

CHAPTER I

INTRODUCTION

Agroforestry is the purposeful growing or deliberate retention of trees with crops and/or animals in interacting combinations for multiple products or benefits from the same management unit (Nair *et al.*, 2021). It is a generic term for land use techniques in which woody perennials are intentionally used in a spatial or temporal sequence with agricultural crops and/or animals on the same land management system, with both ecological and economic interactions between the components. Agroforestry is a land-use strategy practiced by the farmers for a very long time all over the world. It is an integrated land management method that involves in producing food crops, trees, and/or animals together which ensured diverse benefits (Nair *et al.*, 2021b). Among diverse agroforestry practices, Homestead agroforestry/ Homegarden is one of the dominant agroforestry practiced in the tropical and subtropical country like Bangladesh where multiple species (beneficial plants, including trees, shrubs, vines, and herbaceous species) and animal are combined in small land holding around home. Homestead agroforestry is the model of sustainable agroforestry all over the world. It is also widely used method.

Homestead is a place of the house with neighbouring land. A homestead usually contains a house, a bare space and a cultivated space. In Bangladesh, one traditional method of land use is to plant various horticulture species around homesteads (Potapov *et al.*, 2017). This kind of land use is commonly referred to as "homestead forest" and is considered significant because to its impact on the environment and the economy (Baul *et al.*, 2021; Miah *et al.*, 2020; Nath *et al.*, 2015; Roy *et al.*, 2013; Rahman *et al.*, 2005). Trees outside forests, or homestead forests, are well-known and were recently added to the National Forest Monitoring and Assessment (Schnell *et al.*, 2015). The majority of the nation's need for forest products is met by TOF, which also contributes to the country's overall forest cover.

Home gardens, which are located near houses in rural areas, are important for maintaining biodiversity in TOF and for sustaining rural livelihoods by providing a range of ecosystem services. They can be thought of as small-scale agroforestry systems made up of sections of homestead property where a variety of plant. According to Castro *et al.*, (2018) and Mohri *et al.*, (2018), species are grown in many layers, frequently combining herbaceous, tree, shrub, vine, agricultural, and animal components. Homegarden agroforestry systems are more productive to monoculture systems and they provide multiple ecosystem services,

such as soil conservation, water regulation and biodiversity conservation. (Misbahuzzaman, 2016).

Agricultural system that integrates many production functions, enhances food availability, and expands the variety of foods is represented by home gardens. Fresh vegetables are easy to obtain every day from home gardens. Homestead farming is the ultimate solution to the unemployment problem since it allows people to earn money all year long by cultivating fast-growing fruits and vegetables (Ahmad, 1995). The most important source of income for low-income households has been proven to be small-scale homesteading over the years.

In Bangladesh, home gardens cover around 0.88 million hectares, of which 0.81 million are in rural areas (BBS 2020). However, growing populations, the dissolution of joint families, overuse, and conversion of homegardens into other land uses (such as agriculture and house construction) are causing them to become fragmented (Motiur *et al.*, 2006; Nath *et al.*, 2016; Roy *et al.*, 2013).

In Bangladesh homegarden provide provisioning services such as timber, bamboo, and fuelwood (Barua *et al.*, 2020). At present the homestead agroforestry are supplying 80% of the total biomass, 60-70% of the timber requirement and 90% of the fuelwood and bamboo consumed in the country. They also add organic matter in the form of litter fall, symbiotic nitrogen fixation, root biomass, micorrhizal association, and regulates water runoff and increase water holding capacity. The homestead vegetation absorbs CO₂ and greenhouse gas like CFC and thus control air pollution and global warming. They maintain atmospheric balance through increasing rainfall, keeping the air cool and prevent natural disaster. The situation of biodiversity has been shown by a number of research (Bardhan *et al.*, 2012; Alam and Sarker, 2011; Muhammad *et al.*, 2011) and the homestead woods' financial contribution (Rahman, 2018; Ghosh and Sinha, 2018; Sheikh *et al.*, 2021; Foyzal *et al.*, 2013). Furthermore, these forests provide a wide range of ecosystem benefits to people. The benefits of different ecosystem are known as ecosystem services.

According to Pan *et al.*, (2011), forests are crucial for both sequestering carbon dioxide and protecting biodiversity. Forests have a major role in the lives of humans and other species, and they account for large terrestrial carbon reservoirs and reserves (Whittakar and Liknes, 1975). Carbon sequestration in a natural forest is essential in combating increasing CO₂ emission which results in global warming (Murdiyarso *et al.*, 2015). Agroforestry systems

with a high litter fall rate are especially important because they have a large potential for storing carbon in soil (Montagini and Nair 2004; Oelbermann and Voroney 2007).

In order to reduce global warming and consequently ameliorate climate change, carbon sequestration the act of taking carbon out of the atmosphere and storing it in a reservoir is therefore becoming more and more crucial. Due to the significant role that trees play in absorbing and storing atmospheric CO₂ in vegetation, soil, and biomass products (Malhi *et al.*, 2008). Agroforestry systems are thought to sequester carbon more efficiently than field crops or pastures (Sanchez 2000; Roshekto *et al.*, 2002; Kirby and Potvin 2007). It is commonly recognized that by consistently adding organic matter to the soil, home garden agroforestry enhances carbon building, particularly soil organic carbon stock (Twari *et et al.*, 2017).

However, a few researches on the ES valuation of forest resources have been published in the last ten years (Abdullah-Al-Mamun *et al.*, 2017). The largest single area of mangrove forest in the world is the Sundarban. The Sundarban have received the majority of emphasis in Bangladeshi studies on forest ES, with other forest zones receiving less attention. Furthermore, the majority of the research focused solely on the supplying services valuation (Barua *et al.*, 2020). For this reason, a research project was required to value the ecological services that were obtained from the forests of homesteads. Recently, a study was carried out by Baul *et al.*, (2021) to look into the phytosociological characteristics and ES of homestead woods on the nation's Maheskhali Island. However, no specific scientific research has been done to date to determine the ES obtained from homestead forests of Northern Bangladesh.

Thus, this study is designed to explore the following objectives-

1. To quantify the ecosystem provisioning services provided by the homegardens of northern Bangladesh.
2. To characterize the soil chemical properties of homestead agroforests.

CHAPTER II

REVIEW OF LITERATURE

Bangladesh has 17.08% forest coverage; 60% is regulated by the Forest Department, 29% is unclassified state forest, and the remaining 11% is homestead forest (FAO, 2003). The review of literature for this study is written under following heads-

2.1 Home garden Agroforestry in Bangladesh

2.2 Benefits of Home gardens Agroforestry

2.2.1 Economic benefits

2.2.2 Community benefits

2.2.3 Nutritional benefits

2.2.4 Homestead production system that produces provisioning services

2.2.5 Home garden for employment and economic security

2.2.6 Social benefits to the community

2.2.7 Home garden for soil productivity and improving environment

2.3 Carbon sequestrations and its regulators

2.4 Ecosystem services from home garden agroforestry

2.4.1 Provisioning services

2.4.2 Regulating services

2.5 Problems faced by the respondents for practicing homestead agroforestry

2.6 Probable solutions of problems faced by the respondents

2.1 Home garden Agroforestry in Bangladesh

There are about 85,430 villages and each village contains about 278 homesteads (BBS, 2008). It is the focal point of local socioeconomic activity and traditional cultural legacy in Bangladesh. Locally, the homesteads where the residents reside are referred to as "Bari," and they can be found in individual, cluster, or linear patterns (Hussain and Miah, 2004). In Bangladesh, homesteads are arguably the most significant unit of production, employing over 25.36 million people nationwide, of whom 21.90 million live in rural regions (BBS, 2001). The average size of a rural homestead varies greatly depending on the region and socioeconomic condition, although it is relatively modest (0.02 ha). The north of the country has a minor homestead agroforestry sector because of its socioeconomic situation and climate.

