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Traditional agroforestry systems and practices of Assam

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Agroforestry is an age-old practice in Assam, the Northeastern state of India. But the documentation of such traditional practices is very meagre. Assam has six agro-ecological zones. This paper attempts to present the different types of traditional agroforestry systems practiced in North bank plains of agro-ecological zone of Assam. The documentation was done through direct observations. A questionnaire survey was done of 500 households in 250 villages distributed across four districts (Dhemaji, Lakhimpur, Sonitpur and Darrang) of Assam. Altogether 11 types of traditional agroforestry systems are recorded. Homegarden is the most common agroforestry system in all the four districts followed by aquaforestry and commercial crops trailed on support trees. The least common agroforestry system is *Machilus*-based agroforestry system and this system is not recorded from Darrang and Sonitpur districts of Assam. The choice of species and their planting pattern are influenced by their tradition, usage pattern and need of the agroforestry system's owner. These traditional agroforestry systems are a part of their traditional knowledge which is intervened with their traditions and culture. It is a blend of time-tested knowledge of indigenous species, their compatibility and species planting pattern such that the yield is maximized. So, the documentation of these environment-friendly traditional practices is essential to advocate climate-smart and sustainable approach in agriculture.

Keywords: Assam, Aquaforestry, *Areca*-based cropping, Live fence, *Machilus*-based agroforestry

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The traditional agroforestry is a human-managed land-use system in which woody perennials are intentionally grown in association with agricultural crops, pastures as well as livestock. Most of these traditional farming practices are rainfed and for household consumption purposes. The crops planted, the crop combination and the sequence of cropping in these traditional practices depend upon the edaphic, climatic, topographic conditions of the area and socio-economic status of the people. These practices are passed on from generation to generation but are not documented. In the recent years, these traditional ways of farming and cultivation are gaining importance as these practices are sustainable and environment-friendly. Therefore, emphasis is being given on documentation of these fast-depleting traditional methods of cultivation.

The traditional agroforestry systems and its practices have been documented in many countries such as Africa[1], China[2], Turkey[3] and Bangladesh[4]. In India, though agroforestry is being practiced from ancient times, only a few authors have documented these practices. A thorough literature review highlighted an inventory of the existing agroforestry systems in different states of India such as Kerala[5], Uttar Pradesh[6], Meghlaya[7], Arunachal Pradesh[8], Chattisgarh[9] and Nagaland[10]. Four agroforestry systems namely rainfed agrihorticultural system (*Cocos nucifera*, *Areca catechu*, *Citrus* sp., *Zingiber officinale*, *Curcuma longa*), silvipastoral systems (*Artocarpus* sp., Napier grass, Guinea grass), silvihortipastoral systems (*Bombax ceiba*, Thatch) and irrigated silviagrosystem (*Azadirachta indica*, *Oryza sativa* and oilseeds) are reported from Assam[11].

It is quite evident from the above that traditional agroforestry systems are present in Northeast India, and there is only a single case of inventory of the systems practiced in Assam. This shows that many agroforestry systems and practices still remain to be documented from this region. Therefore, there is a need to capture the local and traditional plant management practices before these are lost forever. Also, with the increasing

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risk of climate change, it is necessary to document these traditional agroforestry practices which are generally characterized as eco-friendly, requiring low input and utilizing local resource and knowledge but at the same time generating high output and supporting the livelihood of local people. The documentation of these agroforestry systems can help in conducting further in-depth studies on these sustainable practices and help in replicating these models in other similar regions. This study was designed with the following objectives:

1. To document the different types of traditional agroforestry systems practiced in North bank plains of Assam.
2. To explore the species composition, crop combinations and planting patterns adopted in various traditional agroforestry systems.

In this study, the hypothesis tested is that the species composition, their combinations and planting patterns will vary according to the agroforestry systems.

Materials and Methods

Study area

Assam, a frontier province of India located in the Northeast derived its name from Sanskrit word 'Asama' which meant "unequalled" or "peerless". The famous historian Baden Powell was of an opinion that the name 'Asam' meant "low or level country". Assam is covered on all the three sides by Eastern Himalayas and is identified as a one of the 36-global biodiversity hotspots[12]. Assam lies between $89^0$5' to $96^0$1' East longitude and $24^0$3' to $27^0$58' North latitude[13]. This state is bordered in the North and East by Bhutan and Arunachal Pradesh, respectively. On the South, it has Nagaland, Manipur and Mizoram and Meghalaya in the Southwest, and Bengal and Bangladesh to the West[13]. Around 36.11% of Assam's geographical area is under forest cover[14]. The state forests are comprised of tropical wet evergreen forests, tropical semi evergreen forests, tropical moist deciduous forests, tropical sub-tropical broadleaf hill forest, sub-tropical pine forests, littoral and swamp forests and grassland and savannahs. Assam is divided into six agro-ecological zones. One among them is the North bank plains which has an average rainfall of 1000 mm per year. Majority of the rainfall (50%) is received in the monsoon season. The relative humidity is more than 80%. The temperature ranges from 5°C during January to 37°C during July-August. The soil is acidic and ranges from neutral to less acidic from foothills to river bank[15].

