EVALUATION OF PRODUCTIVITY, PROFITABILITY, AND LAND USE EFFICIENCY OF DIVERSE TREE-BASED MULTISTORIED AGROFORESTRY SYSTEMS

A THESIS

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MASTER OF SCIENCE

IN

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HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY UNIVERSITY, DINAJPUR-5200

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Submitted to the department of Agroforestry and Environment, Hajee Mohammad Danesh Science and Technology University, Dinajpur in partial fulfillment of the requirements of the degree of

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TO

MY BELOVED PARENTS

DECLARATION

I hereby declare that the work presented in this thesis titled "EVALUATION OF PRODUCTIVITY, PROFITABILITY, AND LAND USE EFFICIENCY OF DIVERSE TREE-BASED MULTISTORIED AGROFORESTRY SYSTEMS" has been carried out by myself and that it has not been submitted for any previous degree. All quotations have been distinguished by quotation marks and all sources of infom1ation specifically acknowledged by references to the authors.

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EVALUATION OF PRODUCTIVITY, PROFITABILITY, AND LAND USE EFFICIENCY OF DIVERSE TREE-BASED MULTISTORIED AGROFORESTRY SYSTEMS

ABSTRACTS

Multistoried agroforestry systems involve the integration of multiple layers of vegetation within an agricultural or forestry setting for increasing productivity, profitability, diversifying products, promoting land use efficiency and providing ecological service. Therefore, it is important to explore the benefits and opportunities offered by diverse agroforestry systems. A field experiment was carried out at the Agroforestry Research Field, Hajee Mohammad Danesh Science &Technology University in Dinajpur from April 2023 to July 2023 to study the performance of Snake gourd and stem amaranth in association with mango, litchi and mahogany trees as agroforestry system. The experiment was set following Randomized Complete Block Design (RCBD) with three replications. The five treatments were T_1 = Mango trees + Snake gourd + Stem amaranth, T_2 = Litchi trees + Snake gourd + Stem amaranth, T_3 = Mahogany trees + Snake gourd + Stem amaranth, T_4 = Sole cropping of snake gourd, T_5 = Sole cropping of Stem amaranth. The data on growth, yield contributing characters and yield of Snake gourd and Stem amaranth were collected during this study with or without mango, litchi and mahogany tree combinations. The results of this study revealed that the growth parameters and yield of Snake gourd were found maximum in mango tree-based agroforestry systems i.e. in T_1 and the yield was 22.50 ton ha^{-1} while the lowest yield (9 ton ha^{-1}) was recorded in the sole cropping of snake gourd. In the case of stem amaranth growth, yield attributes and yield (18.99 ton ha^{-1}) were maximum in the mango tree-based agroforestry systems, i.e. T_1 (Mango + Snake gourd + Stem amaranth). The maximum gross return was found in T_3 (1015650 Tk. ha^{-1}) and the lowest gross return was calculated from T_5 (147100 Tk. ha^{-1}). The net return was highest in T_3 (723180 Tk. ha^{-1}) and lowest in T_5 (-13160 Tk. ha^{-1}). The Mahogany - Snake gourd – Stem amaranth (T_3) multistoried agroforestry system performed the best, with a benefit-cost ratio (BCR) of 3.47. However, land equivalent ratio (LER) was the highest (3.04) in T_2 (litchi – snake gourd – stem amaranth) agroforestry system. In a concluding remark, the research indicated that growing vegetables in the form of a multistory agroforestry system may result in increased yields and ensure economic benefits which can support food security and availability, and offer socially beneficial regulating functions.

Key words: Multistoried agroforestry, Productivity, Snake gourd, Stem amaranth, Profitability

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ABBREVIATIONS

AEZ	: Agro-Ecological Zone
AGF	: Agroforestry
BARI	: Bangladesh Agricultural Research Institute
BBS	: Bangladesh Bureau of Statistics
BCR	: Benefit-cost Ratio
cm	: Centimeter
DAP	: Days after Planting
Fer	: Fertilizer
FAO	: Food and Agriculture Organization
g	: Gram
GR	: Gross return
Init	: Initial
IBL	: Interest on bank loan
IVL	: Interest on value of land
IPC	: Initial planting cost
IR	: Irrigation
K	: Potassium
Kg	: Kilogram
m	: Meter
MC	: Maintenance Cost
MIC	: Material Input cost
MiSC	: Miscellaneous cost
NMIC	: Non-material input cost
OC	: overhead cost
Pest	: Pesticide
Tk/tk	: Taka
TSP	: Tripple super phosohate
TNMIC	: Total non –material input cost
TIC	: Total input cost
TCP	: Total cost of production
t/ha^{-1}	: Ton Per hectare

CHAPTER I

INTRODUCTION

The United Nations sustainable development goals and Agenda 2030 include poverty eradication, ending hunger, and environmental restoration, among other objectives (UN, 2015). Related targets are to implement resilient agricultural practices that increase productivity and to maintain ecosystems that strengthen the capacity for adaptation to climate change and risks and improve land health (UN, 2015). Bangladesh, a densely populated South Asian country, has experienced significant demographic changes over the past few decades. As of 2023, the population of Bangladesh has surpassed 170 million, making it one of the most densely populated countries globally (World Bank, 2023).It is fraught with difficulty feeding the escalating population. Food production should be twice by cultivating crops to feed this growing population. According to the Bangladesh Bureau of Statistics (BBS), the total cultivated land in Bangladesh is a critical aspect of its agricultural sector and food security. As of the latest data, Bangladesh has approximately 13.5 million hectares of total cultivable land, out of which about 11.12 million hectares are actively used for agricultural purposes (Bangladesh Bureau of Statistics, 2022). Due to its high population density, it has the lowest per capita arable land, which has risen in the previous fifty years despite a drop in the annual population growth rate from 2.02% in 1971 to 1.22% in 2022 (BBS, 2022). "Again, agricultural production is not increasing expectedly in the background of the overgrowing population. Agriculture is a major source of income and is strongly related to the security of food and nutrients (Rahman *et al.*, 2017). A fall in agricultural output would occur in tandem with a reduction in the amount of arable land under the current scenario of rising human population and unpredictability of the climate. It is shrinking at an alarming rate of 0.005 ha/ head/ year (Ahmed *et al.*, 2019). Surprisingly, the country has impressively grown food grain output during the previous 20 years, approaching self-sufficiency at the national level, by producing around 28 million metric tons of grains, principally rice and wheat (statistics BB; Islam *et al.*, 2016) as well as a decrease in the number of people living in poverty. Despite significant progress in lowering poverty and raising agricultural output, 25% of the population is still although grain production increased, food and nutrition security remain challenged because of scarce fruits and vegetable production against huge demand. Consequently, this rapid population growth exerts tremendous pressure on the country's forestland, with approximately 7,300 hectares lost annually due to the increasing demand for agricultural land, aquaculture, and homesteads

(Khan, 2019; Muhsin *et al*., 2018; Rahman *et al*., 2016). The average consumption of vegetables in Bangladesh is only 70g per head per day including potato and sweet potato. Except for tuber crops, it is only 30g as against the FAO recommendation of 200g. To supply the minimum daily requirement of 200g vegetable/head/day, national production of vegetable should be over 10 million tons in addition. Population of Bangladesh is increasing rapidly; therefore, demand for vegetable is increasing simultaneously. The production of vegetables and fruit tree plantations is essential due to the rising demand for fruits and vegetables. In Bangladesh, Agroforestry efforts are also essential for preserving biodiversity and ecological equilibrium. Consequently, there is an immense strain on the nation's natural resources.

Combining forestry with agricultural crops can offer a stable economic foundation, improved crop and animal productivity, and more variety in long-term societal benefits. It is necessary to adopt sustainable cropping practices to increase productivity. So, climate-smart agricultural technologies like agroforestry would ensure sustainable crop production (Chowdhury and Hasan, 2013). Agroforestry involves the cultivation and use of trees in farming systems and is a practical and low-cost means of implementing many forms of integrated land management, especially for small-scale producers (Leakey, 2010). Agroforestry is found to be one of the appropriate means of achieving sustainable production without causing any environmental destruction (Padmavathy and Poyyamoli, 2013). According to Dhyani *et al*. (2009) agroforestry is a key path to prosperity for millions of farm families, leading to extra income, employment generation, greater food and nutritional security and meeting other basic human needs in a sustainable manner. In addition to satisfying basic human needs, agroforestry has positive impacts on the conservation of the natural resource base and in the protection of the environment (Ajayi *et al*., 2005). Ultimately, agroforestry can significantly contribute for the achievement of the MDGs; Goal 1 (eradicating extreme poverty and hunger) and Goal 7 (ensuring environmental sustainability) on the same piece of land (Weidner *et al*., 2011).

Agroforestry system practices are extremely profitable and significantly improve the farmers' economic standing. When properly planned and managed, agroforestry can help address pressing issues with food, fuel wood, fodder, soil fertility, and ecology (Hafizul, 2007). Agroforestry system would enhance per unit area production and simultaneously maximize the utilization of natural resources (Bhuiyan *et al*., 2012). Furthermore, such cropping systems are highly sustainable and productive, with year-round production potential. “Agroforestry has been an integral part of rural life in many countries of the world, including

Bangladesh, for centuries. It plays a vital role in maintaining the productivity of the land base and by ensuring household food and energy security, income and employment generation, investment opportunities, and environmental protection (Miah *et al*., 2002; Batish *et al*., 2007; Miah *et al*., 2018). Agroforestry can be identified as a promising option for meeting the demands of society and models of sustainable development due to its contribution not only to the economy and society but also to the ecology (Bargali *et al*., 2009; Jahan *et al*., 2022). In the agroforestry system, two components are cultivated however in a multistoried agroforestry system at least three components are cultivated. Multi-storied agroforestry system comprises upper story trees or shrubs with lower stories of horticultural crops or economically valuable crops, where the distance between tree to tree wider enough to let sunlight to lower stories crops to partial shading, moist soil, etc. allowing them to intercropping with timber wood plantation, fruit trees, and others plantation crops (Sujatha *et al*., 2011; Ahmed, 2019). Multistoried agroforestry systems provide production of diverse fruits and vegetables under various shade situations by maximizing different levels of Photo-synthetically Active Radiation (PAR). Different components are organized in several layers in this system. The lower-storied crop's light limitation is therefore the most crucial factor. Therefore, choosing a lower storied crop for a multistoried system is a crucial and challenging challenge. As a result, many initiatives to identify acceptable crops for the lower stories are going on (Reza A *et al*., 2022). Vegetables are screening in a multistory agroforestry system. As a result, a multistoried agroforestry system produces more products than an agroforestry system. In Bangladesh, the adoption of multistoried agroforestry systems, incorporating fruit trees, represents a promising approach to sustainable land use and agricultural production. This system involves the integration of different layers of vegetation, including tall trees, medium-sized trees, shrubs, and crops, to maximize land productivity and biodiversity conservation. Nonetheless, the global fruit-tree-based agroforestry system has grown in popularity among limited producers and can deliver higher economic returns even in stressed growing conditions (Bellow JG, 2004). When integrating ground-storey crops into orchards, potential negative impacts on the constituent parts and growth areas are typically overlooked. Regarding appropriate species composition, ideal plant placement and spacing, and management techniques to maximize the long-term supply of goods and ecosystem services, this includes agroforestry centered on fruit trees. A well-managed tree-based agricultural system might better leverage its potential social, economic, and environmental advantages. Most often, farmers in the area combine vegetable crops with fruit trees to create "temporary" agroforestry. However Mango and litchi orchards grow a wide variety of intercrops. Mangoes and litchi are other often consumed fruits in Bangladesh's north, particularly in the Dinajpur area, due to their capacity to adapt to the country's edaphic and climatic conditions. Dinajpur is the largest litchi producing district in Bangladesh. Mahogony tree is now in high demand in Bangladesh as its wood is used to make various furniture and its value is very high. At present, farmers are cultivating different types of agricultural crops together with Litchi, Mango and Mahogony but do not use scientific techniques. Therefore, it is imperative that we create scientific research and protocols that will assist growers. We want to look at multistoried agroforestry systems based on mahogany, mango and litchi in order to determine which crops are most suited for each level and whether the system is financially feasible. Therefore, the present study was undertaken with the following objectives:

i. To measure the production potential of stem amaranth and snake gourd under multistoried agroforestry system.
ii. To determine the various multistoried agroforestry systems' profitability.
iii. To calculate the land use efficiency of different multistoried agroforestry systems.

CHAPTER II

REVIEW OF LITERATURE

A wide variety of vegetables are grown in the world such as spinach, snake gourd, amaranth, pumpkin, okra, cauliflower etc. These vegetables are rich in nutrients. However the performance of these plants is significantly impacted by inadequate sunlight in multistoried agroforestry systems. In this study, snake gourd and stem amaranth vegetables are grown in association with mango, litchi and mahogany trees. A condensed overview of the literature from previous research on the current experiment is gathered from reports, thesis, journals, and other academic sources. The following headings provide a review of these findings.