Depending on where it sits, the homestead is elevated above the surrounding fields' flood level. Homestead woods are among the most productive land uses and systems in Bangladesh (Kabir, M. E. & Webb, E.L 2008). Homestead woodlands provide 80–90% of the demand for fuelwood and timber. 0.27 million hectares, or 10% of the total land area and 2% of the tree-based land cover, are homestead forests (Mukul *et al.*, 2014).

An essential component of a farmer's farming system, a typical homestead forest is an addition to the house where carefully chosen trees, shrubs, and herbs are grown for food and income as well as for a variety of outputs with both production and service value, such as aesthetic and ecological advantages. Despite the fact that home gardens are listed as an agroforestry practice in the literature (Nair 2001), it could be more appropriate to say that home gardening is a generic concept much like agroforestry itself.

2.2 Benefits of Home gardens Agroforestry

The home gardens are also significant sources of minerals and nutrients (Asfaw and Woldu, 1997). Traditional home gardens have been shown to be ecologically sustainable (Jose and Shanmugaratnam, 1993). Their benefit include maintenance of soil fertility and soil structure and maintaining nutrient cycling (Schroth *et al.*, 2001). Agroforestry systems may play an important role in mitigating climate change, having the ability to sequester atmospheric carbon dioxide (CO₂) in plant parts and soil.

2.2.1 Economic benefits

Traditionally the home gardens are the production systems that can contribute significantly to the household economy. To a home gardener, the economic value of the crops grown is either what they can be sold for or what he or she would pay to purchase them (Vasey, 1990). Consuming food grown in a home garden can reduce the percentage of the household income spent on food. TGHs can also provide construction materials, medicines, decoration etc., with low input of money, resources and time. Clark (1977) noted that in Pacific Island agro-ecosystems, for every caloric of energy invested, returns ranged from 10-20 food calories. Any time saved can be considered a community benefit as well because the time saved can be spent on other activities (i.e., with family, sharing knowledge, processing foods, generating additional income, etc.).

The percentage of income saved or derived from home gardens is directly related to the diversity of plants in the garden. For example, the more complete the diet grown in a home

garden, the greater the savings as fewer food items need to be purchased (Christanty, 1990). One study found that the produced by THGs supplied anywhere from 3% to 44% of the total caloric intake in a household (Torquebiau, 1992). THGs also have a great potential to substitute for imports because many energy crops- fruits, nuts and staples such as cassava can be easily grown in tropical climates. Such energy crops can substitute for imports in those countries or regions that do not meet their own demands for grains and cereals (Vasey, 1990). This reduced dependency on imports not only increases food security, but also buffers against the economic uncertainty of global food prices, while simultaneously supporting local economies. Although interest in home gardens has been primarily focused on producing subsistence items, its role in generating additional cash income cannot be overlooked (Christanty 1990; Torquebiau 1992; Duty *et al.*, 1996; Mendez *et al.*, 2001). Enormous variations have been reported from different regions in the proportion of home garden products that are used for household consumption as opposed to sale. In West Java, as much as two thirds of the home garden production is reported to be sold (Jensen 1993), but only 28% of such products were sold in south African home gardens, the reminder being used for household consumption (High and Shackleton 2000). The net income generated from home gardens is also correspondingly variable. For example, in Indonesia it ranged from 6.6% to 55.7% of total income with an average of 21.1% depending on the size of the gardens, family needs and species composition (Soemarwoto 1987). Beyond the income saving potential, THGs also have the potential to generate income. Homegardens often produce seasonal surpluses o many crops. If market exits, homegardens can sell produce and non-food crops (timber, medicinal plants, etc.) for supplemental income as needed. Certain cash crops may be integrated into THGs, such as cacao, tea, coffee, and vanilla. The economic gain from selling home garden foods and products varies greatly depending on the size of the garden, the needs of the household, and plant diversity (Nair & Kumar, 2004). For example, in Indonesia the percentage of income generated from the sale of home garden products ranged from 6.6% to 55.7% of total income (Soemaewoto, 1987).

2.2.2 Community benefits

The benefits of home gardens go well beyond property lines and garden walls, as home gardens can benefit an entire community in a variety of ways. The community benefits of THGs can be nutritional, social, and cultural. Often underemphasized, they remain largely unpublicized to beginning home gardeners and policy makers who ultimately dictate the zoning and planning of neighborhood. Before the home gardens got low external inputs,

including seeds, inorganic fertilizers, and pesticides. However, since the home gardens have high diversity of plants, they have high stability, equitability, and resilience (Soemarwoto and Conwey 1992; Kehlenbeck and Maass 2004; Arifin 2013; Iskandar and Iskandar 2016).

2.2.3 Nutritional benefits

A homestead is a habitation with land and structures occupied by the owner, or any dwelling with land and buildings where a family lives. Homesteading is a self-sufficient way of living. It is distinguished by sustenance agriculture, food preservation at home. It may or may not also include small-scale textile and apparel production for domestic use or sale. A home garden is a micro-environment that consists of a multi-species (annual to perennial, root crops to climbers, etc.), multi-stored, and multi-purpose garden located near the homestead (Eyzaguiree *et al.*, 2004). A home garden is the traditional land use system surrounding a homestead in which numerous plant species are produced and maintained by household members and their products are primarily intended for family consumption. Several words, such as homestead garden, have been used to describe these garden production systems. Kitchen gardens, mixed gardens, and garden culture, for example (Mictchell *et al.*, 2004). The home garden is the most sophisticated multi-strata integrated production system, including all farming components (tree, crop, livestock, and occasionally fish) and providing food security, employment, and revenue generation opportunities.

Home gardening can significantly improve health by providing diverse and nutritionally balanced plant based diet. Most of the nutrient loss from fresh produce is due to postharvest handling, storage and processing (Harvard, 2010); thus, consuming produce shortly after it has been picked maximize the nutritional benefits. Home gardens are the pinnacle of fresh and local, as food can be picked right before it is consumed or cooked.

In home gardens or agroforestry systems, tree fruits are increasingly cultivated for securing food and nutrition sources during crisis period of a year when adequate access to food is not possible (Rahman *et al.*, 2012). Homestead gardens provide approximate amount of nutrient during different periods of the year.

2.2.4 Homestead production system that produces provisioning services

Homesteads are multipurpose entities with dwellings, vegetables, spices, fruits and fuel wood/timber species. Historically, Homesteads have been providing multiple products to

the households and meet their diversified need through the production of a wide variety of fruits, vegetables, spices and different tree products (Miah *et al.*, 2002). The prevailing climatic and edaphic conditions of Bangladesh are the key factors for providing such a unique opportunity of producing a wide range of products. It has been reported that homestead production system collectively contributes about 70 percent fruits, 40 percent vegetables, 70 percent timber and 90 percent firewood and bamboo requirement of the country (Miah and Ahmed, 2003).

Home garden is a complex sustainable land use system (Marambe *et al.*, 2012), which generally combines multiple farming components, i.e., annual and perennial crops, trees, shrubs, livestock and fishery. The flow of goods and services from home garden not only provides the household needs and employment support, but also environmental services similar to those of natural forests as a result of being a mixed farming system consisting of fruits, vegetables, trees and animals.