More than 50% of the total population of the North bank plains of Assam have agriculture as their main occupation. *Oryza sativa* is the main crop grown. Apart from *Oryza sativa*, *Brassica napus subsp. napus*, *Brassica nigra* and *Saccharum officinarum* are the major crops cultivated in the North bank plains of Assam[15]. Other food crops like *Corchorus* sp., pulses, *Solanum tuberosum*, fruits (*Psidium guajava*, *Artocarpus heterophyllus*, *Musa* sp., *Citrus* sp., *Ananas comosus*), *Camellia sinensis*, *Cocos nucifera*, *Piper betel*, *Zingiber officinale*, *Curcuma domestica*, *Piper nigrum*, *Areca catechu* and *Gossypium* sp. are also cultivated in this zone.

Documentation of agroforestry systems

Four districts viz., Darrang, Dhemaji, Lakhimpur and Sonitpur (undivided) located on the North bank landscape of Bramhaputra River were selected for the documentation of agroforestry systems in Assam (Fig. 1). An inventory of the types of traditional

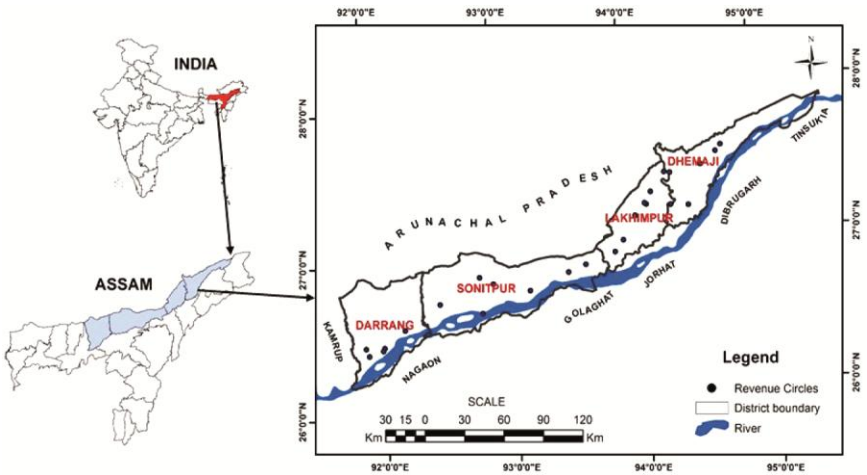

Fig. 1 — Map showing districts and revenue circles surveyed for documentation of types of traditional agroforestry systems practiced[16].

agroforestry systems present in all these four districts was made. The following is a brief description of the selected study sites:

Darrang district

According to Scholar Late Dineswar Sarma, Darrang gets its name from Dawrang which meant 'Gateway' as there is a direct entry to Bhutan, Nepal, and China etc. Darrang district comprises around 1850.58 sq. km. and is located in the central part of Assam ($20^0$9' to 26^0 N and $91^0$45' to $92^0$22' E). It is surrounded by Arunachal Pradesh, Bhutan and Udalgiri district of Assam in the North, Sonitpur district in the East and Kamrup district in the West[17]. It has 563 villages[18].

Dhemaji district

Dhemaji district ($94^0$12' 18" E and 95^0 41' 32" E longitude and 27^0 05' 27" N and 27^0 57' 16" latitude) shares its borders with Arunachal Pradesh in North and East and Lakhimpur district towards its West. This district stretched from foot hills of Arunachal Pradesh to the Brahmaputra River with Subansiri on one side and Siang River on other side[19]. It comprises of 1315 villages[18].

Lakhimpur district

The name of this district is derived from 'Lakhimi' meaning paddy and 'pur' means full, thus, stating that paddy is abundant in this district. This district is approximately situated between $26^0$48' to $27^0$53' N latitude and $93^0$42' to $94^0$20'E longitude. On the North it is bounded by Siang and Papumpare district of Arunachal Pradesh, on the East by Dhemaji district and Subansiri River, on South by Majuli Sub Division of Jorhat district and on the West by Gohpur sub-division of Sonitpur district of Assam. It has 1185 villages[20].

Sonitpur district

Sonitpur literally means 'the city of blood'. The district lies between 92^0 16' to 93^0 43' E longitude and 26^0 30' to 27^0 1' N latitude covering an area of around 5324 sq.km. It is surrounded on its North by Arunachal Pradesh, on its South by Brahmaputra River, on East by Lakhimpur district and by Darrang district of Assam on its West. Overall, 1615 villages come under this district[21].

Methods

To document the types of traditional agroforestry systems practiced in the selected districts of North bank plains of Brahmaputra river landscape of Assam, a survey was initiated from March to August 2017 by directly visiting the study sites and the agroforestry systems. The selected study sites (4 districts) had 25 revenue circles (Fig. 1). Ten villages were randomly chosen from each revenue circle and two households were randomly selected from each village for documenting the types of agroforestry systems. Thus, making a total of 500 households in 250 villages distributed across four districts of Assam. Questionnaire survey was conducted among the household owners who practiced agroforestry. Data was collected on the types of agroforestry system practiced, species composition, plant combinations and planting patterns. The GPS readings of the systems as well as of the villages were noted in field notebook. The documented agroforestry systems were classified based on earlier guidelines[5,22].