2.1 Concept of agroforestry
2.2 Fruit tree based agroforestry system in Bangladesh
2.3 Fruit tree based agroforestry around the world
2.4 Mango based agroforestry system
2.5 Litchi tree based agroforestry system
2.6 Timber tree based agroforestry system
2.7 Mahogany tree based agroforestry system

2.1 Concept of agroforestry

"Agroforestry is a land use system that involves deliberate retention, introduction or mixture of trees or other woody perennials in crops / animal production to benefit from the resultant ecological and economic intersections". Even if a farmer has deliberately planted or retained a single tree, he/she has been considered as the agroforestry farmer (Nair, 1984). As Adeyoju (1980: 157) notes, 'forestry and agriculture were, for centuries in simple societies, a common vocation wherein the farmer, hunter, and woodsman were nearly always the same', and Raintree (1984), while recognizing that agroforestry is a relatively new field of organized scientific activity describes it as an 'ancient land use practice'. For example, the interplanting of trees with crops and the grazing of domesticated animals in forests are practices having a long history (Douglas, 1967; Adams, 1975; Borough, 1979; Commonwealth Agricultural Bureaux, 1982; MacDicken and Vergara, 1990). Similarly, the intermixing of cultivated fields and forests, and the cultivation of shade-tolerant crops in forested areas are traditional centuries old practices in certain tropical areas (Smiet, 1990). As Fernandes and Nair (1986) point out, four main implications follow from the definition. First, agroforestry normally involves two or more species of plants (or plant and animal), at least one of which is a woody perennial; second, an agroforestry system always has two or more outputs; third, the cycle of an agroforestry system is always more than one year; and fourth, even the most simple agroforestry system is more complex, ecologically (structurally and functionally) and economically, than a monocropping system. A comprehensive and coherent classification is outlined by Nair (1985). It is suggested that agroforestry systems can be grouped under four major criteria. These are: (i) structural basis; this refers to the composition of components, including the spatial admixture of the woody component, vertical stratification of the component mix and temporal arrangement of the different components. (ii) functional basis; refers to the major function or role of the system, mainly of the woody components. These can be productive, for example, production of food, fodder or fuelwood, or protective, for example, planting for shelter or soil conservation. (iii) socioeconomic basis; this refers to the level of inputs of management (low or high) or intensity or scale of management, and commercial goals (subsistence, commercial or intermediate). . At the macro scale, agroforestry practices may be applied to whole watersheds or to large expanses of open cereal farms, where the trees may be used to control water or wind erosion, as contour barriers or shelterbelts (Wood and Burley, 1991). (Leakey ,1996) said, "Agroforestry is a dynamic, ecologically based, natural resource management system that, through the integration of trees in farmand rangeland, diversifies and sustains smallholder production for increased social, economic and environmental benefits". As agroforestry is an ecological interaction of the components, so with changing conditions of occurrence there is considerable variation between the interacting components but this dynamism is united by the specific attributes that each and every agroforestry system possesses. Research in agroforestry system establishment should also take into account the tree growth when fast or medium growing species are considered and the effect they have on the light reaching the understorey and its productivity. They should be modelled and should serve as a basis for different tree and understorey price scenarios for developing suitable economic models based on biophysical models for different agroforestry systems similar to those developed in European countries for silvipastoral systems (Losada *et al*., 2012). Agroforestry offers enough potential to solve problems like poverty, hunger eradication, health and wellness, gender equality, clean water, economic growth, and sustainable development. Agroforestry is a wide-spread land-use system. Agricultural crops, vegetables, forest and horticultural trees, shrubs and grasses are the system components, which made it diverse and productive. It may potentially support livelihoods improvement through simultaneous production of food, fodder and firewood as well as mitigate the problems created by abrupt climate change. Through increasing diverse food production, resource conservation, employment generation and enhancing rural income, agroforestry systems may solve food insecurity problems (Pandey, 2007; Singh and Pandey, 2011; Sharma *et al*., 2007).

2.2 Fruit-tree based agroforestry system

Pingki *et al*. (2022) experimented to evaluate d the performance of cauliflower as lower story crop in aonla based multistoried agroforestry system. The experiment was laid out in randomized complete block design (RCBD) with four replication. While most morphological parameters reached their maximum in the Aonla + carambola + lemon + dragon fruit-based system, the highest curd yield of cauliflower was recorded under dragon fruit-based system. The aonla + carambola + lemon + dragon fruit-based system had the hightest land equivalent ratio, while the aonla+dragon+cauliflower-based system had the highest benefit–cost ratio. As a result, the aonla + dragon + cauliflower based agroforestry system showed relatively higher economic returns and maximum land use efficiency in the upland cropping system.

Riyadh *et al*.(2019) conducted a field experiment to analyse the the performance of aroids (Colocasia esculenta L.) under the jackfruit orchard in Belabo upazila of Narsingdi district. To assess the the jackfruit trees performance as an agroforestry crop in contrast to a sole aroid cropping, four distances - !, 2, 3, and 4 meters – from the base of the tree were taken into consideration for aroid planting. According to the findings, aroid cultivation in jackfruit-based agroforestry system under terrace ecosystem can ensure overall higher production and improve economic return.

Rana *et al*.(2017) experimented to evaluate the performance of sweet gourd in association with five years old mango and guava trees in Char Kalibari of Old Brahmaputra River under Sadar Upazila of Mymensingh district. The treatments were T1 (sweet gourd cultivation in association with mango tree), T2 (sweet gourd in association with guava tree) and T3 (sweet gourd cultivation without mango and guava trees) following a Randomized Complete Block Design (RCBD) with three replications. The results showed that growth and yield of sweet gourd were remarkably reduced in association with both mango and guava trees. The yield of sweet gourd decreasd significantly per unit area when compared to plant, but it remained nearly the same when planted alongside guava and mango trees. Land Equivalent Ratio (LER) of mango and guava with sweet gourd were 1.257 and 1.261, respectively, which indicate these combined production system in char land ecosystem are more productive compare to sole cultivation of fruit trees or vegetable crops. From this study it suggested that agroforestry practices in char areas of Bangladesh by combining fruit trees with sweet gourd is profitable than mono cropping system.

Ahmed *et al*. (2018) carried out an experiment to observe the yield performance of four different summer vegetables viz. stem amaranth, jute as leafy vegetables, kangkong and Indian spinach in association with guava fruit trees and d also to observe the effect of each component (guava tree and summer vegetables) to others during summer in two different location viz charland and plainland ecosystems. Three replications of Randomized Complete block Design (RCBD) were followed to experiment . The growth and yield of all summer vegetables tested showed a significant decrease toward the base of guava fruit trees, which is evidence of the study findings. The results from the LER analysis of that study were agroforestry practices based on guava fruit trees were profitable for both the plainland and the charland ecosystems but in the plainland ecosystem profit was higher.

Ranola *et al*. (2007) investigated 300 farming households to ascertain the most profitable alternative farming system in the region of Claveria, Misamis Oriental, Philippines. According to the analysis, Shifting farming strategies from annual cropping systems to annual-crop dominated agroforestry systems (AFS), that is, integrating fruit and timber trees and livestock into annual crop-based farming systems, increases net income of the farming households. The most profitable systems are those where high-value fruit crops (bananas) and fruit trees (mango, lanzones, durian) are integrated at high densities in the farming system.

Talukder *et al*. (2019) investigated profitable agroforestry systems based on fruit trees in different ecosystem of Bangladesh through an intensive survey and also calculated their carbon sequestration potential by algorithmic method to mitigate climate change. The major ecosystem of Bangladesh namely Coastal ecosystem (Khulna and Satkhira district), Barind ecosystem (Rajshahi and Dinajpur district), Terrace ecosystem (Gazipur and Narsingdi district) and Hill ecosystem (Rangamati and Khagrachari district) were considered. The study revealed that, jackfruit, mango, litchi, guava and ber based agroforestry systems were the most suitable considering benefit cost ratio (BCR) and land equivalent ratio (LER). . The total amount of carbon stock in agroforestry under different ecosystem varied significantly. Terrace ecosystem had the highest total carbon stock followed by barind ecosystem and the hill ecosystem had the lowest carbon stock.

Das *et al*. (2020 transformed an early stage of malta orchard into an agroforestry system and analyzed the performances of summer (okra and Indian spinach) and autumn (mungbean and kangkong) crops and year-round spices (ginger and turmeric). A complete randomized block design was used with three replication. The findings indicated that the crops in agroforestry system was less hindered by the shade effect of malta trees due to less dense canopy of young malta trees. In comparison to sole cropping system, the higher benefit-cost ratio (BCR) (2.93) and land equivalent ratio (LER) (2.83) were obtained in the studied agroforestry system that explicated higher system productivity and land uses. Notable improvement of total nitrogen and organic matter were obtained in the soil under agroforestry system. Therefore, malta-based agroforestry system can be a promising alternative to provide higher economic benefits, boosting food and nutritional security, improving soil nutrient status and utilization of land.

2.3 Fruit –tree- based agroforestry around the world

Do *et al*., (2020) experimented the performance of fruit tree-based agroforestry was compared with that of sole cropping, and farmers' perspectives on agroforestry. The experiments were designed as randomized complete blocks with three replicates on three different farms. The findings indicated that, longan (*Dimocarpus longan* Lour.)-maize-forage grass and son tra (*Docynia indica* (Wall.) Decne)-forage grass systems had generated 2.4- and 3.5-fold higher average annual income than sole maize and sole son tra, respectively. Sole longan gave no net profit, due to high investment costs. They also reported that agroforestry enhanced ecosystem services by controlling surface runoff and erosion, increasing soil fertility and improving resilience to extreme weather. Thus, agroforestry practices with fruit trees can be more profitable than sole-crop cultivation within a few years. Integration of seasonal and fast-growing perennial plants (e.g., grass) is essential to ensure quick returns. Wider adoption needs initial incentives or loans, knowledge exchange, and market links.

Das *et al*., (2022) investigated the performance s from different agroforestry arrangements of mango with gamhar and eucalyptus; and sweet orange with gamhar for two years (2017-18 to 2018-19) of alley cropping with pigeon pea, green gram, cowpea and toria in ongoing AF experiments at Regional Research Station (Red & Lateritic Zone), Bidhan Chandra Krishi Viswavidyalaya, Jhargram, West Bengal, India. A Field experiment was conducted under rainfed condition on upland of red and lateritic soil covered with established agroforestry plantations. Total carbon stock as well as potential food energy production were higher in

AFS than either in sole silvi tree, fruit tree or plots under alley crops, because of better performances of all tree and crop components in AFS. Mango with eucalyptus-based AFS gave higher carbon stock (62.33 t ha-1 yr-1) including improvement in degraded acidic soil pH (6.20%), SOC (11.86%), available N (9.09%), available P (13.97%), available K (11.64%) contents in soil. In that way, fruit-based agroforestry systems can be used as a viable alternative land use to improve soil health, diet and livelihood security even of resource-poor farm families throughout the year, especially during their impoverished needy times in a year.

Zahoor *et al*., (2021) carried out at farmer's field in central Kashmir region of India with the aim to acknowledge the potential of apple based agroforestry system for biomass production and carbon stock assessment for climate change mitigation. For conducting the study four intercrops viz., rajmash (*Phaseolus vulgaris*), green gram (*Vigna radiata*), french bean (*P. vulgaris*) and oats (*Avena sativa*) were intercropped with 11-year-old plantation of apple. The maximum total crop biomass was registered under control french bean and oats (7.85 t ha^{-1}). Overall highest values of total biomass were observed under agroforestry system of apple + rajmash and Oats. The treatment, apple + rajmash and oats displayed highest values for both total tree biomass (29.16 t ha^{-1}) and overall biomass of system (33.00 t ha^{-1}). Maximum value of soil organic carbon (46.02 t ha^{-1}) was observed under apple + green gram and oats. The highest ecosystem carbon was stored in the treatment involving the tree crop combination of apple + rajmash and oats (64.18 t ha^{-1}) and is around 1.5 to 2 times higher than agriculture based system. The total ecosystem carbon in apple based land use system ranged between 53.23 and 64.18 t ha^{-1}. These agroforestry systems in Himalayas can go a long way in augmenting the overall production and productivity by satisfying the rural livelihoods besides acting as effective carbon sink through carbon stockpiling and sequestration. The outcome of the present study can be significant in selecting different crop combinations for fruit based land use systems, future carbon studies, climate change contemplates, soil carbon stock estimation and land use planning along the lines of REDD + activities in other fragile Himalayan ecosystems.

Hossain *et al*., (2023) investigated the performance of Indian spinach in an aonla-based multistoried agroforestry which was contrasted alongside the production of open field condition of five different Indian spinach varieties that were also inspected for best-performing varieties. The treatments were T_1 (Aonla+Lemon+Indian Spinach), T_2 (Aonla+Indian Spinach, T_3 (Open field) following a randomized complete block design. the total output of T1 was highest followed by T2 than T3 because diversified products in the Agroforestry system added to the total output and ratified the superiority of the agroforestry system over the sole crop. The study concluded that agroforestry practices with Indian spinach could be an excellent alternative to ensure higher financial benefit, protect and preserve the environment and promote food and nutritional security to the impoverished farmers of Bangladesh.