2.2.5 Home garden for employment and economic security

A majority of rural people in Bangladesh who cultivate land for crop production remains unemployed for a considerable period of the year because of seasonality of production activities and labor requirements. Homestead farming is the best answer to such unemployment situation through both vegetable growing, and culture of quick growing fruits enabling the people to remain employed round the year (Ahmed, 1995). It has been over the decades, small-scale homestead activities have become the most significant income generating activities of poor households. For example, over 5 million people in Bangladesh live in the riverine sand silt landmasses. These areas were highly prone to sudden flooding and erosion of land, and makes living in the chars hazardous and insecure. The Helen Keller International's homestead food production program was found to provide support to the fragile livelihood in the chars and improved the well-being of the entire household by promoting low cost technologies for gardening and livestock-raising, improving food security and dietary practices, providing employment for women and a source of income for the household (Helen Keller International, 2003). *Artocarpus heterophyllus* (Jackfruit) based system provides diversified outputs to the growers. The jackfruit is consumed almost as the main food during the main harvesting periods (July-August) and the seeds are used in various cooked forms (Miah and Ahmed, 2003). Average return per decimal of homestead

land is far more than that of large farm-households, possibly due to the more intensive labor inputs on the part of women in poor households (Ahmad, 1995).

2.2.6 Social benefits to the community

There are many social benefits that homegardens offer are very important to building and maintaining community structure and values. While a large percentage of home garden production is consumed domestically (Soemarwoto, 1987), the tendency of home gardens to produce surpluses leads home gardeners to share garden bounty within their community. Such sharing leads to the maintenance of social ties within a community (Thaman, 1990), as well as the spread of nutritious foods and healthy habits. Another social benefit is the educational value of home gardens. Children learn at an early age about how to grow food and where the foods they eat come from as well as continue agricultural traditions.

2.2.7 Home garden for soil productivity and improving environment

The vegetation of homesteads supply nutrients to the soil and recycle through adding organic matter in the form of litter fall, symbiotic nitrogen fixation, root biomass, mycorrhizal association. It increases the water holding capacity of the soil and regulates water runoff. It improves soil properties like soil texture and structure. The homestead vegetation absorbs CO₂ and greenhouse gas like CFC and thus controls air pollution and global warming. Increasing the rainfall, it keeps the environment cool and maintains atmospheric balance.

2.3 Carbon sequestrations and its regulators

Carbon sequestration is natural or man-made process that involves removing carbon dioxide from the atmosphere and storing it in solid or liquid form. Sequestration does not reduce CO₂ emissions; rather it prevents CO₂ from entering the atmosphere (Johnson & Kern, 2002). Carbon sequestration has the potential to significantly reduce carbon levels as power stations and refineries (Caspersen *et al.*, 2000). Homegarden agroforestry practices which integrate trees into agricultural systems, offer a unique opportunity to store soil C while also growing food, diversifying incomes, and simultaneously providing numerous environmental benefits. These include mitigating soil erosion, improving soil structure, pumping up nutrients from the subsoil (Das DK, *et al.*, 2009) and sequestering atmospheric carbon (Kumar BM *et al.*, 1994). It is also likely that the amount of C stored in the soil will depend

on home garden characteristics such as size and age of the holding. Tree species density in homegardens is inversely proportional to the land-holding size (Kumar BM *et al.*, 1994; Mohan S *et al.*, 2007) therefore, smaller-sized homegardens are likely to sequester more soil C per unit area of land compared to larger-sized home gardens. Older home gardens can be expected to store more quantities of soil C than younger ones (Winnas SK, *et al.*, 2015). Agroforestry systems have higher SOC sequestration rates than conventional agricultural systems as the trees these systems tend to have higher litter fall inputs, and deeper rooting systems, and therefore are capable of sequestering C in the surface soil layer (0-30) as well as in deep layers (>30cm) (Nair PKR *et al.*, 2009; Montagnini F, Nair PKR. 2004). On global scale, the total land area under different types of agroforestry systems is estimated to be about 1.6 billion hectares, with a sequestration potential of 1.1-2.2 Pg C in the aboveground biomass over the next 50 years (Lorenz and Lal 2014).

Soil contains the most important long term soil organic reservoir in terrestrial ecosystems. It can able to contain more C than plant biomass and the atmosphere (Schimel, J.P., 1995). Home gardens systems from a common land use practice while most agroforestry systems have great potential for carbon sequestration, home gardens are unique in this respect. They not only sequester carbon in biomass and soil, but also reduce fossil-fuel burning by promoting wood fuel production, and conserve agro-biodiversity (Kumar and Nair 2004).

Soil plays an important role in C sequestration, being able to store 1.5-3 times more C than in vegetation (Young 1997). Carbon is stored in vegetation and in the soil. There are four components of carbon storage in a forest ecosystem. These are trees, plants growing on the forest floor (under-stored material), detritus such as leaf litter and other decaying matter on the forest floor, and forest soils. Plants store carbon for as long as they live, in terms of live biomass. Once they die, the biomass becomes a part of the food chain and eventually enters the soil as soil carbon.

2.4 Ecosystem services from home garden agroforestry

The natural environment provides a wide range of benefits to people. According to MA, ecosystem services are the benefits people receive from ecosystems these services include providing services such as food, and water, regulating services and supporting services such as climate regulation, and cultural services such as recreation. The MA also proposed a framework to study the association of ecosystem services to five components of wellbeing:

material needs, health, social relations, security, and freedom of choice and action (Millennium Ecosystem Assessment, 2005).

2.4.1 Provisioning services

Water, food, wood and other goods are some of the material benefits peoples obtain from ecosystems called provisioning services.

2.4.2 Regulating services

Maintaining the quality of air and soil, providing flood and disease control or pollinating crops are some of the regulating services of ecosystems. They are often invisible and therefore mostly taken for granted. When they are damaged, the resulting losses can be substantial and difficult to restore.

2.5 Problems faced by the respondents for practicing homestead agroforestry (Source; Galhena *et al.*, 2013)

- Limited access to agricultural inputs such as seeds, planting materials, tools and capital
- Shortage of land and lack of land tenure security
- Inadequate access to water
- Damage due to insect, pests, diseases, animals and theft
- Poor environmental conditions
- Lack of knowledge, information, and advisory services
- Shortage of family or labor
- Poor soil fertility and soil erosion
- Limited access to quality livestock breeds
- Limited marketing opportunities
- Excessive post-harvest losses
- Inadequate research and development on home gardens
- Social and cultural barriers
- Lack of information on nutritional benefits of home gardening

2.6 Probable solutions of problems faced by the respondents

- Increase the value of output on a given area of land through spatial or inter temporal intercropping of the species

- Diversifies the range of outputs from a given area, in order to increase self-sufficiency and/or reduce the risk to income from adverse climatic, biological or market impacts on particular crops
- Spreads the needs for labor input more evenly seasonally so reducing the effects of sharp peaks
- Provides productive applications for underutilized land, labor or capital
- Create capital stocks available to meet intermittent cost
- Provide knowledge, information, and advisory services about traditional homestead agroforestry
- Practices proper cultural management (pruning, training, fertilization, irrigation, pest management)
- Proper training of growers, farmers and extension agent
- Maximum use of homestead areas for fruit, tree and vegetable plantation
- Develop proper marketing facilities
- Establishment of processing facilities
- Encouraging export
- Increasing research and extension efforts

CHAPTER III

METHODOLOGY

This chapter focuses on the study's methodology and description of the whole research procedure. This chapter highlights the brief description of the study area, local climatic condition, sampling strategy, data collection procedures, data processing and statistical analyses.

3.1 Brief description of the study area

3.1.1 Location of the study area

The study was conducted at Kajal Dighi village of 4No. Kajal Dighi union under Boda upazilla of Panchagarh district during September 2022 to October 2022. (Fig 3.1) Panchagarh is a district of the Rangpur division in Northern Bangladesh. Panchagarh is the northernmost district of Bangladesh. The total area of the district is 1,404.62 km². It lies between 26°00' and 26°38' north latitudes and in between 88°19' and 88°49' east longitudes. Geographically this land is part of the lower foothills of the Himalayas so comparatively this land is the highest in Bangladesh, lying 150 feet (46 m) above sea level. The soil composition is also distinct with rich sand and stones.

