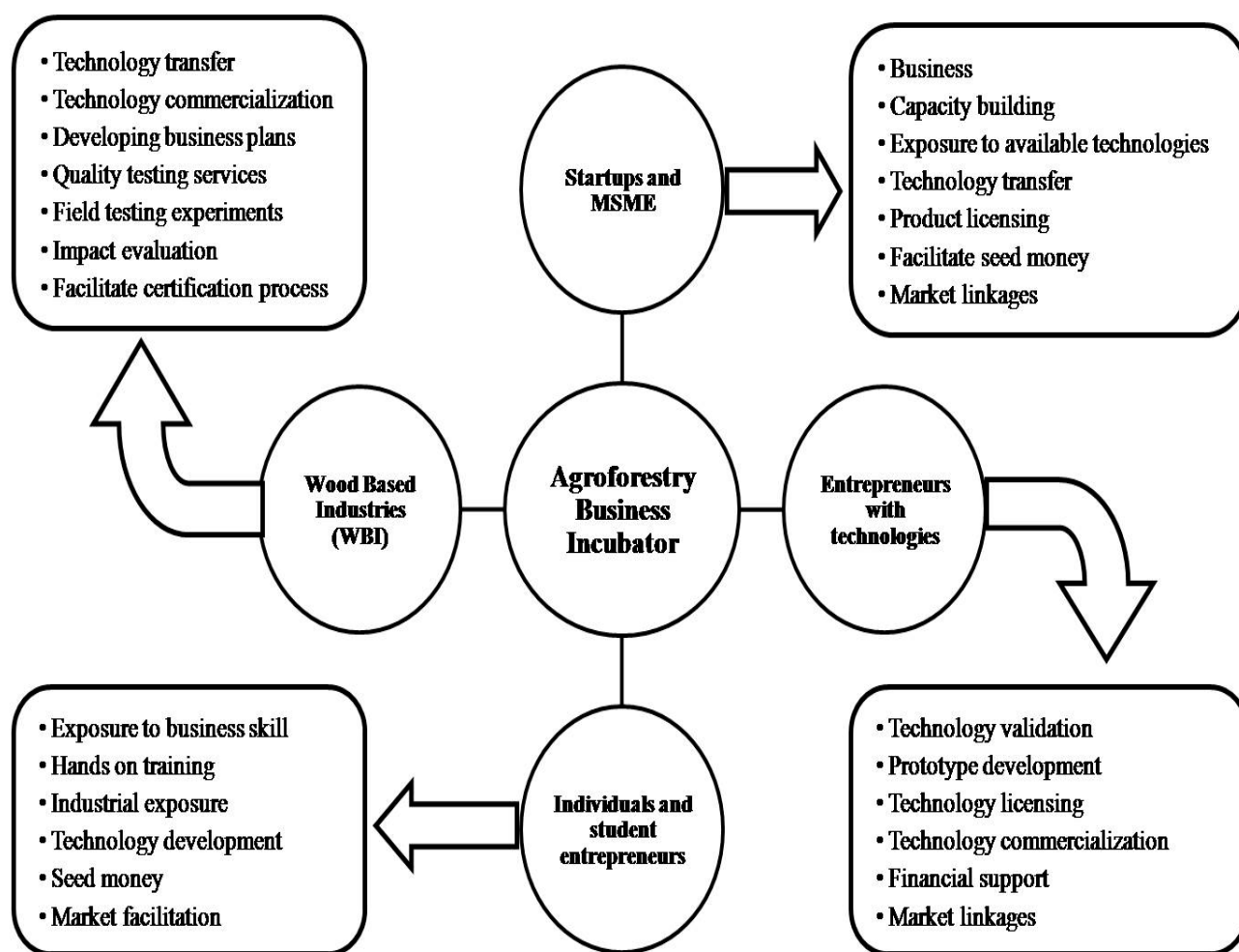


Figure 7. Support and services by the business incubator.

4. Impact of Value Chain

The value chain-based industrial agroforestry promotion has gained significant attention among the wood-based industries, tree growing farmers and other value chain players, which has resulted in area expansion, productivity improvement, increased participation of industries, socio-economic development and an augmented carbon sequestration process. Significant impacts made by the value chain during the last five years alone are furnished below.

4.1. Development of Organized Industrial Agroforestry Plantations

The concept of value chain was introduced in 2008–2009 and demonstrated in 200 ha. During the last decade, it has consistently attracted adoption of value chain-based industrial agroforestry plantations. During the last five years, it has been assessed that organized agroforestry plantation establishment to the tune of 73,957 ha has been done in association with Consortium industries viz., paper, plywood, timber, matchwood, biomass and other industries (Figure 8). These organized and improved agroforestry plantations also meet at least 25% of the industrial raw material resource requirements.