Results

Based on the survey conducted in selected four districts of North bank landscapes of Brahmaputra river, Assam viz., Dhemaji, Lakhimpur, Sonitpur and Darang, 11 types of traditional agroforestry systems namely, homegarden, aquaforestry, plantation crop combinations (*Areca*-based cropping), commercial crops under shade of planted trees, commercial crops trailed on support trees, multipurpose trees on croplands, trees on farm boundaries, scattered trees on farms, live fence, *Morus* and *Castor*-based agroforestry systems, *Machilus*-based agroforestry systems are recorded (Table 1, Plate 1, 2, 3, 4). Homegarden (100%) is the most commonly practiced agroforestry system in the selected study sites followed by aquaforestry and commercial crops trailed on support trees (94%) each. The is followed by *Morus*- and *Castor*-based agroforestry system (43%), Commercial crops under shade of planted trees (23%) and multipurpose trees on croplands (21%). The least common agroforestry system is *Machilus*-based agroforestry system (11%) (Table 1).

Districtwise distribution of agroforestry systems

Darrang district

Homegarden is recorded as the most common agroforestry system (100%) in Darrang district followed by aquaforestry and commercial crops trailed on support trees (94% each), plantation crop combinations (*Areca*-based cropping) (92%), trees on farm boundaries (85%), scattered trees on farm (81%), live fence (76%), *Morus*- and *Castor*-based agroforestry system (44%) and multipurpose trees on

Table 1 — Types of traditional agroforestry systems with their crop combinations recorded in selected study sites.

District of occurrence		Types of AFS	Crop combination of AFS
Darrang, Sonitpur, Lakhimpur and Dhemaji	1)	Homegarden	*Oryza sativa* + *Areca catechu* + Fruit trees (*Mangifera indica*, *Musa* sp.) + Timber trees (*Tectona grandis*, *Shorea robusta*) + *Bambusa tulda*, *Bambusa pallida* + Fish pond + Livestock
	2)	Aquaforestry	*Bambusa* sp./*Musa* sp. + Fish species (*Cirrhinus mrigala*, *Labeo rohita*, *Hypophthalmichthys molitrix*)
	3)	Plantation crop combinations	*Areca catechu* + *Musa* sp. + *Curcuma longa/Zingiber officinale/Ananas comosus*
	4)	Commercial crops under shade of planted trees	*Camellia sinensis* + *Albizia* sp. *Camellia sinensis* + *Areca catechu/Macaranga peltata/Citrus* sp./*Punicum granatum*
	5)	Multipurpose trees on croplands	*Mangifera indica*, *Artocarpus heterophyllus*, *Tectona grandis*, *Shorea robusta*, *Bombax ceiba*, *Gmelina arborea*, *Machilus bombycina*, *Morus alba*, *Castor* sp., *Bambusa* sp., *Dillenia indica*, *Citrus* sp. + agricultural crops (*Oryza sativa*, *Vigna* sp., *Zingiber officinale*, *Curcuma longa*) etc.
	6)	Commercial crops trailed on support trees	*Areca catechu* + *Piper betle/Piper longum/Piper nigrum*
	7)	Trees on farm boundaries	*Tectona grandis/ Bambusa* sp. + *Oryza sativa*
	8)	Scattered trees on farms	*Bambusa* sp./ *Dillenia indica/Mangifera indica/ Bombax ceiba/Lagerstroemia* sp. + *Oryza sativa*
	9)	Live fence	*Cactus* sp. /*Jatropha* sp. /*Sansevieria trifasciata* on boundaries of croplands *Cactus* sp. /*Sansevieria trifasciata* /*Duranta erecta* /*Murraya paniculata* on peripheries of homegardens
Lakhimpur, Dhemaji	10)	*Morus*- and *Castor*-based AFS	*Morus alba* - Leaves fed to Pat muga silkworm (*Bombyx textor*) reared in shaded rooms *Castor* sp. - Leaves fed to Eri silkworm (*Samia cynthia*) reared in shaded rooms
	11)	*Machilus*-based AFS	*Machilus bombycina* /*Litsea polyantha* + *Antheraea assamensis* reared on trees *Machilus bombycina* /*Litsea polyantha* /*Litsea salicifolia* + *Antheraea assamensis* reared on trees

AFS=Agroforestry systems.