The district is located in the extreme north of Bangladesh, and is bounded on three sides by the 288 km (179 mi) long Indian border, with the Darjeeling district on the north, Jalpaiguri and Cooch Behar districts on the northeast, Uttar Dinajpur on the west, Dinajpur and Thakurgaon districts on the south, and Nilphamari district on the east. Panchagarh has 16 rivers, amongst which are the Karatoya (Karatoa), Atrai, Teesta, Nagor, Mahananda, Tangon, Dahuk, Pathraj, Bhulli, Talma, Chawai, Kurum, Tirnoi, and Chilka. The border of this district was designed by Sir Cyril John Radcliffe in 1947. The length of the border in Panchagarh between Bangladesh and India is 286.87 km (178.25 mi) (Wikipedia).

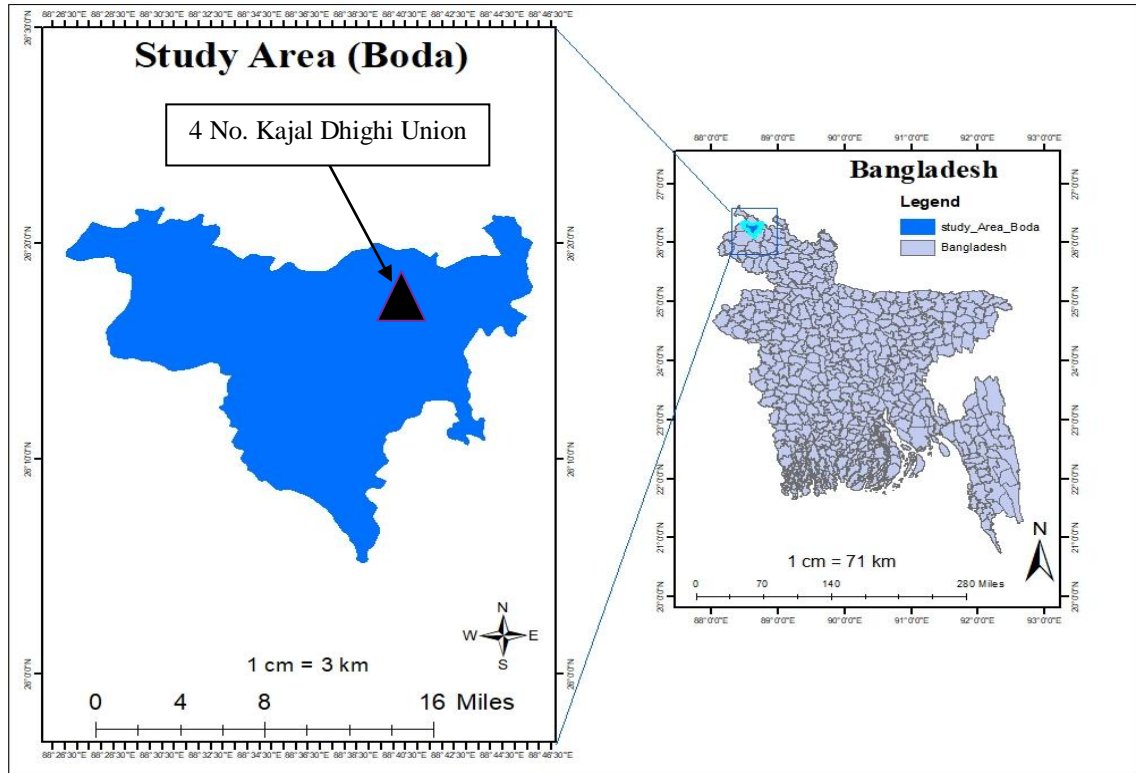


Fig. 3.1 Map showing of Bangladesh and Boda Upazila of Panchagarh District

3.1.2 Climatic scenario of the study area

In Panchagarh, the wet season is hot, oppressive, and mostly cloudy and the dry season is warm and clear. The maximum and minimum average temperature is 30 °C and 17 °C, respectively. Panchagarh receives about 1795.6 millimeters of precipitation (Weather station: Rangpur, Bangladesh). It is among one of the most intensively used agricultural areas in the country consists of two soil physiographic types: Old Himalayan Piedmont plain, Tista Meander Floodplain. The majority of land in this district is highland (58 percent), followed by medium highland (34 percent), and others (8 percent) (BARC, 2005). The homesteads in the study area are predominantly comprised by fruit and timber species.

3.2. Sampling strategy and data collection techniques

3.2.1 Sampling design

Boda Upazilla of Panchagarh district was selected for the study, which is representative of the home gardens of the northernmost region of Bangladesh. Soil samples and information on the plants were gathered using a stratified sampling technique. A multistage random

sampling procedure was used to select the home gardens. To know the biodiversity and ecosystem services, this upazila was selected.

3.2.2 Data collection on diversity attributes of home garden

A 20×20 m sampling plot was laid out in each home garden selected randomly. The surveyed data were recorded which included all woody plants identification, with measurement of height (m), diameter at breast height (DBH, cm) and the area of the homestead forests. The owners of the homestead forests helped in identification with local name, and in few cases, herbarium was prepared to ensure the identification with scientific names. For individual tree species DBH (Diameter at Breast Height) were measured by using DBH tape and height of the species were measured by using Haga altimeter. The coordinates of each point of sample collections were recorded by using GPS. Herbs were not considered as shrubs and trees consist of tree biomass; they may be ignored in estimation of carbon (Ensslin et al., 2015). All perennial trees and shrubs with a diameter at breast height of ≥ 5 cm were identified and recorded to species level or local name.

3.2.3 Soil sample collection and processing

Soil was collected from the plots with a soil auger. Soil was collected from 0-30cm depth from every homegardens, stored in zipper lock bag. Three soil cores were taken from each plot and 63 soil samples for soil moisture and elemental analysis. The soil samples were directly broad into the laboratory; one portion of the sample was used to measure soil moisture and another portion of the soil sample was air dried. Identifiable plant residues, root materials and stones were removed during sieving. Soil samples were later crushed to a fine powder using hammer pestle and stored in zip lock bag for soil chemical analysis.

3.2.4 Estimation of Aboveground Biomass (AGB) and aboveground carbon

Accurate tree biomass estimation is critical and crucial for calculating carbon stock. The non-destructive method of biomass estimation was used to determine the AGB of all documented trees using pantropical allometric equation (Chave et al. 2014).

$$AGB = 0.0673 \times (D^2 \times H \times WD)^{0.976} \quad (1)$$

In this equation, 'WD' is the wood density(gcm^{-3}) collected from global wood density database, 'D' is the DBH measured by dividing the girth at breast height point with 3.1416;

while 'H' is the total plant height. In case of other species, pantropical allometric model was used to measure the AGB.

$$\text{AGB (Kg)} = 4.5 + (7.7H) \quad (2)$$

$$\text{AGB (Kg)} = 10 + (6.5H) \quad (3)$$

Equation (2) and (3) was applied to calculate the AGB of *Cocos nucifera* and *Areca catechu*. The aboveground biomass of individual trees was recorded as AGB, Mg ha⁻¹. Biomass values of each stem were then summed to obtain total aboveground carbon (AGC, Mg ha⁻¹) at plot level, where 50% of the biomass is assumed to be carbon (McGroddy *et al.*, 2004: IPCC, 2006).

3.4 Measurement of soil properties

Standard protocol following Walkley-Black was applied for measuring soil organic carbon (Walkley and Black 1934). Nitrogen and phosphorus content in soil was measured following Kjeldahl (Jackson 1962) and colorimeter digest method (Olsen and Sommer 1982).