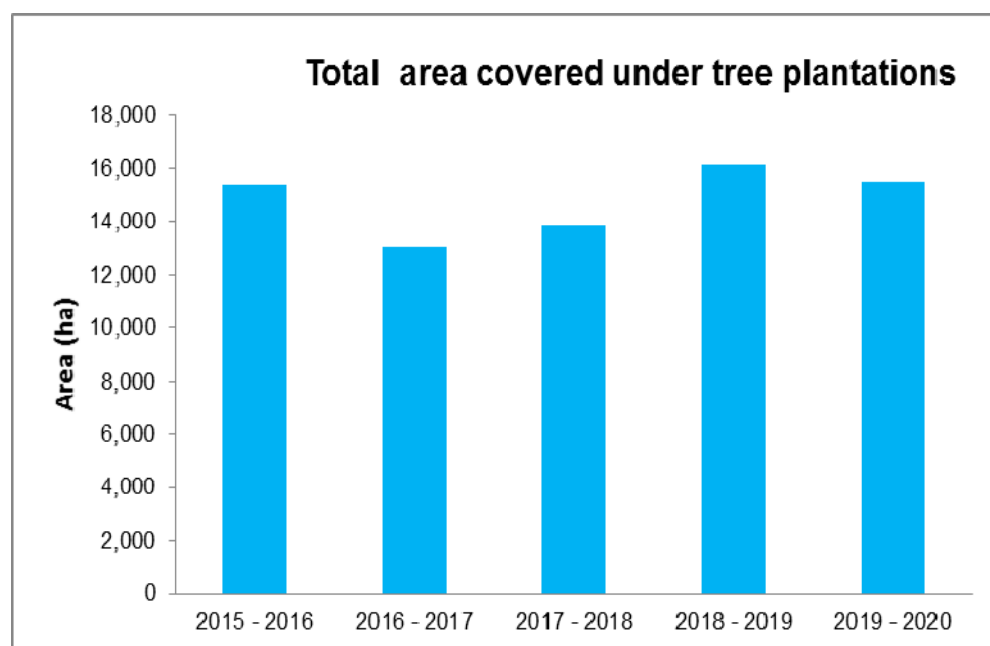


Figure 8. Area under plantations established.

4.2. Productivity Improvement

The baseline study estimated that in most cases, the productivity levels were less than $10 \text{ m}^3/\text{ha}/\text{annum}$ due to unimproved genetic resources along with non-adoption of precision silvicultural packages [16]. In the value chain system, incorporation of HYSR clones, miniclonal technology, precision silviculture and the multifunctional agroforestry model have augmented the productivity levels, which ranged between $25 \text{ m}^3/\text{ha}/\text{yr}$ and $40 \text{ m}^3/\text{ha}/\text{yr}$ depending on the species deployed in agroforestry promotion [17]. This intervention has also reduced the felling age to the levels of 18 to 24 months for pulpwood species and 48 to 60 months in the case of plywood species, which has created a significant impact in agroforestry promotion among the farming community.

4.3. Profitability Enhancement

Technology-based value chain interventions in the entire PCS with assured buy-back and a price supportive system has created a significant jump in income generation. The financial analysis of organized agroforestry plantations, particularly for plywood and pulpwood species, has indicated that the benefit–cost (BC) ratio has increased to 3.5:1 from the levels of 1.2:1, which attracted several farmers towards agroforestry.

4.4. Increased Participation of Industries

In the early stages of value chain model during 2008, only three industries *viz.*, two paper industries and one matchwood industry alone participated. However, currently over 40 different wood-based industries, predominantly plywood, timber, paper, dendropower, biofuel, match wood and other value added industries, are participating, which is one of the significant impacts, and this development addresses the envisaged strategy of increased participation of wood-based industries flagged in the National Agroforestry Policy (2014). The industries are also extending financial support for continued and long term research to the tune of over 0.2 million USD, and this development has a positive impact on progressive research development over the years.

4.5. Socio-Economic Development

Increasing the area under agroforestry and the associated value chain development activities like nursery, plantation development, creation of felling institutions and orga-

nized marketing groups have created sustainable employment and income generation activities. It is estimated that such activities emanating from the production to consumption system in agroforestry have created 220–300 man days of employment for a hectare of plantation establishment and generated 21.9 million man days of employment for 75,000 ha of extended area that has been additionally brought under agroforestry plantations. This ensures significant socio-economic improvement not only for the agroforestry practicing farmers, but also to the other value chain players involved in the PCS. Establishment of the agroforestry business incubator has created 25 different startups through agroforestry, which also created significant economic impact.

4.6. Environmental Amelioration

Trees in general and agroforestry in particular have been identified as one of the potential land use systems to mitigate and adapt to climate change due to their prominent role in carbon sequestration and microclimate moderation. The industrial agroforestry plantations established during the last five years have been estimated to sequester 3.65 million tons of carbon, thereby helping to resolve the environmental issues.

5. Sustainability and Way Forward

Agroforestry has gained significant attention across India due to its role in raw material generation and its contribution to ecosystem services. Though as a land use system, agroforestry is practiced since time immemorial, its exploitation for industrial and commercial utility is of two to three decades old and has witnessed a wide range of challenges and constraints for want of suitable interventions at various levels. Hence, TNAU pioneered in conceptualization of a value chain on industrial agroforestry and demonstrated initially in 200 ha with generous funding support from the World Bank under the aegis of the Indian Council of Agricultural Research (ICAR) through National Agricultural Innovation Project (NAIP). These 200 ha of demonstration incorporating technological, organizational and marketing innovations has attracted more farmers towards agroforestry practice and increased the level of participation of wood-based industries, which aim to become self-reliant in raw material security. To sustain these activities, the current research group has established the Consortium of Industrial Agroforestry and is successfully resolving the issues in the entire production to consumption system in agroforestry through innovative ideas, processes and technologies. This Consortium is a self-sustaining institution and has created a corpus fund to sustain the financial and managerial activities in agroforestry promotion. The Consortium industries have extended funding support for technology development processes, which has promoted organized agroforestry development and has sustained the long-term research thrust of the host institute. Creation of decentralized clonal production centers, plantation establishment and felling institutions coupled with increased participation of wood-based industries are the major factors for sustaining agroforestry development, and this successful model has been acknowledged at the national and global levels. Besides all these accomplishments, establishment of a business incubator has created an effective platform for business enterprise development, thereby creating a sustainable system for implementation and utilization of the developments made in agroforestry sector. These institutional developmental mechanisms and activities need to be accelerated and replicated, not only within India, but rather globally, with particular focus on tropical regions, which shall help to resolve the issues of raw material security besides playing a vital role in ecosystem stability and ensuring sustainability.

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