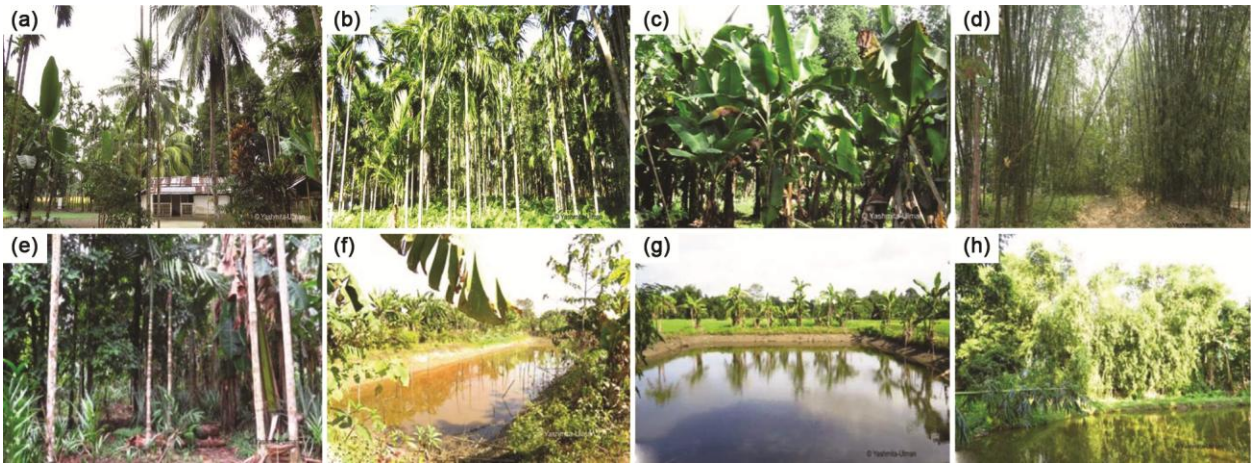

Plate 1 — Photographs showing traditional agroforestry systems in the study area [a] Homegarden; [b] *Areca catechu* plantation in homegarden; [c] *Musa* sp. plantation in homegarden; [d] Bamboo plantation in homegarden; [e] Multipurpose trees plantation in homegarden; [f] Pond in homegarden; [g] Aquaforestry (Pond with *Musa* sp. on boundary); [h] Aquaforestry (Pond with Bamboo on boundary).

croplands (21%). The least common agroforestry system is commercial crops under shade of planted trees (2%). *Machilus*-based agroforestry system is absent in the district (Table 1, Fig. 2a).

Sonitpur district

Similar to Darrang district, homegarden (100%) is the most common agroforestry system practiced in Sonitpur district, followed by aquaforestry (94%), commercial

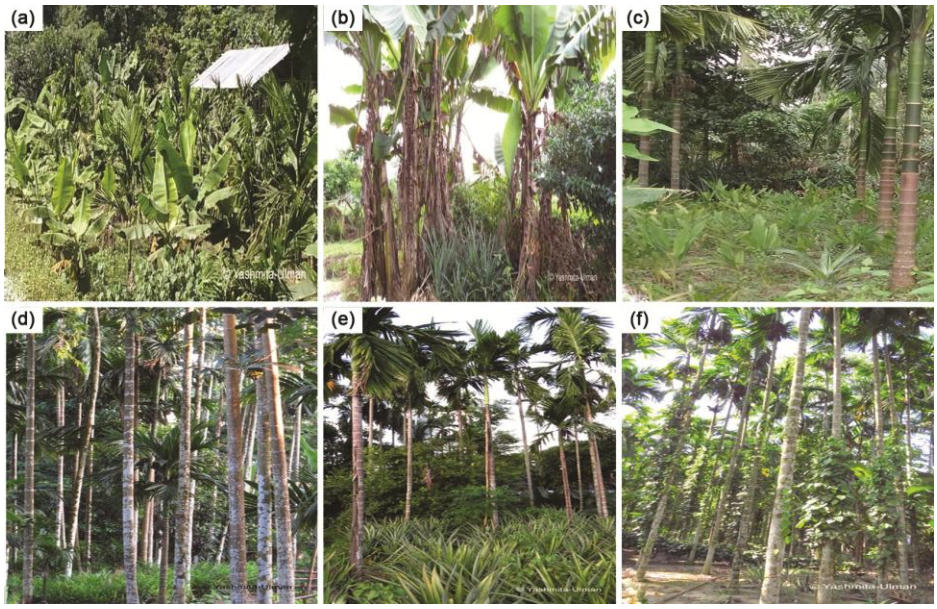

Plate 2 — Photographs showing Plantation crop combinations in the study area [a] *Musa* sp. + *Areca catechu*; [b] *Musa* sp. + *Ananas comosus*; [c] *Areca catechu* + *Curcuma longa*; [d] *Areca catechu* + *Zingiber officinale;* [e] *Areca catechu* + *Ananas comosus*; [f] *Areca catechu* + *Piper betle* + *Ananas comosus*.