3.4.1 Estimation of soil pH

Soil sample was mixed with distilled water with a ratio of 1:2.5 and the mixture was allowed sit for minutes. After that, soil pH was measured by a pH meter (Sonkir pH meter, New York, USA).

3.4.2 Estimation of soil organic carbon and soil organic matter

For the determination of organic carbon, soil samples were air dried for 3 days, gently ground and passed through a 2mm sieve. Identifiable plant residues, root materials and stones were removed during sieving. Soil samples were later crushed to a fine powder using hammer pestle. The organic C content (%) in the crushed soil sample was determined using a modified Mebius method (Nelson and Sommers, 1996). Briefly, 10grams air-dried soil was taken and added 20ml of K₂Cr₂O₇ (potassium dichromate) solution to it. Then, added 20ml of concentrated H₂SO₄ (sulfuric acid) to the soil mixture and shaken it well. Heat the mixture on a hot plate until it turns dark green. It was allowed to cool and then added 200ml of distilled water to it. The absorbance of the mixture could be measured at 600nm using a spectrophotometer, and the organic matter content could be estimated using a calibration

curve. All analyses were carried out at the laboratory of Soil Research, Soil Resources Development /institute (SRDI), Dinajpur, Bangladesh (www.srdi.gov.bd).

10grams air-dried soil was taken and added 20ml of 1N $K_2Cr_2O_7$ (potassium dichromate) solution to it. Then, 20ml of concentrated H_2SO_4 was added (sulfuric acid) to the soil mixture and shaken it well. The mixture was heated on a hot plate until it turns dark green. Then it was allowed to cool and then 200ml of distilled water was added to it. The absorbance of the mixture could be measured at 600nm using a spectrophotometer, and the organic matter content could be estimated using a calibration curve.

3.4.4 Estimation of soil total nitrogen (TN)

The Kjeldahl method is divided into three main steps. The method has to be carried out in proper sequence. The steps include digestion, distillation, and titration. In laboratory 10 grams of air-dried soil was taken and 10 ml of concentrated H_2SO_4 was added (sulfuric acid) to it. Then, 5g of $K_2Cr_2O_7$ (potassium dichromate) was taken with $CuSO_4$ (copper sulfate) was amalgamated and shaken it well. After shaking, 100 ml of distilled water was added and allowed the mixture to sit for 30 minutes. Then the mixture was filtered by using Whatman filter paper, and the nitrogen content in the filtrate could be estimated using the Kjeldahl method.

3.4.5 Estimation of total phosphorus (TP)

Phosphorus content in each sample was determined using the Olsen method to extract the available soil phosphorus (Olsen *et al.*, 1954) and Murphy and Riley method (1962) was used to measure the extracted phosphorus amount. Olsen method was used because the pH of soil samples collection was in the range of 4.4 to 7.1 represents the mild acidic to basic condition. Olsen method was the appropriate and low cost.

Olsen's reagent was made up of sodium bicarbonate and was used for extracting phosphorus from soils with $pH > 6.5$. It also works well with calcareous soil. It was separated Ca-phosphates, Al-phosphates and Fe-phosphates in the soil by precipitating Ca as $CaCO_3$. Thus, extract obtained by adding Olsen's reagent to soil and filtering the content contains our required phosphorus which is further treated with ammonium molybdate to obtain blue colored solution of phosphor-molybdate complex. The intensity of the blue color provides a measure for the concentration of P, in the test solution.

3.4.6 Estimation of soil total Potassium (TK)

Available potassium in soil was determined (ammonium acetate extractable) by flamephotometer (Pansu and Gautheyrou 2006).

Available potassium in soil was extracted using ammonium acetate solution. Ammonium acetate when mixed in soil reacts with potassium compounds in the soil to form potash. The potassium from potash is then detected using flame photometry.

25ml extracting solution was added to 5g soil and shaken it for 5 min. Filtered the contents and collect the filtrate. Atomized the above extract on flame photometer and recorded the reading. And determine this formula:

$$\text{Available K} = R \times \frac{\text{Volume of extract soil solution}}{\text{soil weight}} \times 2.24 \times 10^6 \times 10^{-6}$$

Where R is the concentration in ppm from the standard curve.

3.5 Statistical analysis

The socioeconomic data were coded for statistical analysis. Frequency tests on socioeconomic parameters were conducted using SPSS software. The problem-finding index was calculated based on Hanif et al. (2018). The average height, DBH and carbon stock were also analyzed on SPSS software. Pearson correlation test was conducted to find relationships among different structural and soil parameters.

CHAPTER IV

RESULT AND DISCUSSION

4.1 Demographic characteristics of the respondents

4.1.1 Age

The age of the respondents of the study area ranged from 20 to 71 years, having mean age 45.59 years (Table 4.1). The age of the respondents was further categorized into three categories. Maximum number (39.4%) of the respondents was equally from middle and old age group while 21.2% of the respondents were from young aged group (Table 4.1).

4.1.2 Family size

The number of family members of the respondent ranged from 2 to 13 with a mean of 5 (Table 4.1). The family size of the respondents was also categorized into three categories. Among the respondents, 49% belongs to small family followed by 32.7% from medium sized family and 18.3% were from large sized family (Table 4.1).

4.1.3 Education

The education level of the study area ranged from 0.5 to 18, with a mean value of 6.85 (Table 4.2). The education level was categorized into five categories. Among these, no illiterate respondents were found in the study area, 39.4% of the respondents were from secondary level (6-10), 26.9% were from can sign only (0.5), 17.3% were from above secondary level (>10) and 16.3% of the respondents were from primary level (1-5) (Table 4.1).

4.1.4 Farm size

The farm size of the study area ranged from 0.2 to 8.28ha with a mean value of 0.89ha (Table 4.1). In the table farm size was categorized into five categories. The respondents 43.3% were from marginal (0.201-0.6) sized farm, 21.2% and 15.4% of the respondents were from the small (0.601-1.0) and landless (<0.2), 13.5% and 6.7% of the respondents were from medium (1.01-2.5) and large (>2.5) sized farm (Table 4.1).

Table 4.1 Descriptive statistics showing the demographic characteristics of the respondents in the study area

Characteristics	Scoring method	Ranged observed	Categories	Respondents		Mean	SD
				No.	Percent		
Age	No. of year	20-71	Young (18-35)	22	21.2	45.59	12.533
			Middle (36-50)	41	39.4		
			Old (>50)	41	39.4		
Family size	Number	2-13	Small (<4)	51	49.0	5.00	2.151
			Medium (4-6)	34	32.7		
			Large (>6)	19	18.3		
Education	Year of Schooling	0.5-18	Illiterate (0.0)	0	0	6.85	5.379
			Can sign only (0.5)	28	26.9		
			Primary level (1-5)	17	16.3		
			Secondary level (6-10)	41	39.4		
			Above secondary level (>10)	18	17.3		
Farm size	Hectares	0.2-8.28	Landless (<0.2)	16	15.4	0.89	1.259
			Marginal (0.201-0.6)	45	43.3		
			Small (0.601-1.0)	22	21.2		
			Medium (1.01-2.5)	14	13.5		
			Large (>2.5)	7	6.7		
Family income	“000” Taka	20-1080	Low (<120)	62	59.6	165.50	186.98
			Middle (120-240)	24	23.1		
			High (>240)	18	17.3		

4.1.5 Family income

Table 4.1 shows the Family income of the respondents in the study area ranged from 20-1080 thousand taka, having a mean of 186.98 thousand taka. The respondents were categorized into three categories. 59.6% of the respondents from low (<120) income followed by 23.1% and 18% of the respondents were from middle (120-240) and high (>240) income categories (Table 4.1).

4.2 Farming experience

The farming experience of the study area ranged from 0 to 60 years, with a mean value of 29.25 years (Table 4.2). It was also categorized into three categories. 62.5% of the

respondents had farming experiences of four decades, 29.8% and 7.7% of the respondents had two and more than four decades of farming experiences (Table 4.2).