Adane *et al.*, (2019) examined e fruit tree based agroforestry system and its contribution of household income for livelihood improvement in Dale District. The results revealed that the status of fruit based agroforestry in the study area varies with land holding size. Fruit trees such as; Musa acuminate, Persea americana and Mangifera indica were the major types of tree species grown in the system in the study area. The contribution of fruit for poor, medium and rich households was 3166.8 Birr, 3713.8 Birr and 1380 Birr respectively. The fruit tree contributes 24.75% for poor HHs, 23.34% for medium HHs and 5.16% for rich HHs from the total income. The average income earned from fruit trees was 2754 Ethiopian Birr (ETB) per year. Besides, the result from the econometric analysis indicates that access to extension service, family size, land size, and the number of livestock influenced the income from fruit trees. Further studies of examining of the market value chain, areas of intervention along the chain and economic value of the fruit tree based agroforestry system including environmental function served by the system is needed to fully understand the contribution of fruit tree based agroforestry system and livelihood improvement.

Ferdous *et al.*, (2022) carried out an experiment to determine the performance of different radish varieties in aonla based multistoried agroforestry systems. The study consisted of two factors viz. four agroforestry systems (aonla + carambola, aonla + lemon, aonla only, and open field) and four radish varieties (BU mula-1, BARI Mula-1, BARI Mula-2 and Rocky 45) laid out in a two factorial randomized complete block design with three replications. The aonla + carambola system yielded the largest leaf fresh weight (276.47 g) generated by Rocky 45, whereas an open field yielded the lowest leaf weight produced by BU mula-1. Rocky 45 generated the greatest root fresh weight (592 g) in the open field, while BU mula-1 provided the lowest root fresh weight (102.6 g) in the aonla + carambola based system. Among the four radish varieties, BU mula-1 generated the highest leaf yield (18.43 t/ha), whereas Rocky 45 provided the best root yield (39.47 t/ha) in an open field. Rocky 45 outperformed the other three radish cultivars in terms of yield in both an aonla-based agroforestry system and open fields.

Kassa *et al* (2015 investigated the determinants of practicing fruit-tree based agroforestry and the associated costs incurred and returns earned by practitioners.) It compared the economic performance of monocropping systems with agroforestry systems based on household-level economic performance indicators in Wondo District. Data were gathered from 149 selected households through market assessments, key informant interviews, focus groups, and structured interviews. Fruit-tree based agroforestry practices were significantly influenced by factors such as income, land size, farming experience, and proximity to the main road. Policies and strategies that promote this more financially advantageous, labor-saving, and less risky investment option need to be carefully designed.

Anshiso *et al*., (2017) carried out an experiment t to evaluate the profitability of fruit tree based agroforestry practice with those of monocropping. For data gathering, the study used a home survey in addition to participatory research techniques (focus groups, Key informant interviews, and field observations). Descriptive statistics and financial analysis were also used. The outcome demonstrates that the agroforestry system in the study region based on fruit trees is ubiquitous. Agroforestry practices based on fruit trees are not only more lucrative than monocropping systems, but they are also less susceptible to fluctuations in price, production, and discount rate, according to the financial study. Agroforestry practices based on fruit trees are often better than monocropping systems in terms of their advantages to the economy, the environment, and their reduced sensitivity to outside influences. For this reason, the government and other relevant organizations have to focus on assisting smallholder farmers so they can employ agroforestry.

Dubey (2022) Experimented the performance of Aonla's orchard-based agri-horticultural system which has immense potential for the betterment of people's livelihoods. Due to its thin canopy and leaf shedding nature in the winter season, orchards of this fruit tree species are well suited for agro-forestry. Data on the production of grains, straw, and agricultural crops (paddy and wheat) were documented under the Aonla orchard-based agroforestry system. Farmers continued to receive additional revenue from Aonla fruits even while the yield of agricultural crops decreased. All things considered, Aonla's orchard-based agroforestry generates a healthy financial return. In the Gangetic area of Uttar Pradesh, India, using Aonla orchard interspace with the conventional cropping technique proved to be beneficial.

Bost, J. (2013) Carried out an experiment in six villages composing the Comité de Recursos Naturales de la Chinantla Alta (CORENCHI) in Oaxaca, Mexico shows that *Persea* *schiedeana* has potential as a supplement to avocado production in subsistence systems and as a potential oil crop in more market oriented agroforestry systems. Between February and July 2008, both management data and morphological data were collected on *Persea schiedeana* in the Chinantla area, specifically in the village of San Mateo Yetla and the six villages compromising CORENCHI. This survey of *Persea schiedeana* in the Chinantla area reports on the ethnoecology and management of *chinene*, as well as on the morphological diversity of the fruit in the area. High morphological diversity for fruit characters was noted and it is suggested that artificial selection has occurred and been modestly successful for desired fruit characters.

Islam *et al*., (2021) experimented the performance of the Date palm and Jackfruit-based TAS (Traditional Agroforestry System) practiced in the Jashore and Mymensingh districts of Bangladesh. According to the study, farmers in Bangladesh's Jashore district extensively cultivate a variety of winter vegetables (such as cabbage, cauliflower, radish, turnip, green pea, carrot, Indian spinach, etc.) and cereal crops (like rice and mustard) alongside Date palm trees. The practice of Date palm-based agroforestry can last for up to 30 years, and farmers receive Date palm juice after 5 years of tree planting. In this system, the Jackfruit trees are grown in the boundary or inside the cropland, and different agricultural crops are cultivated in association with Jackfruit trees. The results revealed that the TAS enhanced farm productivity and the benefit–cost ratio of both systems were much higher than the general agricultural practices in Bangladesh. The TAS also improved resilience of rural farmers through more efficient water utilization, enhancing soil fertility, improving microclimate, controlling pests and diseases, and diversifying products.

Miah *et al*., (2018) experimented a number of traditional and modern agroforestry systems in the agricultural landscape of Bangladesh. One of these is based on jackfruit (*Artocarpus heterophyllus* Lam.), which is primarily found in terrace ecosystems. There is a great opportunity to improve the system by making use of the available space by growing compatible associated crops. To this end, a jackfruit orchard was converted into a multistoried agroforestry system between 2012 and 2013, with jackfruit trees maintained as the over story and associated crops like papaya and eggplant grown as middle and lower story crops, respectively. In the improved system, jackfruit yield increased by 32.7% thanks to fertilizers and irrigation applied for the middle and lower-storied crops, while yields of papaya and eggplant were reduced by 22.8 and 17.4%, respectively, due to competition for both belowground and aboveground resource. These results suggested that the traditional jackfruit orchard could be transformed to multistoried agroforestry systems for its higher system productivity including higher yield, and increased income that ultimately will improve the livelihood of the farming community.

2.4 Mango tree-based agroforestry System

Sharma *et al*., (2017) conducted an experiment plot of agroforestry systems at Regional Research Station of (B.C.K.V., started from 2007) Jhargram, West Bengal during two consecutive years i.e. 2014-15 to 2015-16. The experiment included one cereal crop, maize, one oilseed crop, groundnut, and two trees, gamhar (silvi tree) and mango (fruit tree). A per-hectare basis was used to record and convert the yield of each distinct entity. The Mango+ Gamhar+ Groundnut treatment had the best yield, or groundnut equivalent yield, of 14.29 and 15.97 t ha^{-1} in 2014–15 and 2015–16, respectively. This was followed by the Mango+ Gamhar+ Maize treatment. For two years in a row, the maize monocropping option yielded the lowest peanut equivalent yield. Under the Mango+ Gamhar+ Groundnut based method, the greatest gross return was recorded in INR. 357334 in 2014–15 and 478996 in 2015–16, respectively. When compared to mono-cropping systems, the mango-based agroforestry system is a more sustainable and appropriate method for rainfed conditions.

Dharma & Sharma (2015) experimented the productivity of crops grown in lateritic and red soil under tree- based agroforestry system. To find out suitable agroforestry model, field experimental was conducted at Regional Research Station (red and laterite zone), Bidhan Chandra Krishi Viswavidyalaya, Jhargram, West Bengal, India. The crops that were grown during kharif and mustard during rabi season were peas, black grams, bottle gourds, lady fingers, and maize. According to the experimental findings, all of E. tereticornis' growth characteristics and mango output were higher under the agroforestry system than they were when compared to silvi species and fruit trees alone. The fifth year of intercropped lady's finger (kharif) cultivation yielded the highest gross income (Rs. 1.864 lakh ha^{-1} year-1), closely followed by bottle gourd (Rs. 1.666 lakh ha^{-1} year-1). Fruit-based agroforestry systems improve soil health (raise soil OC, pH, and accessible N, P, and K) in addition to increasing profitability. According to studies on soil fertility, all fruit-based agroforestry systems improved soil health, but intercropping with black gram and pigeon pea led to the greatest improvement.

Rahman *et al*., (2021) conducted an experiment to evaluate the performance of radish, sweet gourd and mustard leaf cultivation under mango fruit tree based agroforestry system, to increase the production of vegetables by using the fallow land under mango garden and to increase income of the farmers in char areas of Jamalpur and Sherpur. The experiment was laid out in Randomized Complete Block design (RCBD) with 3 replications. At the farmers' fields in Bangladesh's Jamalpur and Sherpur regions—Naovangar, Bolaier, and Laxmir—an experiment was carried out. Following sweet gourd, radish cultivation produced the highest radish equivalent yield, gross return, net return, and BCR at Naovangar char. Mustard leaf cultivation produced the lowest yields. The cultivation of radish produced the highest radish equivalent yield, gross return, net return, and BCR at Bolaier Char. The lowest yield was produced by mustard leaf. Sweet gourd came in second. The greatest gross return, net return, and BCR all showed similar trends at Laxmir Char. In conclusion, growing radish in agroforestry systems is more lucrative than growing other winter crops. Thus, in Bangladesh's Jamalpur and Sherpur regions, the growing of vegetables and radish under an agroforestry system based on mango fruit trees may be promoted.

Rana (2022) carried out an experiment in the Madhupur Sal forest of Bangladesh to perform the productivity analysis of mango-based agroforestry systems. Randomly chosen at three sites within the research region were three distinct mango-based agroforestry systems and three control plots with three replications. The selected three mango-based agroforestry systems were viz. i) mango + pineapple+ ginger + papaya + banana + turmeric, ii) mango + pineapple + ginger + papaya + banana, and iii) mango + turmeric+ papaya + aroid based agroforestry systems. The results revealed that the total calculated cost of production (tk/ha) and total yield (tk/ha) from selected mango-based agroforestry systems were Tk. 202421, 186373 and 163631 along with Tk. 1076344, 956095 and 816520 respectively. The BCR and LER of the selected above mango-based agroforestry systems were 5.32, 5.13, 4.99 and 3.27, 2.76, 2.32 respectively. Therefore, mango-based agroforestry systems are more profitable than sole cropping system.

Amin *et al*., (2021) experimented the yield potential and the economic benefits of potato production under a mango-based agroforestry system. The experiment was set up following a split plot design with three (3) replications. The potato tubers were planted in a 10-year-old mango orchard and open field conditions. Potato production system under mango orchard and open field were arranged in main plots T0 = potato sole cropping (control) and T_1 = potato under mango-based agroforestry system. On the other hand, potato intra-row plant spacing were in sub-plots $S_0 = 60 \times 20$ cm^2, $S_1 = 60 \times 25$ cm^2 and $S_2 = 60 \times 30$ cm^2. The results show that the closest (60 x 20 cm^2) intra-row plant spacing produced the highest yield while the economic returns from potatoes grown under the mango-based agroforestry system were higher than those derived from cropped grown as a sole crop or potatoes cultivation alone. Further, the benefit-cost ratio from the combined cultivation of potatoes and mangos was 2.14, which was 20 % higher than growing potatoes as a sole crop. Thus, the cultivation of potatoes under a mango-based agroforestry system offers a significant financial benefit to farmers while ensuring the sustainable use of vacant space in mango orchards.

2.5 Litchi tree-based agroforestry

Uddin *et al*., (2010) carried out an experiment to examine the growth performance of Indian spinach grown in association with pineapple at different orientations of litchi tree. For the purpose of producing Indian spinach, there were five treatments total—four distinct orientations of litchi trees (north, south, east, and west) and one control plot. The study's objective was to determine how the orientation of an agroforestry system based on Litchi and Pineapples affected the yield performance of Indian spinach. The longest Indian spinach plant measured captured with the east in mind. In an open field with full solar light, the values of all other factors were determined to be maximum. Notably, the open field produced the maximum output (7.12 tha-1) of Indian spinach, which was followed by the south orientation (6.60 tha-1), while the east orientation produced the lowest yield (5.80 tha-1). Furthermore, the findings suggest that the agroforestry system based on Litchi and pineapple has the potential to produce Indian.

Hanif *et al*., (2010) experimented to evaluate the performance of Okra plant under litchi based agroforestry system at the Agroforestry Farm, Hajee Mohammad Danesh Science and Technology University, Dinajpur, during 08 January 2009 to 08 April 2009. A Randomized Complete Block Design with three replications was used to set up the experiments. The hybrid okra sole cropping method has the highest yield contributing characteristics. The hybrid okra monocropping method had the maximum yield (10.24 t ha-1), whereas the T6 (Litchi + Local okra variety) yielded the lowest (4.24 t ha^{-1}). In contrast to solitary cropping, the litchi-based agroforestry method guarantees a greater yield and is more sustainable. Okra hybrid variety > BARI-1 okra > Local okra variety is a possible ranking system for okra variety appropriateness.