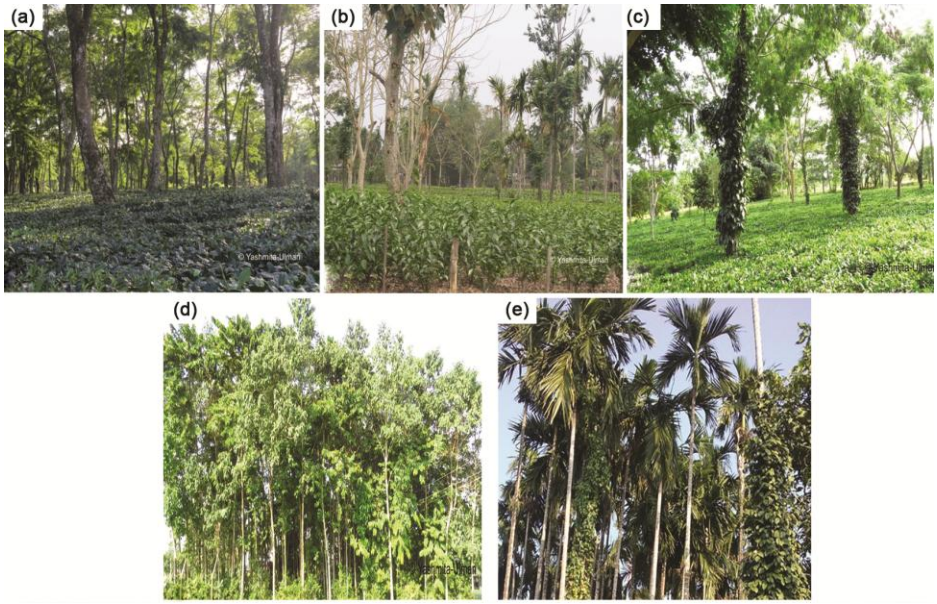

Plate 3 — [a] Commercial crops under shade of planted trees (*Camellia sinensis* + *Albizia* sp.); [b] Commercial crops under shade of planted trees (*Camellia sinensis* + *Areca catechu/Macaranga peltata*); [c] Commercial crops under shade of planted trees (*Cameliia sinensis* + *Albizia* sp. + *Piper longum*); [d] Multipurpose trees on cropland; [e] Commercial crops trailed on support trees (*Areca catechu* + *Piper betle/Piper longum*).

crops trailed on support trees (94%), plantation crop combinations (*Areca*-based cropping) (92%), scattered trees on farm and trees on farm boundaries (78%) each, live fence (73%), commercial crops under shade of planted trees (52%) and *Morus*- and *Castor*-based agroforestry system (47%). Growing multipurpose trees on croplands is recorded as the least common agroforestry system (21%) (Table 1, Fig. 2b). *Machilus*-based agroforestry system is absent in Sonitpur district.

Lakhimpur district

This district has all eleven types of agroforestry systems. Homegarden is the most common (100%) agroforestry system, like in the other two above-

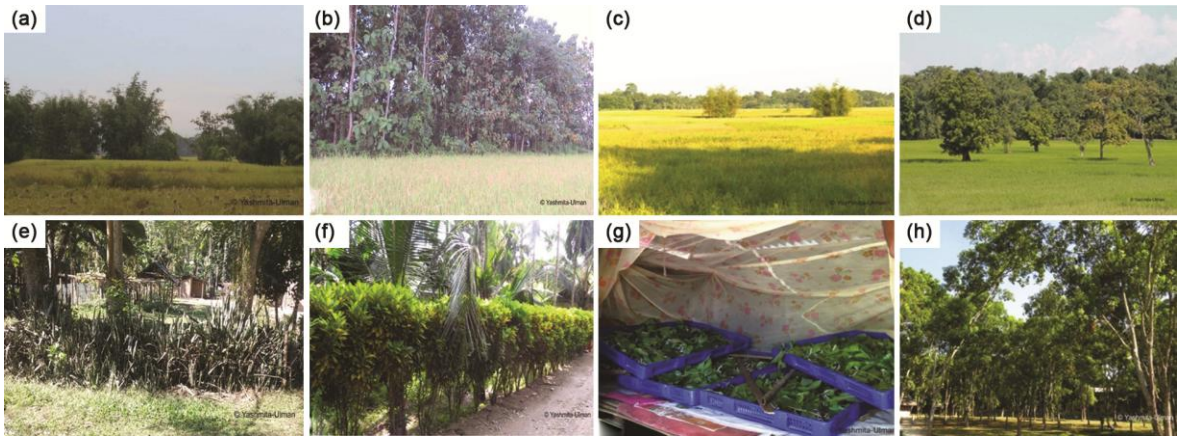

Plate 4 — [a] Trees on farm boundaries (*Bambusa* sp. + *Oryza sativa*); [b] Trees on farm boundaries (*Tectona grandis* + *Oryza sativa*); [c] Scattered trees on farms (*Bambusa* sp. + *Oryza sativa*); [d] Scattered trees on farms (Multipurpose trees + *Oryza sativa*); [e] Live fence (*Sansevieria trifasciata*); [f] Live fence (*Codiaeum variegatum*); [g] *Morus*- and *Castor*-based silvipastoral sericulture (*Castor* sp. - Leaves fed to *Samia cynthia* silkworm reared in shaded rooms); [h] *Machilus*-based silvipastoral sericulture (*Machilus bombycina* + *Antheraea assamensis* reared on trees).