Table 4.2 Descriptive statistics showing the farm experience of the respondents in the study area.

Characteristics	Scoring method	Ranged observed	Categories	Respondents		Mean	SD
				No.	Percent		
Farming experience	Years	0-60	2 decades	31	29.8	29.25	14.26
			4 decades	65	62.5		
			>4 decades	8	7.7		

4.3 AGF Farming Experience

The AGF farming experience of the study area was ranged from 3 to 60 years, having the mean 29.08 years (Table 4.3). It was categorized into three categories: 63.5% of the respondents were from four decades, 29.8% and 7% of the respondents were from two decades and more than four decades of categories (Table 4.3).

Table 4.3 Descriptive statistics showing the AGF farm experience of the respondents in the study area

Characteristics	Scoring method	Ranged observed	Categories	Respondents		Mean	SD
				No.	Percent		
Agroforestry farming experience	Years	3-60	2 decades	31	29.8	29.08	14.025
			4 decades	66	63.5		
			>4 decades	7	6.7		

4.4 Valuation of ecosystem services derived from homestead forests

The results from this study show that perceived ecosystem services supply from the homegardens.

4.4.1 Provisioning services:

Table 4.4 shows the provisioning services of homegardens as perceived by the respondents. The respondents mentioned the provisioning services (PS) supply was moderate (69.23%); the food supply (69.2%), quality of food (71.2%) and fuelwood supply (67.3%) also in moderate category. A remarkable number of species in the study area provide multiple provisioning services, for example, *Artocarpus heterophyllus*, *Areca catechu*, *Cocos nucifera*, *Mangifera indica*, *Spondias pinnata*, *Zizipus mauritiana* etc. Respondents reported that these tree species had utility values as fruits, timber, medicine, fodder and fuelwood. (Table 4.4).

Table 4.4 Showing the households perception of ecosystem services from homegardens of the study area.

Ecosystem services	High (%)	Moderate (%)	Little (%)	No change (%)
Provisioning services (PS)				
Food supply	4.9	69.2	14.4	11.5
Quality of food	2.9	71.2	20.2	5.8
Fuelwood supply	22.1	67.3	8.7	1.9
Total average of PS	9.97	69.23	14.43	6.4
Regulating services (RS)				
Cooling effect	26.9	56.7	12.5	3.8
Local climate regulation	48.1	45.2	2.9	3.8
Biodiversity conservation	17.3	64.4	13.5	4.8
Protection from disaster	31.7	57.7	9.6	1.0
Total average of RS	31	56	9.63	3.35
Cultural services (CS)				
Aesthetic value	9.6	67.3	18.3	4.8
Relax and stress reduction	44.2	40.4	8.7	6.7
Total average of CS	26.9	53.85	13.5	5.75

4.4.2 Regulating services

The regulating service supply from home gardens were moderate to high category (Table 4.4). The majority of respondents mentioned moderate regulating service supply. The local climatic regulation was high (48.1%); cooling effect (56.7%), biodiversity conservation (64.4%) and protection from disaster (57.7%) were in moderate category.

4.4.3 Cultural services

The cultural services supply from home gardens was moderate (53.85%). Aesthetic value (67.3%) was in moderate, relax and stress reduction (44.2%) was in high category (Table 4.4).

The individual ecosystem service supply from the home gardens were almost similar; numerically regulating service (36%) supply was higher followed by provisioning (34%) and cultural services (30%) (Fig.4.1).

The ecosystem of the homestead forests of the study area serves various types of provisioning services to the community people. Homestead forests were found as a source of fuelwood, different types of seasonal fruits and building materials in their daily life.

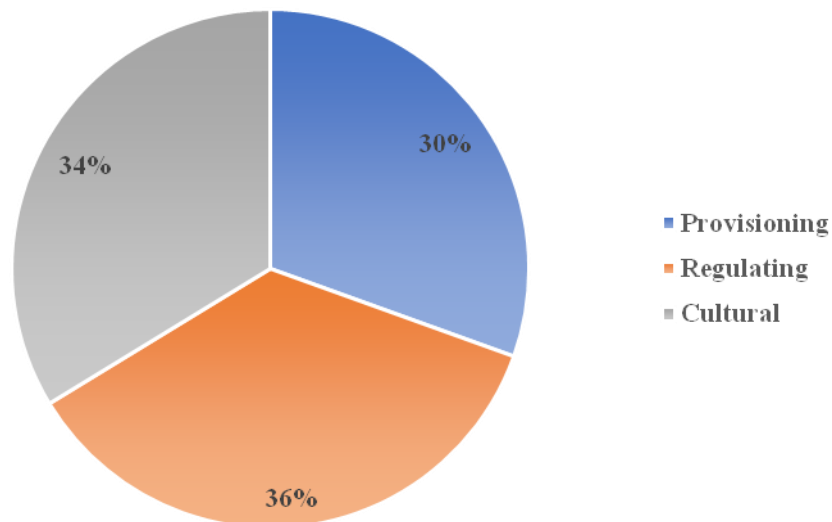


Fig. 4.1 Valuation of Ecosystem services derived from homestead forests

4.5 Problems faced by the respondents for practicing homestead agroforestry

From the problem finding index (PFI), the major problems faced by the respondents was lack of training (289.4) of the study area followed by attack of insect, pest and diseases (282.7), less production (251.9), shade created by trees (181.5), lack of quality planting materials (179.7), competition for nutrients (173.1), root competition (172.2), free grazing of animals (134.6), allelopathic effect (113.3) (Table 4.5).

Other includes weather and climatic hazards, labour insufficiency, seed unavailability, insufficient support from different agencies, gardening tools, thief, unfit plot. Lack of

proper irrigation facility, inaccessibility of technical manpower in crop protection and labour migration might be the findings of Marsh (1998) and Pandey et.al. (2007).

Table 4.5 Problem finding index (PFI)

Problems	PFI
Attack of insect, pest and diseases	282.7
Free grazing of animals	134.6
Shade created by the trees	181.5
Root competition	172.2
Competition for nutrients	173.1
Less production	251.9
Allelopathic effect	113.3
Lack of quality planting materials	179.7
Lack of training	289.4

4.6 Descriptive statistics showing tree structural, aboveground biomass and carbon sequestration

The presented table shows the descriptive statistics of the variable Height, DBH, AGB and AGC of the tree species in the study area.

Table 4.6 Descriptive statistics showing species Height, DBH, AGB and AGC composition of the study area

Variables	Unit	Minimum	Maximum	Mean	SE Mean
Height	meter	2.29	11.99	8.23	0.416
DBH	cm	2.31	21.96	14.17	0.224
AGB	Mgha ⁻¹	0.29	90.75	27.00	2.137
AGC	Mgha ⁻¹	0.14	42.65	10.78	1.169

The minimum and maximum values of height were 2.29 and 11.99 meters, with a mean of 8.23meters. The mean DBH was 14.17 cm, with a range of 2.31-21.96 cm. And respectively the mean AGB and AGC were 27.00g and 10.78g with a range of 0.29-90.75g and 0.14-42.65g.

The results of this study comparing with other regions in Bangladesh, it is important to note that the tree species, soil types and climate conditions may vary significantly between regions, which can impact the results. For instance, a study conducted in Rajshahi reported a mean tree height of 7.35 meters and a mean DBH of 11.07cm for six species of trees (Hossain *et al.*, 2016), while a study in Chittagong reported a mean tree height of 4.1 meters and a DBH of 6.4 cm for six species of trees (Kabir *et al.*, 2018). In the comparison to these studies, the mean height and DBH of trees in the study area were higher, which may be due to differences in species composition or environmental factors. Globally, the results of this study are consistent with other studies that have found a positive correlation between tree diversity and AGB and AGC in agroforestry systems (Rahman *et al.*, 2018, Tan *et al.*, 2019). In particular, a study conducted in Indonesia found that higher tree diversity was associated with higher soil organic carbon content (Syakir *et al.*, 2020). This suggests that tree diversity may play an important role in improving soil quality and carbon sequestration in agroforestry systems.