Uddin *et al*., (2010) conducted an experiment to examine the biological performance of Indian spinach and papaya in litchi based agroforestry system at Borjona village of Kapasia, Gazipur district during September 2011 to October 2012. The experiment was laid out in one factor Randomized Complete Block Design (RCBD) with five replications. Growing Indian spinach cultivars as part of an agroforestry system based on litchi-papaya did not affect yield or yield contributing characteristics. The other parameters remained constant, however there was a considerable effect on the sprout plant^{-1} and sprout weight of Indian spinach cultivars cultivated in a litchi-papaya based system. The local variety (2.89) and KS green variety (2.97) sprout plant-1 were similar, but higher than the KS red variety (2.57). The local variety and KS green had similar but lower sprout weights, with the KS red type having the greatest weight at 85.80 g. The largest yield was produced by KS red (36.32 t ha^{-1}), followed by local (34.61 t ha^{-1}) and KS green (34.00 t ha^{-1}). However, the yield was the same for all the types. In the event that litchi grow, plant height.

2.6 Timber tree-based agroforestry

Akter *et al*., (2020) experimented to find out the suitable agroforestry systems based on their productivity in the Madhupur Sal forest of Bangladesh. Five agroforestry practices namely Akashmoni tree with Ginger and Banana crops, Akashmoni tree with Turmeric and Banana crops, Akashmoni, Acacia Hybrid, Ghoraneem, and Gamar trees with Turmeric crops, Jackfruit and Akashmoni trees with Turmeric and Aroid crops, and Litchi tree with Pineapple, Ginger. The net profit showed that the agroforestry practice based on Litchi, Pineapple, Ginger, Papaya, and Banana was financially more profitable than the other practices. On the other hand, the agroforestry practice based on Akashmoni, Ginger, and Banana had higher land equivalent ratio (LER) and benefit-cost ratio (BCR) (3.66 and 1.76, respectively), followed by Litchi, Pineapple, Ginger, Papaya, Banana, Akashmoni- Acacia Hybrid- Ghoraneem- Gamar- Turmeric, and Jackfruit- Akashmoni. Both economical and ecological point of view, Akashmoni- Ginger- Banana based agroforestry practice was more suitable than the other practices in the Madhupur Sal forest of Bangladesh.

Roshetko *et al*., (2013) experimented to examine the contributions of teak systems to smallholders' livelihoods in Indonesia, where farmers have been producing teak for over 50 years. Indonesian farmers cultivate teak as one component in integrated multispecies agroforestry systems. Supplying food for households, smallholder teak systems provide 40% of household income from agricultural and timber crops. Teak and other tree crops allow households to re-allocate labor to off-farm employment when those opportunities are lucrative.

Rahman *et al*., (2018) carried out an experiment to assess the productivity and profitability of jackfruit-eggplant based agroforestry system after modification from a traditional jackfruit orchard during the period of July 2012 to December 2013. Five treatments covering four orientations of jackfruit tree and an open field was used as a control treatments. The results showed that the yield of jackfruit dramatically increased by 81% in the agroforestry system in compared to sole cropping, while eggplant shows inverse trend. After analyzing the primary results, we can conclude that agroforestry systems may be used in jackfruit orchards to increase yield, provide revenue, and preserve the environment.

Islam *et al*., (2016) experimented 5 to observe the performance of wheat in association with six timber yielding tree species viz. kalo koroi (Albizia lebbeck), sissoo (Dalbergia sissoo), jhau (Casuarina equisetifolia), minjiri (Cassia siamea), akashmoni (Acacia auriculiformis), and eucalyptus (Eucalyptus camaldulensis). A Randomized Complete Block Design (RCBD) with three replications was used for each tree species separately. As evident from the result it was found that yield of wheat gradually increased with increasing distance from the base of Kalo koroi, Sissoo, Jhau, Akashmoni, Minjiri and Eucalyptus spec Overall average yield of wheat with Jhau, Akashmoni, Kalo Koroi, Minjiri, Eucalyptus and Sissoo were 1.27, 1.18, 1.37, 1.35, 1.05 and 1.18 t/ha, respectively which were 37.13, 41.58, 32.18, 33.17, 48.02 and 41.58% lower compare to control condition. Considering the results of this study suitability of wheat cultivation as agroforestry system with studied tree species ranked as Kalo koroi > Minjiri > Jhau > Akashmoni > Sissoo > Eucalyptus.

Hasan *et al*., (2013) conducted an experiment to evaluate the growth performance of two winter vegetable crops (Radish and Bitter gourd) grown under two years old Eucalyptus (Eucalyptus camaldulensis) tree of different distances at the Kalibari char which is situated by the side of Brahmaputra river adjacent to the Bangladesh Agricultural University, Mymensingh. The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. The highest values were observed under T_0 (open field as control) treatment and the lowest value was recorded under the close distance T_1 (< 50 cm from the tree base). Consequently, the best distance for increased radish and bitter gourd production in an agroforestry system would be either long distance or control.

2.7 Mahogany tree- based agroforestry

Noman *et al.*, (2018) experimented to evaluate the growth performance of rice cultivated in association with seven years old boundary planted mahogany tree during aman season under irrigated condition. On the plot’s west, north,and suth sides mahogany trees were planted. Of all the sides from the tree's base, the west side had the most yield reduction. Similar yield decreases were reported on the north and south sides; however, the shadowing impact of the tree-crop combination and competition for nutrients, water, and light on the north side resulted in a numerically slight increase in yield reduction.

CHAPTER III

METHODS AND MATERIALS

The experiment aimed to determine the optimal tree crop interactions in the agroforestry system and assess the performance of snake gourd and stem amaranth to the mango, litchi and mahogany trees. This chapter provides a detailed presentation of the materials, procedures, and other pertinent activities that took place during the experimental period. This chapter includes summaries of the experimental details under the following headings.

3.1 Location and Time of Experiment

The study was conducted in the existing HSTU research farm at the Department of Agroforestry and Environment, Dinajpur from 12^{th} April 2023 to 2^{nd} july 2023. The location was between 25 13 latitude and 88 23 longitude 37.5 meters above sea level in a medium – high land that belonged to the old Himalayan Piedmont Plain area (AEZ 01). The drainage system was well-developed, and the land had good drainage.

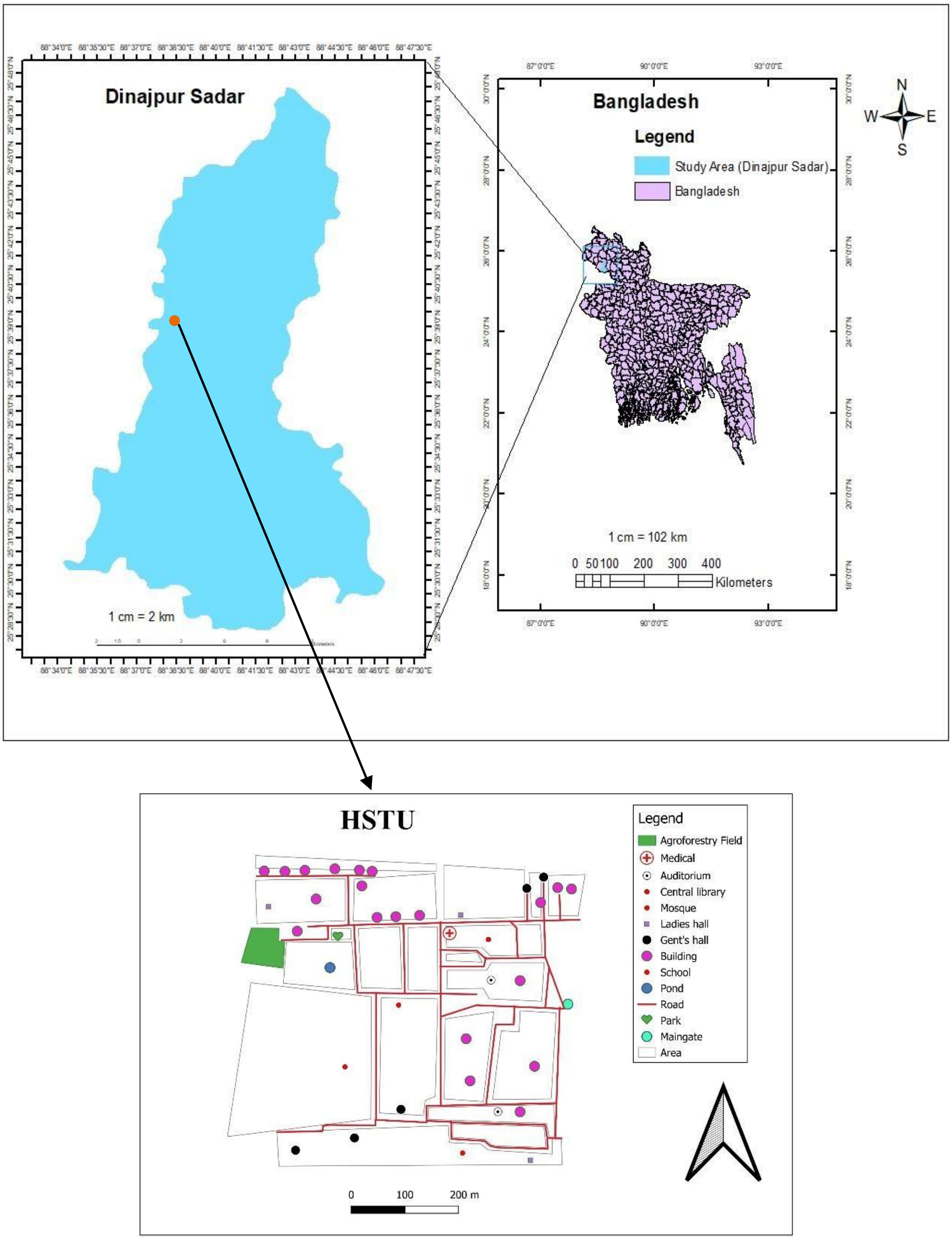

Figure 3.1 Location of the Study Area

3.2 Description of Experimental Materials

3.2.1 Mango Plant

In 2008, the Mango cultivar known as Amrapali was planted. Every year, the intercultural operations are carried out according to standard protocol. The Mango trees were planted six meter apart from one another. Mango production in Bangladesh has experienced notable growth, driven by both an increase in the land area dedicated to mango cultivation and improvements in agricultural practices. According to recent data, the area under mango cultivation has expanded significantly, reaching approximately 123,000 hectares in 2022, compared to about 100,000 hectares in 2010 (Bangladesh Bureau of Statistics, 2023). This expansion is partly due to government initiatives promoting high-value crop production and farmer adoption of improved mango varieties and management practices (Hossain *et al*., 2021). The areas surrounding Rajshahi, Chapainawabganj, and Dinajpur are the primary mango-growing regions in Bangladesh. Because of their adaptability to different climates, mangoes are a popular fruit in the northern part of Bangladesh, particularly in the Dinajpur region. The mango is a staple of homestead gardening in the Dinajpur region. Mango (*Mangifera indica*) is the favorite fruit in Bangladesh and has been repeatedly acclaimed as the king of fruits (Ahmed, 1994). It is the most popular fruit in Bangladesh in terms of economic value and flavor. On the other hand, mango gardens are growing every day. Farmers now grow a variety of annual crops in association with mangoes, but they do so with little scientific thought. In a young mango orchard, intercrossing vegetables, spices, some oil seeds, and serial pulses can be a beneficial method to employ the space between mango trees. Mango production land area has seen significant changes in recent years due to varying factors such as climate change, urbanization, and agricultural practices.

3.2.2 Litchi Plants

In 2006, the china -3 litchi cultivar was planted in a spacing of 6m x 6m. It is one of the best cultivars of this variety found in the Bengali region in the eastern section of the Indian subcontinent intercultural operations are conducted annually by standard protocol. Litchi production in Bangladesh has shown a positive trend, with the land area dedicated to its cultivation increasing steadily over the past decade. Recent statistics indicate that the area under litchi cultivation has grown to approximately 30,000 hectares in 2022, up from around 25,000 hectares in 2010 (Bangladesh Bureau of Statistics, 2023). This expansion is attributed to the high market demand for litchis, both domestically and for export, as well as the profitability of litchi farming compared to other crops (Islam *et al*., 2021). Key production regions, such as Dinajpur, have benefitted from government support and farmer training programs focused on best practices in litchi cultivation.

3.2.3 Mahogany Plants

In 2020, the mahogany plants were grown in 6m x 6m spacing. Because of its color and durability, mahogany is used in the commercial production of a wide range of goods. Although it is native to the America, it has also been brought to plantations in Asia and Oceania. Mahogany production in Bangladesh has been on the rise as part of broader efforts to promote sustainable forestry and agroforestry practices. The land area dedicated to mahogany cultivation has increased significantly, with recent estimates indicating over 50,000 hectares planted by 2022, compared to around 35,000 hectares in 2015 (Bangladesh Forest Department, 2023). This growth is driven by the high economic value of mahogany timber, which is in demand both domestically and internationally for furniture and construction (Chowdhury *et al*., 2021).