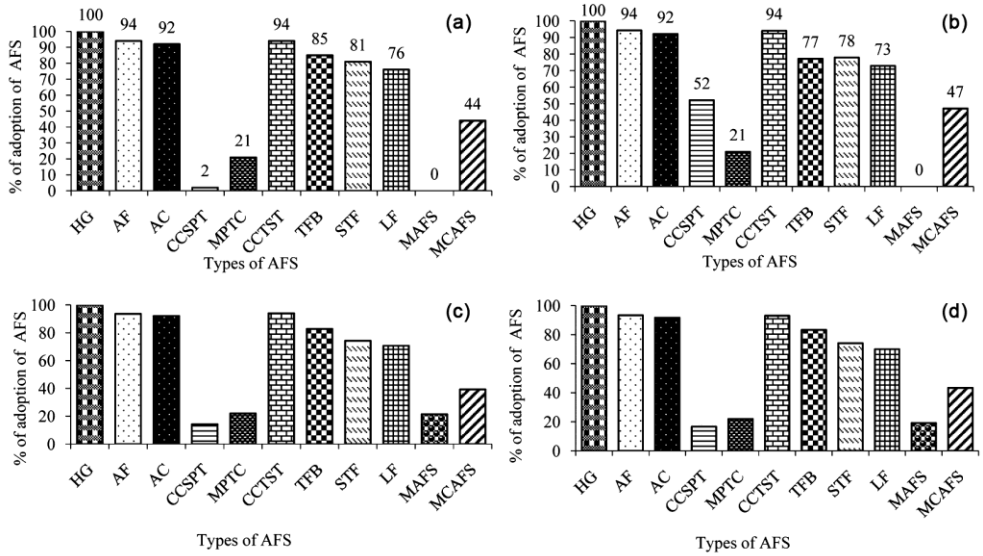

Fig. 2 — Pattern of adoption (%) of different types of traditional agroforestry systems in [a] Darrang, [b] Sonitpur, [c] Lakhimpur, [d] Dhemaji districts of Assam. (AFS=Agroforestry systems, HG=Homegarden, AF=Aquaforestry, AC=*Areca*-based cropping, CCSPT=Commercial crops under shade of planted trees, CCTST=Commercial crops trailed on support trees, MPTC=Multipurpose trees on cropland, TFB=Trees on farm boundaries, STF=Scattered trees on farms, LF=Live fences, MAFS=*Machilus*-based AFS, MCAFS=*Morus*- and *Castor*-based AFS).

mentioned districts. This is followed by commercial crops trailed on support trees and aquaforestry (94% each), plantation crop combinations (*Areca*-based cropping) (92%), trees on farm boundaries (83%), scattered trees on farm (74%), live fence (71%). The least common agroforestry system is commercial crops under shade of planted trees (14%) (Table 1, Fig. 2c).

Dhemaji district

This district also has all the eleven types of agroforestry systems. Homegarden is the most common (100%) agroforestry system, followed by commercial crops trailed on support trees (93%), aquaforestry (93%), plantation crop combinations (*Areca*-based cropping) (92%), trees on farm boundaries (83%), scattered trees on farm (74%), live fence (70%), *Morus*- and *Castor*-based agroforestry system (43%), multipurpose trees on croplands (22%) and *Machilus*-based agroforestry system (19%). Growing commercial crops under shade of planted trees is less common (17%) (Table 1, Fig. 2d).

Distribution and crop combination of agroforestry systems recorded in selected study sites

The following types of agroforestry systems are adopted by the people in North bank plains of Assam:

1. Homegarden: It is the most common type of agroforestry system followed in all selected districts (Fig. 2a-d). The main crops consist of cash crops like *Areca catechu*; fruit trees namely, *Mangifera indica, Musa* sp., *Syzygium cumini;* timber trees such as *Tectona grandis, Bombax ceiba, Shorea robusta;* bamboo species such as *Bambusa tulda, Bambusa pallida*, etc. and agricultural crops like *Oryza sativa, Vigna* sp. etc. (Table 1, Plate 1a-f). It also has a livestock component such as fish ponds, cows, sheep, goats and pigs etc. When the area under homegarden is small, the crops appear to have a scattered arrangement (Table 1), but in households having large acres of land under homegarden, there are specific block plantations of bamboo species, *Areca catechu,* agricultural crops, timber species and fruit trees.
2. Aquaforestry: This system is also very common (93% to 94%) in the selected districts (Fig. 2: a-d). The crops like *Bambusa* sp., *Musa* sp. are arranged linearly on the periphery of the farm boundaries. The fishes namely, *Cirrhinus mrigala, Labeo rohita, Hypophthalmichthys molitrix, Ctenopharyngodon idella* are reared in the ponds (Table 1, Plate 1g-h).
3. Plantation crop combinations (*Areca*-based cropping): This is also one of the commonly practiced system (92%) by the people of the selected four districts of Assam (Fig. 2a-d). The main plantation crop is *Areca catechu*. The shade loving crops like *Curcuma longa, Zingiber officinale, Ananas comosus* and *Piper* sp. are cultivated under the *Areca catechu* plantation crop (Table 1, Plate 2).
4. Commercial crops under shade of planted trees: Though this system exists in all the four districts but the adoption of this system varies. The highest adoption of this system is in Sonitpur (52%), followed by Dhemaji (17%), Lakhimpur (14%) and the least in Darrang (2%) (Fig. 2a-d). In large-scale plantations, the main commercial crop i.e., *Camellia sinensis* is planted under the shade trees like *Albizia odoratissima, Albizia lebbeck, Albizia procera* etc. Whereas, in small-scale plantations, *Areca catechu, Macaranga peltata, Citrus* sp. and *Punicum granatum* are planted as alternative shade trees (Table 1, Plate 3a-c).
5. Multipurpose trees on croplands: This agroforestry system is commonly found in all districts but adoption percentage is very low (21% to 22%) (Fig. 2a-d). This system comprises of trees species viz., *Mangifera indica, Artocarpus heterophyllus, Tectona grandis, Shorea robusta, Bombax ceiba, Gmelina arborea, Machilus bombycina, Morus alba, Castor* sp., *Dillenia indica, Citrus* sp. and bamboo species such as *Bambusa tulda, B. pallida* and *B. nutans.* These species are planted on the croplands either in block or square planting pattern along with agricultural crops namely, *Oryza sativa, Vigna* sp., *Zingiber officinale, Curcuma longa, Brassica oleracea, Solanum tuberosum, Spinacia oleracea* etc. (Table 1, Plate 3d).
6. Commercial crops trailed on support trees: It is a commonly adopted (93% to 94%) system in North bank plains of Assam (Fig. 2a-d). The vines of *Piper betle, Piper longum* and *Piper nigrum* are grown around the trunk of *Areca catechu* planted in the homegardens, using them as support trees (Table 1, Plate 3e).
7. Trees on farm boundaries: This system is commonly adopted by the people in all the four districts with a higher adoption percentage (77% to 85%) (Fig. 2a-d). In this system, *Tectona grandis* and bamboo species viz., *Bambusa tulda, B. pallida* etc. are arranged on the farm boundaries in a linear fashion surrounding the *Oryza sativa* crops growing in the fields. (Table 1, Plate 4a-b).
8. Scattered trees on farms: This system is recorded in all the four districts (74% to 81%) (Fig. 2a-d). In this type of agroforestry system, trees species such as *Dillenia indica, Mangifera indica, Bombax ceiba, Lagerstroemia* sp. and bamboo species are scattered within the farmlands cultivating *Oryza sativa* (Table 1, Plate 4c-d).
9. Live fence: Adoption of this system varies from 70% to 76% in all the four districts (Fig. 2a-d). The plants such as *Cactus* sp., *Jatropha* sp., *Euphorbia* sp., *Sansevieria trifasciata* are grown on farm boundaries to demarcate the fields. These hedges are very dense and thus, prevent grazing animals from entering the paddy fields. Similarly, *Cactus* sp., *Sansevieria trifasciata, Duranta erecta, Murraya paniculata* are planted on