The results of this study demonstrate that the height, DBH, AGB and AGC of tree species in the homegarden agroforestry system in northern Bangladesh vary widely, and are generally higher in other regions of Bangladesh. However, the results are consistent with other studies globally that have found positive relationship between tree diversity and soil organic content in agroforestry systems. The findings of this study underscore the importance of promoting tree diversity in agroforestry systems to enhance soil quality and carbon sequestration.

4.7 Descriptive statistics potential soil parameters regulating carbon stock

The presented table (Table 4.7) showed the soil properties such as pH, soil organic carbon (SOC), soil organic matter (SOM), total nitrogen (TN), total phosphorus (TP) and total potassium (TK) of the study area.

Table 4.7 Descriptive statistics showing composition soil pH, SOC, SOM, TN, TP, TK of the study area-

Variables	Unit	Minimum	Maximum	Mean	SE Mean
pH		4.55	6.42	5.46	0.049
SOC	%	0.16	2.19	1.27	0.053
SOM	%	0.28	3.78	2.09	0.102
TN	%	0.01	0.28	0.11	0.005
TP	µg/g	22.14	89.8	62.51	2.147
TK	meq/100g of soil	0.14	1.24	0.49	0.035

Note. SOC= Soil Organic Carbon, SOM= Soil Organic Matter, TN= Total Nitrogen, TP= Total Phosphorus, TK= Total Potassium.

In the context of home garden agroforestry, soil properties are crucial for plant growth and productivity. pH is an important soil parameter, as it affects the availability of nutrients to the plants. In this study, the pH of the soil ranged from 4.55 to 6.42, with a mean value of 5.46, including slightly acidic to slightly alkaline soil conditions. SOC and SOM are important indicators of soil quality and fertility, which influence soil structure and nutrient cycling. The mean value of SOC and SOM in the study area were 0.053 and 0.102%, respectively. The TN value ranged from 0.01 to 0.28%, with a mean value of 0.11%, indicating low nitrogen content in the soil. The TP value ranged from 22.14 to 89.8 µg/g, with a mean value of 62.51 µg/g, indicating high phosphorus content in the soil. The TK value ranged from 0.14 to 1.24 meq/100g, with a mean value of 0.49 meq/100g, indicating low potassium content in the soil (Table 4.7).

The soil pH and TN values in the study area are similar to those reported by Hasan et al. (2020) in their study on home garden agroforestry in the Chittagong Hill Tracts region. However, the SOC and SOM values in the study area are lower than those reported by Hasan et al. (2020), indicating poorer soil quality in the study area. In a global context, the soil properties in the study area are similar to those reported by Jha et al. (2017) in their study on home garden agroforestry in Nepal.

Table 4.8 Descriptive statistics showing correlations between the compositions of the study area-

	AGB	AGC	Height	DBH	PH	OC	OM	TN	TP	TK
AGB	1	.893**	.465**	0.239	-.305*	0.049	0.097	0.01	0.07	-0.241
AGC	.893**	1	.408**	.249*	-.388**	0.044	0.075	0.042	0.004	-0.178
Height	.465**	.408**	1	.461**	-0.203	-0.102	0.009	-0.166	0.144	0.044
DBH	0.239	.249*	.461**	1	-.310*	0.147	0.174	0.082	0.169	-0.017
PH	-.305*	-.388**	-0.203	-.310*	1	-0.183	-0.09	-.292*	-0.125	.325**
OC	0.049	0.044	-0.102	0.147	-0.183	1	.875**	.869**	-0.108	0.126
OM	0.097	0.075	0.009	0.174	-0.09	.875**	1	.552**	0.003	0.17
TN	0.01	0.042	-0.166	0.082	-.292*	.869**	.552**	1	-0.14	0.073
TP	0.07	0.004	0.144	0.169	-0.125	-0.108	0.003	-0.14	1	-0.025
TK	-0.241	-0.178	0.044	-0.017	.325**	0.126	0.17	0.073	-0.025	1

The table 4.8 shows the correlation among the composition in the analyzed study. The result indicated a strongly significant positive relationship was obtained for the above ground biomass (AGB) with above ground carbon (AGC), and plant height. On the other hand, a significant negative relationship was obtained for AGB and pH. The result indicated a strongly significant positive relationship was obtained for AGC with AGB and plant height, and a significant positive relationship between AGC and DBH. On the other hand, a strongly significant negative relationship between AGC and pH was found.

There is a strongly significant positive relationship was obtained for plant height with AGB, AGC and DBH. A strongly significant correlation was found DBH with height, a significant positive relation between DBH and AGC. On the other hand, a significant negative correlation was obtained for DBH and pH (Table 4.8).

From the result of the analysis presented in Table 4.8, it is showed that there is a strongly significant negative relationship between pH and total AGC and a strongly significant

positive relationship between pH and total potassium (TK). There is also significant negative correlation was obtained for pH with AGB, DBH, and TN. There is a strongly significant positive relationship was obtained for organic carbon (OC) with organic matter (OM) and total nitrogen (TN).

From the table 4.8 there is a strongly significant positive relationship was found for organic matter (OM) with organic carbon (OC) and total nitrogen (TN). Again there is a significant negative relationship between total nitrogen (TN) and pH. In essence, 1% increases the TN causes the pH decreases by 0.292. And there is also a strongly significant positive relationship between total nitrogen (TN) and organic carbon (OC), total nitrogen (TN) and organic matter (OM).

In the table 4.8, there is no significant relationship between total phosphorus (TP) and others. And lastly, there is a strongly significant positive relationship between total potassium (TK) and pH (Table 4.8).

The positive correlation may indicate the presence of one value could be the reason of the other to be higher and for the negative correlation, the existence of one value could be the reason that the other be lower. In addition to this, no significant correlation indicates that the presence of one value has no role in the existence of the other value.

CHAPTER V

SUMMARY AND CONCLUSION

5.1 Summary

The experiment was conducted at Kajal Dighi village of 4no. Kajal Dighi union under Boda upazilla of Panchagarh district during September 2022 to October 2022. Panchagarh is a district of the Rangpur division in Northern Bangladesh. Panchagarh is the northernmost district of Bangladesh. The total area of the district is 1,404.62 km². It lies between 26°00' and 26°38' north latitudes and in between 88°19' and 88°49' east longitudes. Geographically this land is part of the lower foothills of the Himalayas so comparatively this land is the highest in Bangladesh, lying 150 feet (46 m) above sea level. The soil composition is also distinct with rich sand and stones. Boda Upazilla of Panchagarh district was selected for the study, which is representative of the home gardens of the northernmost region of Bangladesh. Soil samples and information on the plants were gathered using a stratified sampling technique. A multistage random sampling procedure was used to select the home gardens. To know the biodiversity and ecosystem services, this upazila was selected. A 20×20 m sampling plot was laid out in each home garden selected randomly. The surveyed data were recorded which included all woody plants identification, with measurement of height (m), DBH (cm) and the area of the homestead forests. The owners of the homestead forests helped in identification with local name, and in few cases, herbarium was prepared to ensure the identification with scientific names. For individual tree species DBH were measured by using DBH tape and height of the species were measured by using Haga altimeter. The co-ordinates of each point of sample collections were recorded by using GPS. All perennial trees and shrubs with a diameter at breast height of ≥ 5 cm were identified and recorded to species level or local name. Soil was collected from the plots with a soil auger. Soil was collected from 0-30 cm depth from every home garden, stored in zipper lock bag. Three soil cores were taken from each plot and 63 soil samples for soil moisture and elemental analysis. The soil samples were directly broad into the laboratory; one portion of the sample was used to measure soil moisture and another portion of the soil sample was air dried. Identifiable plant residues, root materials and stones were removed during sieving. Soil samples were later crushed to a fine powder using hammer pestle. The organic C content (%) in the crushed soil sample was determined.