3.2.4 Snake gourd

A high yielding variety of snake gourd was planted in the experiment field. *Trichosanthes cucumeria* is commonly known as snake gourd (chichinga) in Bangladesh. In our country it is mainly cultivated during summer. Like most flora of the gourd family, the snake gourd vegetables, seeds, leaves and juice extracts are enriched with a multitude of crucial fundamental dietary components like carbohydrates, fats, proteins and fibers, vital trace compounds such as Vitamin A, Vitamin B6, Vitamin C and Vitamin E and minerals and a host of plant substances including phenolics and cucurbitacins. 100% edible portion of snake gourd contains 95% water, 3.2-3.7g sugar, 0.4-0.7g fat, 35-40mg calcium, 0.5-0.7mg iron and 5-8mg dietary fiber(bamis.gov.bd). The vegetable is known for its high content of vitamins A and C, dietary fiber, and various antioxidants, making it a valuable addition to the diet (Hossain *et al*., 2020). The land area dedicated to snake gourd production in Bangladesh has expanded in recent years, with estimates indicating that approximately 12,000 hectares were under cultivation in 2022, up from around 9,000 hectares in 2015 (Bangladesh Bureau of Statistics, 2023).

3.2.5 Stem amaranth

Hybrid varieties of stem amaranth were planted in the field. In Bangladesh including south-east Asia, Africa, South America, the edible stem amaranth leaves are a very famous vegetable. Its popularity is continuously increasing in the Asian continent and elsewhere because of high nutritional value, taste, and attractive leaf color. In Bangladesh, stem amaranth is grown year-round and it could be grown in the gaps period of leafy vegetables between winter and hot summer(Sarker *et al*.,2015 Amaranth is also tolerant to abiotic stresses like drought and salinity (Sarker *et al*.,2018). It is an inexpensive vegetable and has abundant dietary fiber and protein with essential amino acids such as methionine and lysine, minerals, pigments and phytochemicals like betacyanin, betaxanthin, chlorophyll, carotenoids, beta-carotene, vitamin C, phenolic compounds, and flavonoids(Venskutonis *et al*., 2013; Sarker *et al*., 2014;Sarker., 2016). Leaf pigments (betacyanin, betaxanthin, chlorophyll, and carotenoids), vitamin C, phenolics and flavonoids are available natural antioxidants in amaranths (Venskutonis *et al*., 2013;Repo-carrasca-valencia *et al*., 2010). For vegetarians and the impoverished in low-income nations, stem amaranth is their primary protein source.

3.3 Experimental Design and Treatment Combination

The experiment was conducted on the floor of 16 –year old mango (30ft), 18-year –old litchi (28ft), and 3-year- old mahogany trees (20ft). The snake gourd seeds were sown directly into the pit around 50-60 cm apart while the stem amaranth was sown in the vacant spaces between the tree-to-tree distances. The experiment followed single factor Randomized Complete Block Design (RCBD) with three replications. There were five treatments-

T_1= Mango + Snake gourd + Stem Amaranth

T_2= Litchi trees + Snake gourd + Stem Amaranth

T_3= Mahogany + Snake gourd + Stem Amaranth

T_4= Sole cropping of Snake gourd

T_5= sole cropping of stem amaranth

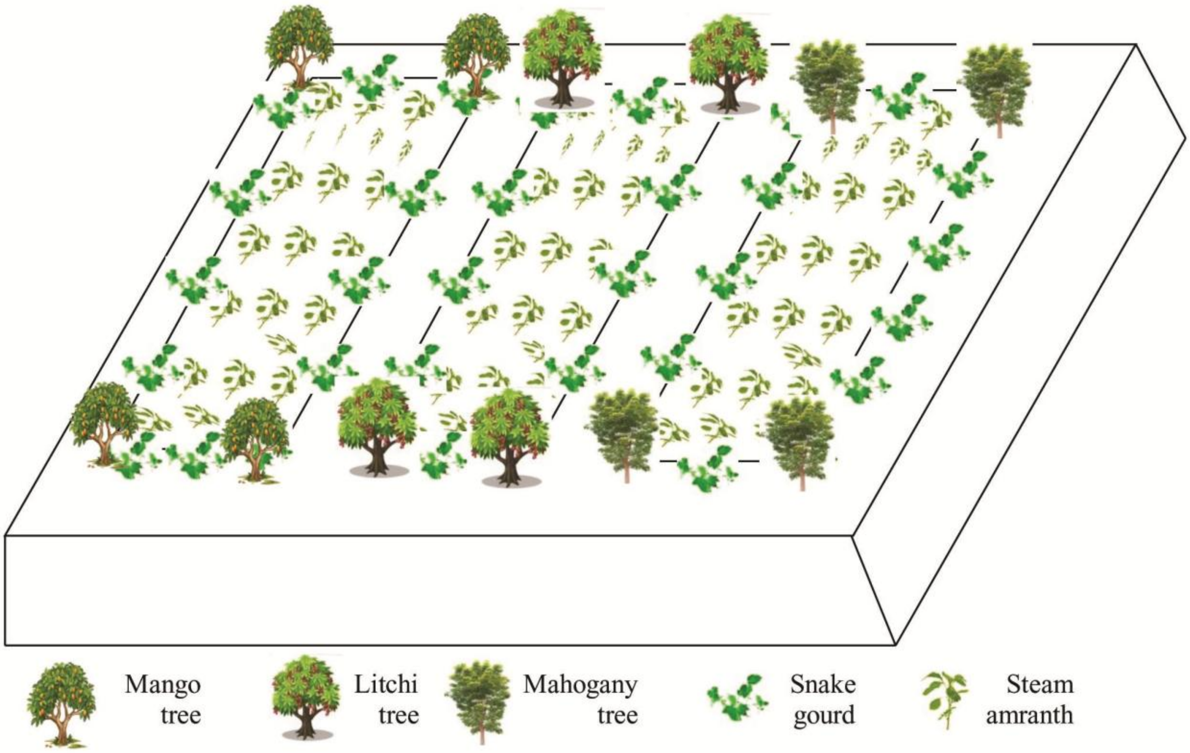

Figure 3.2: Representation of the planting design of trees and vegetables in multistoried agroforestry

3.4 Plot size, land preparation, and crop establishment

Each plot size for cultivation was 3m x 2m = 6m^2 as determined by measuring tape fitting, pits of 40cm×40cm×25cm were prepared and plant to plant spacing 60 cm, respectively. Using a tractor and harrow, the field was initially tilled to achieve the proper soil condition. In the last stage of soil preparation, the land was fertilized with cowdung (20000 kg ha^{-1}), triple super phosphate (175kg ha^{-1}), K_2O in the form of muriate of potash (150 kg ha-^{1}), boric acid (boron) (10 kg ha-^{1}). For the snake gourd, 175 kg ha^{-1} of urea-based nitrogen (N) fertilizer was applied. When required, irrigation was done using a flexible hose pipe to ensure that the soil was sufficiently moist

Crops were regularly weeded in order to reduce weed competition for the same resources. Fresh, vigorous seedlings were used from the same experiment stock to replace the dead, wounded, and feeble seedlings. Dursban 20 EC was used to control viral vectors. Common pesticides were used for snake gourd include insecticides like Malathion and Carbaryl to control insect pests such as aphids and fruit flies, as well as fungicides like Mancozeb and Copper Oxychloride to manage fungal diseases like powdery mildew and downy mildew

(Rahman *et al*., 2022). There was a plan to protect the plant from the attack of insects-pests specially fruit flies and fruit borer by spraying of pesticides. Pheromon trap was also used to control fruit flies and fruit borer. For proper growth and development of the plants the vines were managed by hand to spread them over the net of trellis. Six bamboo poles were set slantingly keeping 5 feet high from the ground level in every plot. The poles were connected to one another tightly by iron rope in such a way that they make opposite "V" shaped. A net from rope were placed on iron rope. Thus a trellis for each plot was made for creeping the vines of crop. Under the agroforestry system, mango, Litchi, and mahogany trees were only pruned; no additional management practices, such as fertilizer application, were used.

3.5 Fertilizer and Manures

The recommended fertilizer doses and application techniques for the four treatment in this experiment– nitrogen, phosphorus, potassium, gypsum, boric acid, and ammonium molybdate by Krishi Projukti Hatboi, January 2020 BARI are listed below.

Table 3.1 Organic and inorganic fertilizers were applied for Snake gourd production during the experiment

Fertilizers	Total amount of the dose (kg/ha)	Last tillage	Pit preparation	1st dose (15 days after planting)	2nd dose (15 days after planting)
Cow dung	20000	5	5	-	-
Urea	175	-	-	75	75
TSP	175	75	75	-	-
MP(Potash)	150	-	-	60	60
Gypsum	100	100	-	-	-
Boric acid (Boron)	10	3	-	-	-
Ammonium molybdate (Molybdenum)	1	1	-	-	-

Source: Krishi Projukti Hatboi, (2020)

3.6 Data collection

3.6.1 Plant

The data on growth parameters of snake gourd and stem amaranth was collected at 30 and 45 days after sowing/planting. The data on stem amaranth (length and weight) was collected during harvesting. The snake gourd fruits were harvested sequentially: the length, breadth, weight of the fruits was recorded by measuring scale and weight machine. Moreover, the data on mango and litchi yield was calculated to the total yield and profitability of the system. In the case of mahogany, the annual wood value was added to calculate the systems profitability.

3.7 Data analysis

3.7.1 Gross return

It was computed using the formula that follows. Gross return (TK /ha)= Trees outcomes+ crops outcome.

3.7.2 Net Return

It was calculated using the formula below.

Net return (Tk ha^{-1}) = Total cost of production (TK ha^{-1})/ gross return (TK ha^{-1})

3.7.3 Benefit– cost ratio

The ratio of gross return to total production cost is known as the benefit – cost ratio, or BCR (Islam *et al*., 2004). The following formula was used to calculate it (Islam *et al*., 2004). The profitability of multistoried agroforestry was estimated in the term Benefit- cost ratio by the following formula:

Benefit-cost ratio (BCR)= Gross return/ Total cost of production

3.7.4 LER

The comparative advantage of land use through agroforestry and traditional farming will be calculated in the term Land Equivalent Ratio (LER) by the following formula:

LER= $X_i/X_s + Y_i/Y_s$, Where X and Y are the yields of crop components in agroforestry (i) and sole cropping systems (s).

3.8 Statistical Analysis

The recorded data were statistically analyzed using the “Analysis of Variance” technique with the help of ‘STATISTICS 10’. The means were separated by Tukey HSD (Honestly Significant Difference) test.

CHAPTER IV

RESULTS

This chapter discusses the relationships between crops and trees in an agroforestry system based on mango, litchi, and mahogany trees. The study's analytical conclusion was presented, analyzed and possible interpretations were shown with a variety of tables and graphs. The experiment's goal was to look at how mango, litchi, and mahogany trees affected the growth, production, and yield-contributing qualities of stem amaranth and snake gourd. The findings of the experiments are shown and discussed below with headings.

4.1 Growth Parameters of Snake gourd

4.1.1 Plant Height (cm)

The Snake gourd plant height did not vary significantly at 30 DAP but varied significantly at 45 DAP. The Snake gourd plants under T_1 treatment had the tallest plants at all sampling dates. At 30 DAP the maximum plant height was recorded from T_1 (161.67cm) which was followed by T_3 (153 cm) and T_4 (151 cm) respectively whereas the lowest plant height was recorded from T_2 (132.67 cm). At 45 DAP, the maximum plant height was recorded from T_1 (454.33 cm) which was statistically similar with T_2 and T_3 respectively whereas the lowest plant height was recorded from T_4 (300.00 cm).

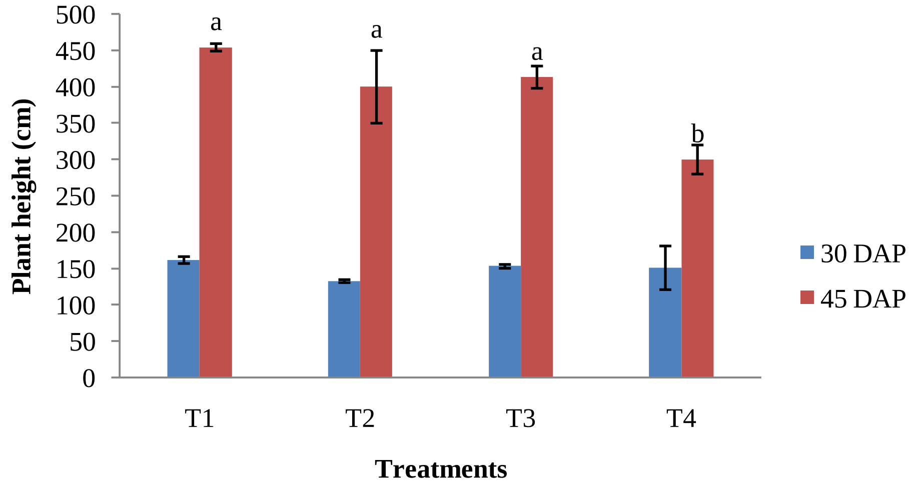

Figure 4.1: Plant height (cm) of Snake gourd on different days after planting (DAP) under different agroforestry systems.

Figures having similar letter (s) means they do not differ significantly. On the other hand, figures bearing different letter (s) differ significantly at 5% level of probability.

Here, T_1= Mango+ Snake gourd + Stem amaranth, T_2= Litchi+ Snake gourd + Stem amaranth, T_3= Mahogany + Snake gourd + Stem amaranth, T_4= Sole cropping of Snake gourd.