peripheries of homegardens to beautify the homes and protect it from livestock intruders (Table 1, Plate 4e-f).

10. *Morus*- and *Castor*-based agroforestry systems: This system is present in all the four districts but is not very commonly adopted (39% to 47%) (Fig. 2a-d). The trees like *Morus alba* and *Castor* sp. are raised in available spaces in homegardens to feed the silkworm species of *Bombyx textor* and *Samia cynthia*, respectively. The silkworms are raised in shaded rooms (Table 1, Plate 4g).
11. *Machilus*-based agroforestry systems: This system is absent in the Darrang and Sonitpur districts and is present only in Lakhimpur (21%) and Dhemaji (19%) districts with a very low adoption pattern (Fig. 2a-d). The *Antheraea assamensis* (silkworm) feed on leaves of *Machilus bombycina, Litsea polyantha* and *Litsea salicifolia.* These trees are planted mostly in square pattern to rear silkworms (Table 1, Plate 4h).

Discussion

In the present study, 11 types of traditional agroforestry systems are identified in North bank plains of Assam. This study helps in further classification of the already reported four agroforestry systems[11] from Assam. The agroforestry systems reported in Turkey (13)[3] and Kerala, South India (16)[5] have higher number of agroforestry systems in comparison to the present study. On the other hand, Chattisgarh (7)[9] has lower number but similar types of agroforestry systems in comparison with the current study. In Uttar Pradesh, crop combinations varied according to regions[6]. Such kinds of regional differences in crop combination preferences are also observed in the study area.

In the current study, homegardens were found to be the most common agroforestry systems in North bank plains of Brahmaputra River, Assam, which is similar to the observations of other studies done in this area[23,24]. The area of home gardens ranged from 0.01 ha to 2.17 ha with an average of 0.42 ha per home garden[25]. In the study area, the homegardens have been maintained through generations[26]. The homegardens are dominated by agricultural crops (*Oryza sativa, Vigna* sp., etc.), timber trees (*Gmelina arborea, Tectona grandis,* etc.), fruit trees (*Musa acuminata, Musa balbisiana, Mangifera indica*, *Artocarpus heterophyllus* etc.) and bamboo species (*Bambusa tulda, B. nutans* and *B. balcooa*). This crop composition in homegardens is similar to other studies in this region[27]. The presence of such high plant diversity in a small unit area indicates that the presence and absence of plants in a homegarden is governed by factors like soil, climate and selection pressure of the homegarden owners[27]. The owners mostly prefer plants which meet the basic day-to-day requirements of food, fodder, timber and fuelwood and cater to the cultural practices of the society. The bamboo and timber species are maintained for its economic value[28] whereas, the presence of crops such as *Areca catechu* are an indicator of social status[23]. It was observed that, aquaforestry is a very common agroforestry system practiced in all four surveyed districts. The pond boundaries are planted with *Musa* sp. and bamboo species. Similarly, coconut and betel nut trees are observed on the pond boundaries in hill zones of Assam[29]. Ponds are used to rear fish varieties like Mrigal (*Cirrhinus mrigala*), Rohu (*Labeo rohita*), Silver carp (*Hypophthalmichthys molitrix*), and Grass carp (*Ctenopharyngodon idella*) etc. Rearing of similar fish varieties in ponds is reported from this region[30].