The age of the respondents was categorized into three categories. Maximum number (39.4%) of the respondents was equally from middle and old age group while 21.2% of the respondents were from young aged group. Among the respondents, 49% belongs to small family followed by 32.7% from medium sized family and 18.3% were from large sized family. The education level was categorized into five categories. Among these, no illiterate respondents were found in the study area, 39.4% of the respondents were from secondary level (6-10), 26.9% were from can sign only (0.5), 17.3% were from above secondary level (>10) and 16.3% respondents were from primary level (1-5). The respondents 43.3% were from marginal (0.201-0.6) sized farm, 21.2% and 15.4% of the respondents were from the small (0.601-1.0) and landless (<0.2), 13.5% and 6.7% of the respondents were from medium (1.01-2.5) and large (>2.5) sized farm. The Family income of the study area ranged from 20-1080 thousand taka, having a mean of 186.98 thousand taka. In where, the respondents were categorized into three categories. 59.6% of the respondents from low (<120) income followed by 23.1% and 18% of the respondents were from middle (120-240) and high (>240) income categories. The farming experience of the respondents in the study area ranged from 0 to 60 years and the AGF farming experience in the study area ranged from 3 to 60 years.

The respondents mentioned of provisioning service (PS) supply was moderate (69.23%); the food supply (69.2%), quality of food (71.2%) and fuelwood supply (67.3%) also in moderate category. The regulating and cultural services were also in moderate category. Maximum above ground biomass (AGB) was 90.75 Mgha^{-1} and the above ground carbon (AGC) was 42.65 Mgha^{-1} .

In the context of home garden agroforestry, soil properties are crucial for plant growth and productivity. pH is an important soil parameter, as it affects the availability of nutrients to the plants. In this study, the pH of the soil ranged from 4.55 to 6.42, with a mean value of 5.46, including slightly acidic to slightly alkaline soil conditions. SOC and SOM are important indicators of soil quality and fertility, which influence soil structure and nutrient cycling. The mean value of SOC and SOM in the study area were 0.053 and 0.102%, respectively. The TN value ranged from 0.01 to 0.28%, with a mean value of 0.11%, indicating low nitrogen content in the soil. TP value ranged from 22.14 to 89.8 $\mu\text{g/g}$, with a mean value of 62.51 $\mu\text{g/g}$, indicates high phosphorus content in the soil. The TK value ranged from 0.14 to 1.24 meq/100g, with a mean value of 0.49 meq/100g, indicating low potassium content in the soil.

Strong positive correlations was for AGB with AGC and pH, AGC with AGB and height, height with AGB ,AGC and DBH, pH and TK, OC with OM and TN, OM with OC and TN, TN with OC and OM, TK and pH. And there is no correlation between total phosphorus (TP) and others. There is also a negative correlation between AGB and pH, DBH and pH, pH and TN, and strongly significant correlation pH and AGC.

5.2 Conclusion

The study unveiled that homestead agroforestry possess good potential for providing different ecosystem services. Homestead agroforestry of Panchagarh district, Bangladesh provides a wide range of goods and services which categorized in three categories, provisioning services, regulating services and cultural services. There are various types of provisioning services include consumption of fruits, collection of fuelwoods, timber and wood etc. Villagers could also sell some amount of fruits and other provisions after their consumption. As homestead forests appeared as a source of food, timber, as well as substantial income, government and other non-government organizations can work together for a planned and productive homestead ecosystem in Bangladesh. Such initiative will largely contribute in rural development and poverty alleviation. Moreover, biodiversity conservation and carbon sequestration are crucial ecological benefits derived from homestead forests. Thus promoting such household based forestry activities will contribute largely to tackle future environmental challenges.

5.3 Recommendation

- The Northern Bangladesh needs more detailed investigation for current homestead forest measurements to be able to clearly report the amount of soil organic carbon and biomass.
- Agroforestry practices that integrate trees into the existing farmland. This can increase the provisioning services and other potential benefits for human being and environmental sustainability.

Limitations of the study:

This study looked at people's perceptions on various ecosystem services of homegardens. However, we could not quantify the total economic value of these ecosystem services. A study on the economic valuation of ecosystem services of homegardens deserves future study. Even though respondents reported that homegardens were declining, a spatial analysis of the trends of homestead gardens would provide useful information on changes and drivers.

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APPENDICES

Appendix-I: Problems faced by the respondents for practicing homestead agroforestry

Extent of problems				
Problems	High	Medium	Low	No
Attack of insect, pest and diseases	85.6	11.5	2.9	0.0
Free grazing of animals	0.0	39.4	55.8	4.8
Shade created by the trees	3.8	74.0	22.1	0.0
Root competition	1.0	70.2	28.8	0.0
Competition for nutrients	2.9	67.3	29.8	0.0
Less production	56.7	38.5	4.8	0.0
Allelopathic effect	3.8	22.1	57.7	16.3
Lack of quality planting materials	11.5	59.6	26.0	2.9
Lack of training	94.2	1.0	4.8	0.0

Appendix-II: Questionnaire for data collection

An interview schedule on

Unveiling potential regulators of above and below-ground carbon sequestration and ecosystem services of homegarden agroforestry of northern Bangladesh

SI No. : _____
Name of the respondent : _____ **Village** : _____
Union : _____ **Upazilla** : _____
Occupation : _____ **House type** : _____

1.Age	2.Family size		3. Farming experience	4. AGF farming experience
	Male	Female		

5. Educational Qualification

- a. Cannot read & write (YES/NO)
- b. Can sign name only (YES/NO)
- c. I have passed class.....

6. Farm size: Please indicate of your land according to use

Sl. No.	Use	Local Unit	Hectare
1.	Homestead area		
2.	Own land under own cultivation		
3.	Land taken from others as lease		
4.	Land taken from others as borga		
5.	Land given others from borga		
6.	Land use under AGF		
	Total land (Equation)		

7. Annual income: please indicate the production & income of your family has earned last year from different source

Sl.	Source of income	Production (kg)	Market price (Tk.)	Total price (Tk.)
A.	Agriculture			
B.	Service			
C.	Business			
D.	Others(please specify)			
	Total income			

8. Farm area under agroforestry system

Sl. No.	Use	Local unit	Hectare
	Homestead agroforestry		
	Cropland agroforestry		
	Mixed fruit garden		
	Others		

10. Ecosystem service derived from homestead forests

	High	Moderate	Little	No Change
Provisioning services				
Food supply				
Quality of food				
Fuelwood supply				
Total avg. of PS				
Regulating services				
Cooling effect				
Local climate regulation				
Biodiversity conservation				
Protection from disaster				
Total avg. of RS				
Cultural services				
Aesthetic value				
Relax and stress reduction				
Total avg. of CS				

11. Problems faced by the respondents for practicing homestead agroforestry

Problems	Extent of problems			
	High	Medium	Low	No
Attack of insect, pest and diseases				
Free grazing of animals				
Shade created by the trees				
Root competition				
Competition for nutrients				
Less production				
Allelopathic effect				
Lack of quality planting materials				
Lack of training				

12. Opinion of respondents about agroforestry

- 1.....
- 2.....
- 3.....
- 4.....

Biophysical information of homestead agroforests

Appendix-III: Some plates of experiments



Plate 1: Soil Sampling Procedure



Plate 2: Data Collection From Homestead Area