4.1.2 Leaf Length (cm)

At various sampling dates, there were no significant differences in the length of Snake gourd leaf length across all treatment groups in the study. At 30 DAP the maximum leaf length was recorded from T_1 (14.667 cm) which was followed by T_3 (14.167 cm) and T_2 (13.33 cm) respectively whereas the lowest leaf length was recorded from T_4 (12.933 cm). At 45 DAP the the maximum leaf length was recorded from T_1 (18.500 cm) which was followed by T_3 and T_2 respectively whereas the lowest leaf length was recorded from T_4 (14.833cm).

Table 4.1: Leaf length (cm) of Sanke gourd on different days after planting (DAP) under different agroforestry systems

Treatments	**Leaf Length (cm)**	
	30 DAP	**45 DAP**
T_1	14.667	18.500
T_2	13.333	16.167
T_3	14.167	16.500
T_4	12.933	14.833
Level of Significance	NS	NS
CV (%)	11.90	9.57

Here, T_1= Mango+ Snake gourd + Stem amaranth, T_2= Litchi+ Snake gourd + Stem amaranth, T_3= Mahogany + Snake gourd + Stem amaranth, T_4= Sole cropping of Snake gourd

4.1.3 Leaf Breadth (cm)

At various sampling dates, there were no significant differences in the leaf breadth of Snake gourd across all treatment groups in the study. The highest leaf breadth at 30 DAP was noted from T_1 (14.53 cm) which was followed by T_2 whereas the lowest leaf length was recorded from both T_3 and T_4 (12.16cm). At 45 DAP the the maximum leaf breadth was recorded from

T_1 (17.50 cm) which was followed by T_3 (15.16 cm) and T_2 (14.16) respectively whereas the lowest leaf breadth was recorded from T_4 (13.33 cm).

Table 4.2: Leaf breadth (cm) of Snake gourd on different days after planting (DAP) under different agroforestry systems.

Treatments	Leaf Breadth (cm)	
	30 DAP	**45 DAP**
T_1	14.533	17.500
T_2	12.833	14.167
T_3	12.167	15.167
T_4	12.167	13.333
Level of Significance	NS	NS
CV (%)	15.36	12.39

Here, T_1= Mango+ Snake gourd + Stem amaranth, T_2= Litchi+ Snake gourd + Stem amaranth, T_3= Mahogany + Snake gourd + Stem amaranth, T_4= Sole cropping of Snake gourd

4.1.4 Number of Branch

At 30 DAP the the maximum branch number was recorded from T_3 (8.333 cm) which was followed by T_1 (6.33 cm) and T_2 (5.33 cm) respectively whereas the lowest branch number was recorded from T_4 (3.666 cm). The number of branch was significant at 5% level of probability.

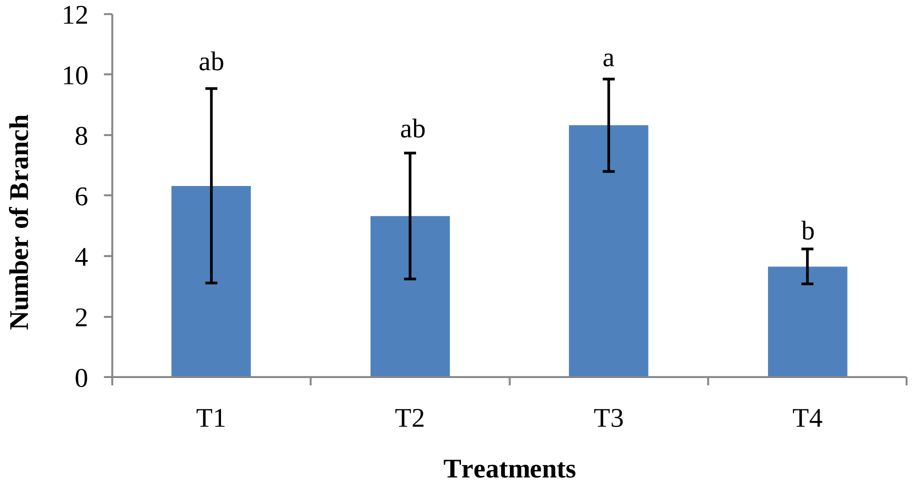

Figure 4.2: Number of branch under different agroforestry systems

Figures having similar letter (s) means they do not differ significantly. On the other hand, figures bearing different letter (s) differ significantly at 5% level of probability.

Here, T_1= Mango+ Snake gourd + Stem amaranth, T_2= Litchi+ Snake gourd + Stem amaranth, T_3= Mahogany + Snake gourd + Stem amaranth, T_4= Sole cropping of Snake gourd

4.1.5 Fruit Length (cm)

The fruit length of the Snake gourd varied significantly among treatments in various agroforestry systems. When comparing the tree crop association treatments, T_1 (under the mango tree) yielded the longest fruit (40.733 cm) which was followed by T_2 (40.20 cm) and T_3 (39.60 cm) respectively whereas T_4 (in open field conditions) treatment produced the shortest fruit (32.133 cm). The fruit length was significant at 5% level of probability.

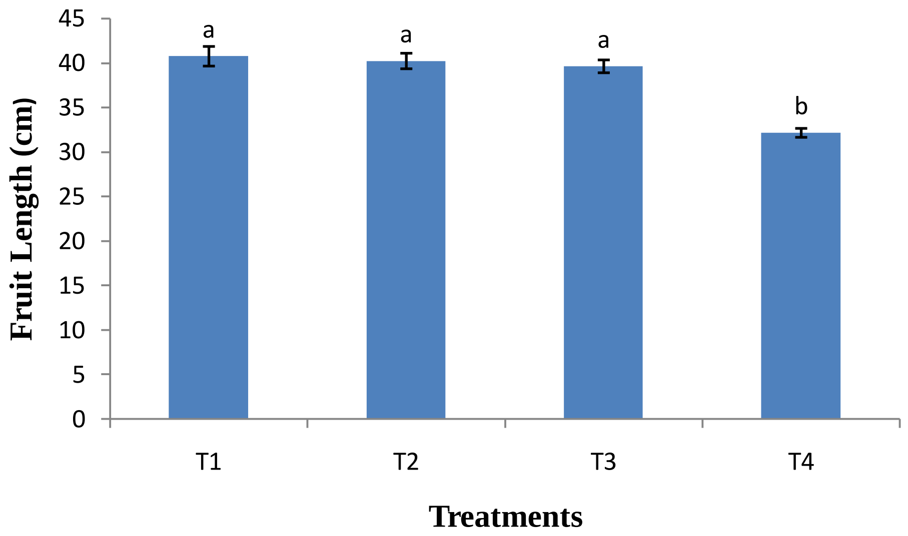

Figure 4.3: Fruit length (cm) of Snake gourd under different agroforestry systems

Figures having similar letter (s) means they do not differ significantly. On the other hand, figures bearing different letter (s) differ significantly at 5% level of probability.

Here, T_1= Mango+ Snake gourd + Stem amaranth, T_2= Litchi+ Snake gourd + Stem amaranth, T_3= Mahogany + Snake gourd + Stem amaranth, T_4= Sole cropping of Snake gourd

4.1.6 Fruit Breadth (cm)

The fruit breadth of the Snake gourd varied significantly in open and multistoried agroforestry systems. The largest fruit breadth was measured in T_1 (13.6 cm) treatment) which was followed by T_2 (13.2 cm) and T_3 (13.16 cm) respectively whereas the shortest fruit breadth was measured in T_4 (11.46 cm) treatment. The fruit breadth was significant at 5% level of probability.

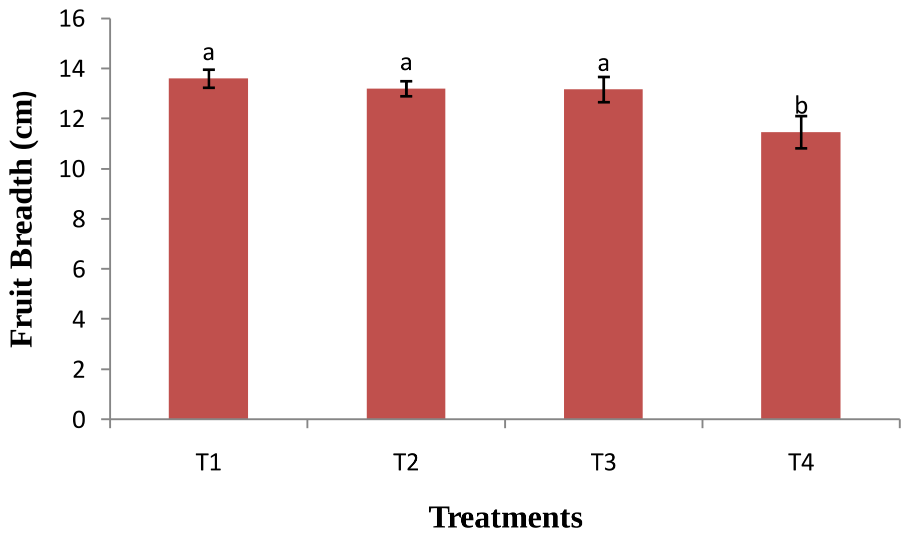

Figure 4.4: Fruit breadth (cm) of Snake gourd under different agroforestry systems

Figures having similar letter (s) means they do not differ significantly. On the other hand, figures bearing different letter (s) differ significantly at 5% level of probability.

Here, T_1= Mango+ Snake gourd + Stem amaranth, T_2= Litchi+ Snake gourd + Stem amaranth, T_3= Mahogany + Snake gourd + Stem amaranth, T_4= Sole cropping of Snake gourd

4.1.7 Fruit Weight (g)

The weight of Snake gourd fruit showed significant differences in open and multistoried agroforestry systems. The maximum fruit weight of the Snake gourd was noted from T_1 (275 g) which was followed by T_3 (223.33 g) and T_2 (186.67 g) respectively whereas the least fruit weight was noted from T_4 (Sole cropping of Snake gourd) and the value was 145 (g).

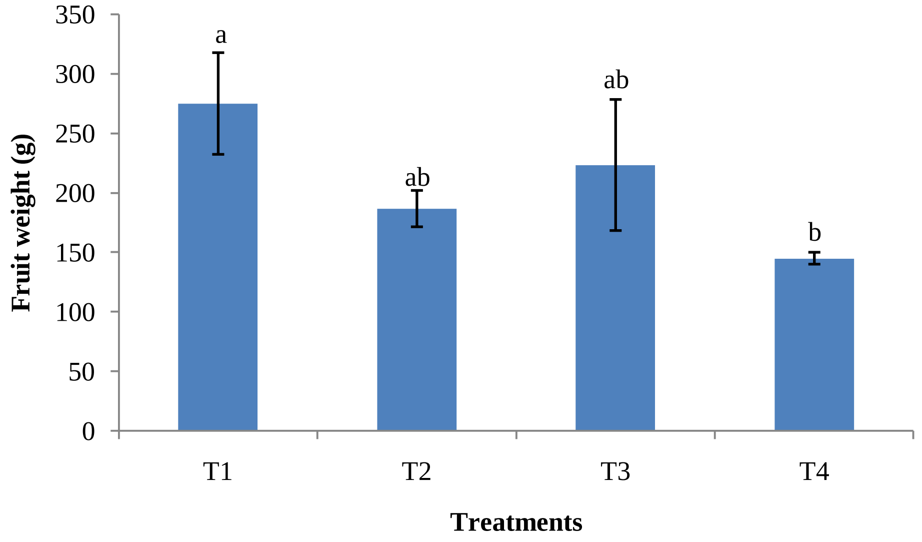

Figure 4.5: Fruit weight (g) of Snake gourd under different agroforestry systems

Figures having similar letter (s) means they do not differ significantly. On the other hand, figures bearing different letter (s) differ significantly at 5% level of probability.

Here, T_1= Mango+ Snake gourd + Stem amaranth, T_2= Litchi+ Snake gourd + Stem amaranth, T_3= Mahogany + Snake gourd + Stem amaranth, T_4= Sole cropping of Snake gourd

4.1.8 Yield (ton/ha)

The T_1 (Mango + Snake gourd +Stem amaranth) produced the highest yield per hectare (22.50 tons) which was followed by T_3 (17.5) and T_2 (12.5) respectively whereas the T_4 (sole Snake gourd) produced the lowest yield (9 tons).The outcome demonstrated that the yield of snake gourd varied significantly between open and agroforestry systems.