Areca catechu, *Cocos nucifera* and *Camellia sinensis* are the important plantation crops found in Assam. In the current study, intercropping *Areca catechu* with shade-loving plants like *Zingiber officinale, Curcuma longa* and *Ananas comosus* is a very commonly found crop combination. Similar crops are intercropped with *Areca catechu* in Kerala[5] and Assam[31]. Many crops can be grown along with *Areca catechu* depending upon the farmer's requirements and market needs. Growing commercial crops under shade of planted trees is not a very common agroforestry system practice in North bank plains of Assam. The maximum adoption of this system is reported in Sonitpur district (52%), followed by Dhemaji (17%), Lakhimpur (14%) and the minimum in Darrang (2%). The higher rate of adoption of this system in Sonitpur district suggests that the climatic and edaphic conditions required for growth of tea is available in this district. This district has higher number of large- and small-scale tea gardens as compared to any other district under this study. In large-scale tea gardens, *Camellia sinensis* is planted under the shade of trees viz., *Albizia odoratissima, A. chinensis*, *A. lebbeck*, *A. lucidor* and *A. procera* for their better growth and production. These shade tree species belong to Fabaceae family which are well known to provide nutrient-rich and fast decomposing litter, thereby, naturally enhancing the soil nutrients (organic matter) in the plantation

area[32]. So, this may be the reason for observing shade trees of Fabaceae family in large-scale tea gardens. On other hand, small-scale tea gardens form a small component of a larger homegarden[33] and are managed privately. These small-scale tea gardens are recorded to have shade trees like *Melia azedarach, Macaranga peltata, Areca catechu* with or without *Piper betel, Piper nigrum and Piper longum, Albizia odoratissima, Citrus* sp., *Litchi sinensis, Punica granatum* etc. which not only provide shade to the tea plant but also contribute in livelihood. Similar crop combinations are also reported in Meghalaya[34]. The use of *Cocos nucifera, Areca catechu* and *Aquilaria agallocha* as shade trees is reported from Golaghat, Assam[35]. In Lakhimpur district, tea cultivation is seen restricted to areas bordering Arunachal Pradesh. This emphasises on the fact that edaphic[36] and climatic[37] conditions play a major role in adoption of this system.

Commercial crops trailed on support trees is a very common agroforestry system found in all the four districts of North bank plains of Assam. Trees such as *Areca catechu* (most dominant), *Cocos nucifera*, *Artocarpus heterophyllus* etc. are used as support trees for climbers namely, *Piper nigrum, Piper betle* and *Piper longum* trailing on it. Similar crop combinations are recorded in Kerala[5], Meghalaya[7] and Assam[11]. Some studies have also reported trees viz., *Erythrina indica, Mangifera indica, Tectona grandis* being used as support trees for *Piper* sp.[5].

Trees on farm boundaries are commonly (82%) found in North bank plains of Assam. In the current study, the trees like *Tectona grandis, Syzygium cumini, Dillenia indica, Artocarpus heterophyllus* and Bamboo species are found to be planted on farm bunds along with agricultural crops. Similar systems are found in Kerala[5] and Assam[28]. Species such as *Casuarina* sp., *Ailanthus* sp., *Borassus* sp. are reported on the farm bunds in Kerala[5]. Live fence is commonly found in all the four districts (70-76%) in North bank plains of Assam. Similar systems are found in Nepal[38]. In the current study, the species like *Cactus* sp., *Jatropha* sp., *Sansevieria trifasciata, Ziziphus mauritiana, Duranta erecta, Murraya paniculata* etc. are used as live fence in agricultural field and homegardens. In Central America, 161 tree and palm species are used in live fence[39]. The *Erythrina* sp. and *Gliricidia* sp. are used as fences which not only fix nitrogen in the soil but also serve as fuelwood and fodder[5]. In homegardens, the live fences help in beautification of the area and sequesters carbon. The *Machilus*-based system is found only in two districts of North bank plains of Assam (Lakhimpur and Dhemaji). The restriction of this system to just two districts in North bank plains of Assam may be due to the influencing factors like host plant distribution and farmer's interest. The Muga silkworm (*Antheraea assamensis*) are reared on the host plants namely *Machilus bombycina* and *Litsea polyantha*. In the current study, *Machilus bombycina* is intercropped with *Litsea polyantha* whereas, in Meghalaya, *Machilus bombycina* is intercropped with *Zea mays* and broom grass[34]. All these above-mentioned agroforestry systems incorporate management techniques such as crop rotation, mixed cropping, mulching, use of farm yard manure which helps in soil and water retention and conservation and thus, forms a sustainable land-use practice.

Conclusion

The inventory of the agroforestry systems in North bank plains of Assam revealed 11 types of traditional agroforestry systems. Homegarden being the most common agroforestry system in all the four districts followed by aquaforestry and commercial crops trailed on support trees. The least common agroforestry system is *Machilus*-based agroforestry system and this system was not recorded from Darrang and Sonitpur districts of Assam. *Bambusa tulda* and plant species like *Areca catechu, Musa* sp., *Camellia sinensis, Curcuma longa, Zingiber officinale, Ananas comosus* and *Piper* sp. are spatially arranged in scattered or square planting pattern in various combinations. This pattern of cropping has been evolved over the years by the locals to fulfill their needs from the limited resources at their hand. In the current scenario of climate change, these practices will solve problems of depleting natural resources, malnutrition and livelihood. Documentation of these systems practiced in North bank plains of Assam has helped in creating a baseline data, based on which further research and scientific interventions on plant species combination, spacing, above and below ground interactions can be carried out. These systems can then be replicated as model practices, thus improving the land management system and providing food security.

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Conflict of Interests

Authors declare no conflict of interest.

Authors' Contributions

Y-U carried out the field work and drafted the manuscript. AK and MS had edited and finalized the manuscript.

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