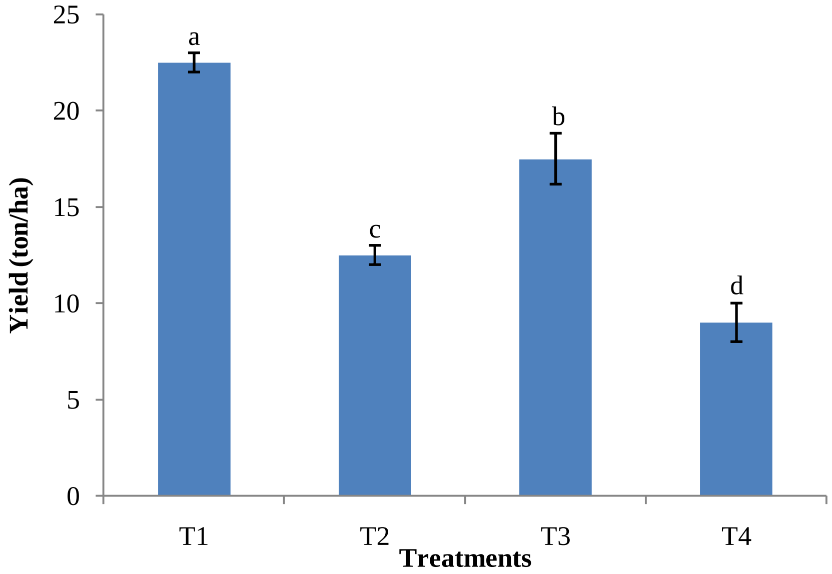

Figure 4.6: Yield (ton/ha) of Snake gourd under different agroforestry systems

Figures having similar letter (s) means they do not differ significantly. On the other hand, figures bearing different letter (s) differ significantly at 5% level of probability.

Here, T_1= Mango+ Snake gourd + Stem amaranth, T_2= Litchi+ Snake gourd + Stem amaranth, T_3= Mahogany + Snake gourd + Stem amaranth, T_4= Sole cropping of Snake gourd

4.2 Growth Parameters of Stem amaranth

4.2.1 Plant Height (cm)

The plants under T_1 treatment had the tallest plants at all sampling dates. At 30 DAS, the maximum plant height was recorded from T_1 (23.00 cm) which was followed by T_3 (18 cm) and T_5 (15 cm) respectively whereas the lowest plant height was recorded from T_2 (14.00 cm). At 45 DAS, the maximum plant height was recorded from T_1 (61.66 cm) which was followed by T_5 (58.33 cm) and T_3 (55.66 cm) respectively whereas the lowest plant height was recorded from T_2 (49.66cm). At 30 DAS and 45 DAS Sampling dates, there were significant differences in the height of stem amaranth across all treatment groups in the study.

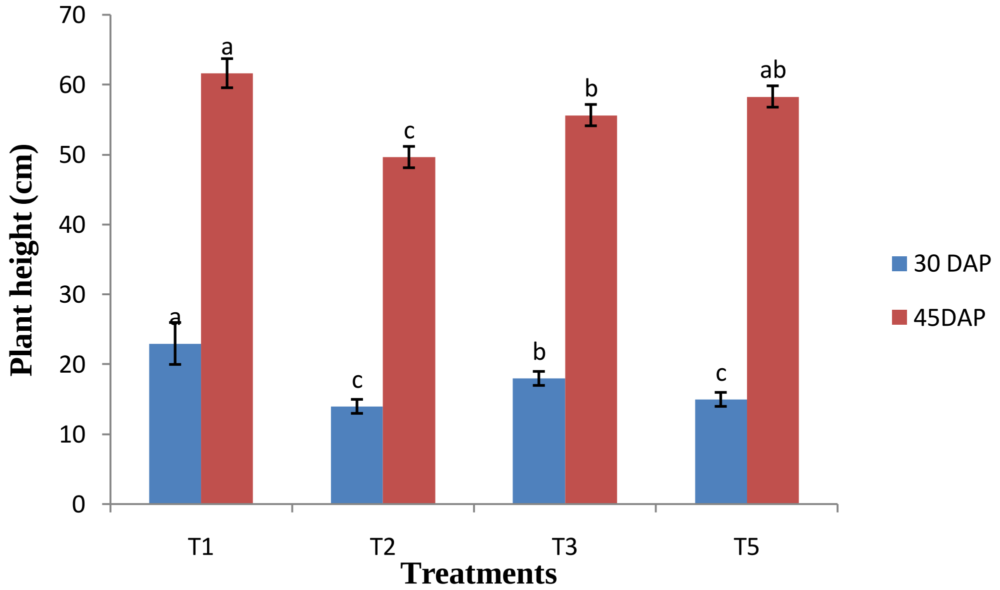

Figure 4.7: Plant height (cm) of Stem amaranth under different agroforestry systems

Figures having similar letter (s) means they do not differ significantly. On the other hand, figures bearing different letter (s) differ significantly at 5% level of probability.

Here, T_1= Mango+ Snake gourd + Stem amaranth, T_2= Litchi+ Snake gourd + Stem amaranth, T_3= Mahogany + Snake gourd + Stem amaranth, T_4= Sole cropping of Snake gourd

4.2.2 Leaf Number

The leaf number of the stem amaranth at 30 and 45 days after sowing, there was no significant differences. At 30 DAS the maximum leaf number was recorded from T_1 (9.00) which was followed by T_3 (8.00) and T_5 (7.00) respectively whereas the lowest leaf number was recorded from T_2 (6.333). At 45 DAS the maximum leaf number was recorded from T_1 (17.00) which was followed by T_5 (16.00) and T_3 (15.337) respectively whereas the lowest leaf number was recorded from T_2 (14.667).

Table 4.3: Number of leaf of Stem amaranth on different days after sowing (DAS) under different agroforestry systems.

Treatments	Number of Leaf	
	30 DAS	**45 DAS**
T_1	9.000	17.00
T_2	6.333	14.667
T_3	8.000	15.337
T_5	7.000	16.000
Level of Significance	NS	NS
CV (%)	12.63	8.73

Here, T_1= Mango+ Snake gourd + Stem amaranth, T_2= Litchi+ Snake gourd + Stem amaranth, T_3= Mahogany + Snake gourd + Stem amaranth, T_4= Sole cropping of Snake gourd

4.2.3 Length of Stem amaranth

At harvesting time, the largest length was recorded from T_1 (78.77 cm) which was followed by T_3 (73.33 cm) and T_5 (72.88 cm) respectively whereas the smallest length was recorded from T_2 (69.778cm). The length of Stem amaranth was statistically significant.

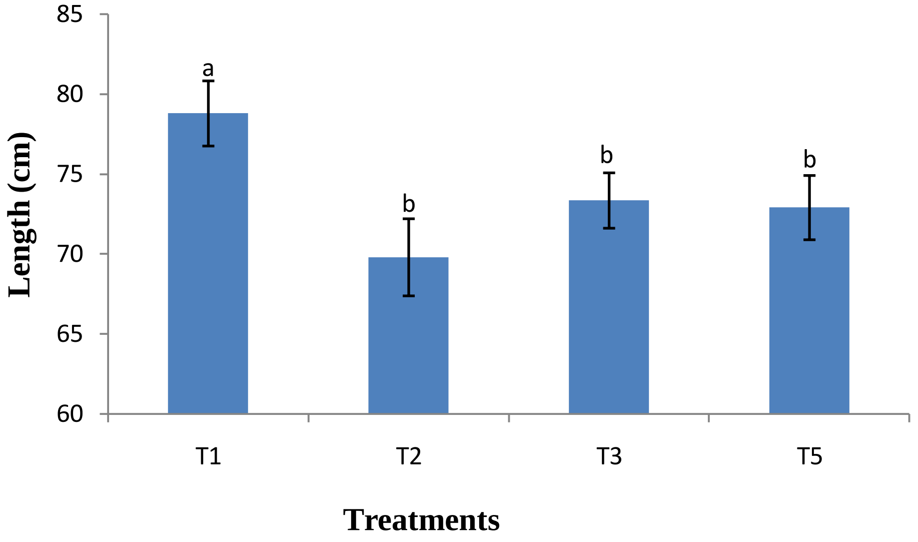

Figure 4.8: Length (cm) of Stem amaranth under different agroforestry systems

Figures having similar letter (s) means they do not differ significantly. On the other hand, figures bearing different letter (s) differ significantly at 5% level of probability.

Here, T_1= Mango+ Snake gourd + Stem amaranth, T_2= Litchi+ Snake gourd + Stem amaranth, T_3= Mahogany + Snake gourd + Stem amaranth, T_4= Sole cropping of Snake gourd

4.2.4 Weight (g) of Stem amaranth

At the time of harvesting, the maximum weight of stem amaranth was recorded from T_1 (38.31 g) which was followed by T_5 (25.84 g) and T_3 (24.51 g) respectively whereas the lowest weight was recorded from T_2 (21.93 g). There were significant differences in the weight of stem amaranth.

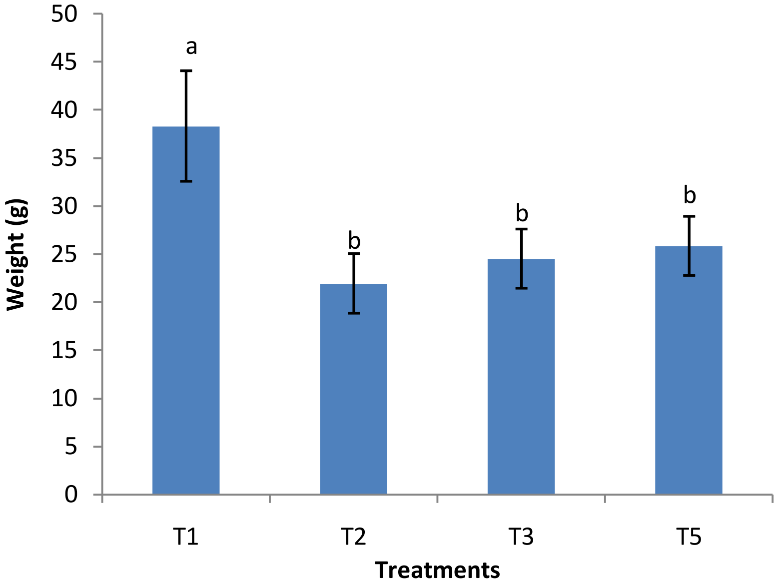

Figure 4.9: Weight (g) of Stem amaranth under different agroforestry systems

Figures having similar letter (s) means they do not differ significantly. On the other hand, figures bearing different letter (s) differ significantly at 5% level of probability.

Here, T_1= Mango+ Snake gourd + Stem amaranth, T_2= Litchi+ Snake gourd + Stem amaranth, T_3= Mahogany + Snake gourd + Stem amaranth, T_4= Sole cropping of Snake gourd

4.2.5 Yield (ton/ha) of Stem amaranth

The yield of stem amaranth showed significant differences in open and multistoried agroforestry systems. The T_1 (Mango + Snake gourd + Stem amaranth) produced the highest yield per hectare (18.997 tons) which was followed by T_5 (14.71 tons) and T_3 (14.44 tons) respectively whereas the T_2 (Litchi + Snake gourd + Stem amaranth) produced the lowest yield per hectare (11.107 tons). The yield (ton/ha) of Stem amaranth was significant at 5% level of probability.

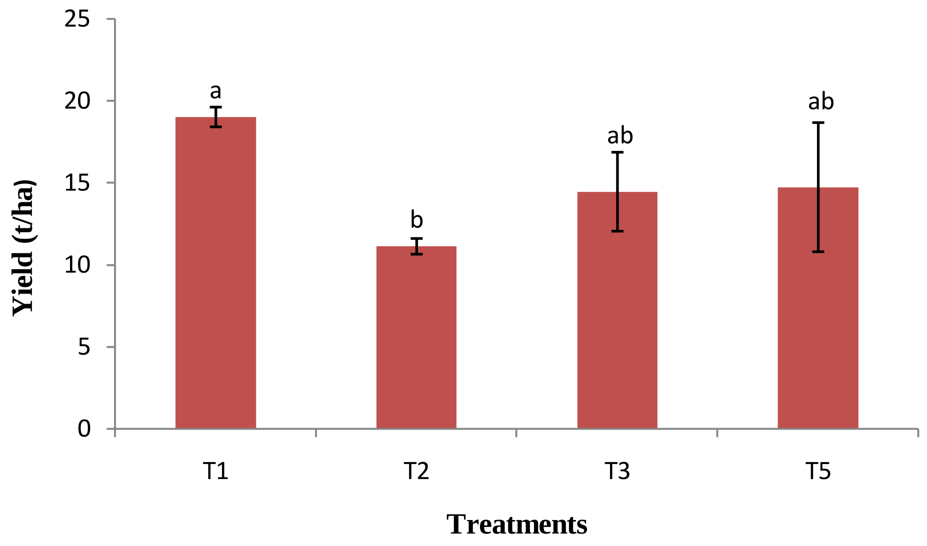

Figure 4.10: Yield (ton/ha) of Stem amaranth under different agroforestry

Figures having similar letter (s) means they do not differ significantly. On the other hand, figures bearing different letter (s) differ significantly at 5% level of probability.

Here, T_1= Mango+ Snake gourd + Stem amaranth, T_2= Litchi+ Snake gourd + Stem amaranth, T_3= Mahogany + Snake gourd + Stem amaranth, T_5= Sole cropping of Stem amaranth

4.3 Economic Analysis

Table 4.4: Economic analysis of Snake gourd and Stem amaranth production under different multistoried agroforestry systems

Treatments	Outcome (Tk/ha)			Gross Returns of the production systems (Tk/ha)	Total cost of production (Tk/ha)	Net Return (Tk/ha)	Benefit Cost Ratio (BCR)	LER
	Trees	Crop						
		Snake gourd	Stem amaranth					
T_1	250000	450000	189970	889970	301540	588430	2.95	2.17
T_2	412800	250000	111070	819570	299250	520320	2.58	3.04
T_3	521250	350000	144400	1015650	292470	723180	3.47	2.52
T_4	0	180000	0	180000	242750	-62750	0.74	-
T_5	0	0	147100	147100	160260	-13160	0.91	-

T_1 = Mango trees + Snake gourd + Stem amaranth, T_2 = Litchi trees + Snake gourd + Stem amaranth, T_3 = Mahogany + Snake gourd + Stem amaranth, T_4 = Sole cropping of Snake gourd, T_5 = Sole cropping of Stem amaranth

4.3.1 Gross returns of the production systems Tk. ha^{-1}

The gross return showed variation among different production systems. The highest gross return (1015650 Tk.) was achieved from T_3 representing the mahogany + snake gourd + stem amaranth –based agroforestry system. The second-highest gross return (889970 Tk.) was achieved from T_1 and the least gross was recorded in T_5 (147100 Tk.) which was sole cropping of stem amaranth following the traditional agriculture.

4.3.2 Total cost of production Tk. ha^{-1}

The highest production cost, amounting to 301540 Tk. per hectare, was observed for T_1 = Mango trees + Snake gourd + Stem amaranth cropping system (Table). In contrast, the sole cropping of Stem amaranth had the lowest production cost at 160260 Tk. Additionally, there were significant differences in costs between sole cropping and multistoried agroforestry systems.

4.3.3 Net return Tk. ha^{-1}

The net return was higher in the T_3, Mahogany + Snake gourd + Stem amaranth -based agroforestry systems, 723180 Tk. (Table 4) followed by T_1 (588430 Tk.) and T_2 (520320 Tk.) respectively. While sole cropping of both Snake gourd (T_4) and Stem amaranth (T_5) showed the loss of the production (-62750 Tk.) for T_4 and (-160260 Tk.) for T_5 .

4.3.4 Benefit-cost ratio

The benefit cost ratio was determined as the highest in the Mahogany + Snake gourd + Stem amaranth –based agroforestry (3.47). The least was determined from T_4 (0.74) sole cropping of Snake gourd (Table)

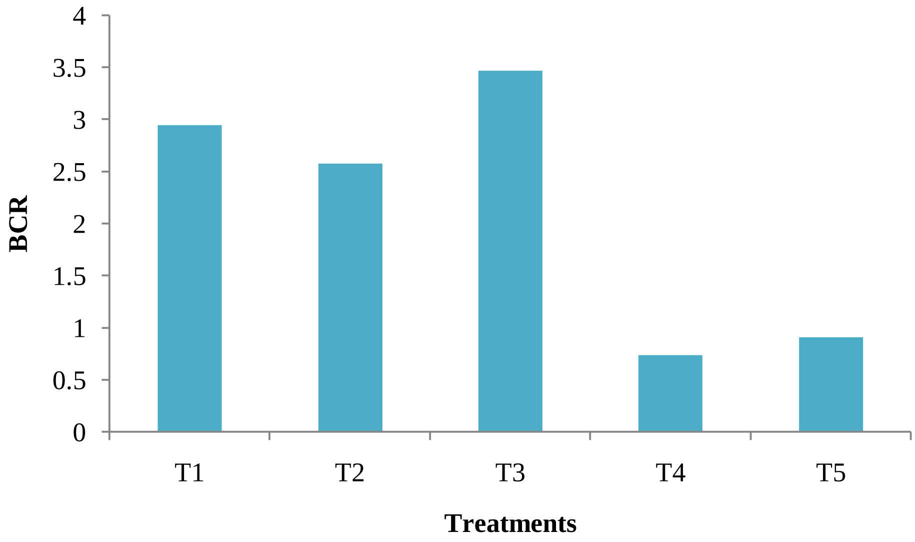

Figure 4.11: BCR of different agroforestry systems

T_1 = Mango trees + Snake gourd + Stem amaranth, T_2 = Litchi trees + Snake gourd + Stem amaranth, T_3 = Mahogany + Snake gourd + Stem amaranth, T_4 = Sole cropping of Snake gourd, T_5 = Sole cropping of Stem amaranth

4.3.5 Land equivalent ratio

According to Table results, the litchi+ snake gourd + stem amaranth –based agroforestry system (T_2) had the highest LER (3.04), while the mango + snake gourd + stem amaranth based agroforestry system (T_1) had the lowest LER (2.17). The tree- crop – based system based on mahogany + snake gourd + stem amaranth had a moderate LER of 2.52 (T_3).

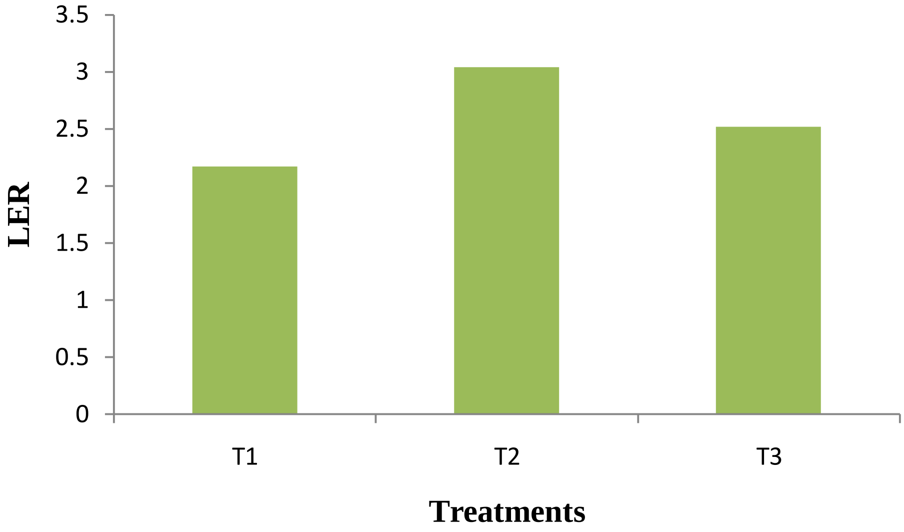

Figure 4.12: LER of different agroforestry systems

T_1 = Mango trees + Snake gourd + Stem amaranth, T_2 = Litchi trees + Snake gourd + Stem amaranth, T_3 = Mahogany + Snake gourd + Stem amaranth

CHAPTER V

DISCUSSION

The experiment findings are presented in the previous chapter under various headings which include components that contribute to the development and yield of the Snake gourd and Stem amaranth. All the attributes, along with references, are covered in this discussion.

Plant development may be strongly impacted by the structural arrangement and variety of the agroforestry setup, according to research on snake gourd plant height in multistoried agroforestry systems. The results of this study among the five treatments showed that the growth parameters of Snake gourd like plant height, leaf length, leaf breadth branch number relatively higher under multistoried agroforestry systems (mango + Snake gourd + Stem amaranth). This may be due to sunlight variation in open fields and under mango trees. The growth parameters of snake gourd were maximum under shade condition might be due to the higher moisture present in shade conditions that supported plant growth. This result was similar to the findings of Rahman *et al*., (2018). Rahman *et al*., (2018) found that Snake gourd plants exhibited greater height in multistoried systems compared to monoculture systems. The layered vegetation structure's facilitation of enhanced microclimatic conditions and higher nutrient availability was the reason for the growth of Snake gourd.

Similar to this, a research by Kumar *et al*. (2021) showed that improved plant height and overall growth performance resulted from integrating snake gourd with other crops and tree species in multistoried systems. According to the research, the shade that the top canopy layers give helps to improve the growing circumstances for the snake gourd plants by reducing extremes in temperature and water stress. These results suggest that the synergistic effects of the many plant species included in multistoried agroforestry systems might be advantageous for the production of snake gourd, encouraging taller and healthier plants.

Additionally, a study by Singh and Patel (2019) found that multistoried snake gourd plants benefited from improved soil quality and moisture retention, which led to an increase in plant height. Growing stronger and taller Snake gourd plants was made possible by the agroforestry system's diversified root systems, which benefited from enhanced soil structure and nutrient cycling. These results were further corroborated by Zhang *et al*., (2020) research, which showed that by maximizing the efficiency of light, water, and nutrient usage, the intricate plant interactions in multistoried agroforestry systems optimize the development conditions for snake gourd plants.

This research findings also showed that the stem amaranth growth parameters like plant height, leaf number were highest in mango based multistoried systems (mango + snake gourd + stem amaranth) and lowest in litchi based multistoried agroforestry systems (litchi +snake gourd + stem amaranth).There are numerous factors that cause variation in growth parameters including soil conditions and nutrient status. The plant growth of stem amaranth was maximum at shady conditions compared to open sunlight might be due to the higher rate of photosynthesis under shady conditions, moisture content of the soil, leaf litter inputs from agroforestry tress. Growth of stem amaranth in open field is comparatively less than mango based agroforestry.

Growing in the shade of fruit trees, such mango and guava, allowed stem amaranth to develop more quickly than in monoculture environments, according to Das *et al*. (2020).

It was suggested that this improvement stemmed from the fruit trees' varied root systems, which enhanced nutrient cycling and microclimate regulation. Findings of this study are similar to the findings of Das *et al*., (2020); chen *et al*., (2019); Rahman *et al*., (2021); Singh & verma (2022). This finding also alings with the research by Gupta *et al*. (2018), which showed that the multistoried agroforestry setup improved soil health and nutrient availability, benefiting the growth performance of understorey crops like Stem amaranth.

In terms of economic analysis, the gross returns, total cost of production, net returns, benefit-cost ratio and land equivalent ratio multistoried agroforestry system for Snake gourd and stem amaranth production found maximum. Agroforestry systems have greater overall costs of production than sole cropping because of the extra demand for supplies, expenditures, and maintenance. They also have higher net returns because of the gross returns from numerous outputs and a higher benefit-cost ratio. The benefit-cost ratio of agroforestry systems based on mahogany has been shown to be greater for a number of reasons than sole cropping agriculture. Firstly, mahogany trees provide high-quality timber that commands premium market prices, significantly enhancing economic returns. Profits can be made from the extra resources that mahogany trees produce, such as firewood (obtained after extensive pruning). Secondly, these systems improve soil fertility through leaf litter and root biomass, which reduces the need for external fertilizers and lowers production costs. In addition to, mahogany's compatibility with various crops allows for diversified income streams, ensuring financial stability. The snake gourd stem amaranth agroforestry system based on mahogany trees yielded a higher economic return (BCR = 3.47) in comparison to the other two multistoried agroforestry systems (Table 4.1).The findings of this study revealed that the findings are similar to the findings of Huth *et al.*, (2012); Wadsworth, (2000); Lamb, (2011). LER measures the relative performance of a component in a crop combination relative to the sole stands of that species (Miah *et al.*, 2018). On the other hand, LER values greater than 1 indicate that intercropping offers benefits in terms of how environmental resources are used for plant development. According to our research, the litchi- snake gourd- and stem amaranth based multistoried agroforestry systems indicates higher Land Equivalent Ratio (3.04), underscoring the efficiency and productivity of such intercropping practices. These systems, which utilize vertical space efficiently, allow for the simultaneous cultivation of litchi in the upper story and snake gourd and stem amaranth in the lower layers, leading to enhanced overall yield. The litchi – snake gourd – stem amaranth based agroforestry systems LER value (3.04) means that 3.04 times more land would be needed to produce the same amount of crop products through sole cropping (Table 4.1). The findings of this study are in accordance with the findings of Akter *et al.*, (2019); Rahman *et al.*, (2020); Chowdhury *et al.*, (2018); Haque *et al.*, (2021).

CHAPTER VI

SUMMARY AND CONCLUSION

6.1 SUMMARY

In this study, the effects of various shade levels on Snake gourd and stem amaranth growth and yield characteristics were examined under several agroforestry production systems. The plants growth contributing parameters such as leaf number, leaf length, leaf breadth, and plant height were evaluated. The yield contributing characteristics such as fruit length, fruit breadth, fruit weight, stem length, stem weight were also evaluated. An economic study that included the benefit- cost ratio, gross return, and total cost of production was also conducted for the production of snake gourd and stem amaranth. Based on the results, it was found that growing snake gourd and stem amaranth under the shade of mango trees yielded good results at various growth phases, including plant height. Notable outcomes were also shown by the multistoried agroforestry system under shade with regard to the fruit length and width of the snake gourd. However, the plant's height and other growth characteristics were reduced by the snake gourd in direct sunlight. Concerning yield parameters, agroforestry involving mango- snake gourd- stem amaranth under shade produced higher yields of snake gourd than snake gourd grown in direct sunlight. An economic study revealed that, in terms of both gross return and net return, the mahogany - snake gourd - stem amaranth (T_3) multistoried agroforestry system was the most practicable. However, the benefit – cost ratio in T_3 agroforestry systems is higher because of the outcome of mahogany trees. This experiment showed that the associated multistoried agroforestry system of snake gourd and stem amaranth yielded a greater economic benefits than sole cropping system. This outcome might be attributed to the snake gourd's satisfactory production in addition to the mango, litchi and stem amaranth crops' high yields.

6.2 Conclusion

The study's findings emphasize the importance of production techniques in determining the development, yield, and economic sustainability of stem amaranth and snake gourd cultivations.

It is clear from the study's findings that the development of snake gourd was not appreciably hampered by the difference in production techniques. In conditions of shade, the growth parameters were at an acceptable level. As a result, in the multistoried agroforestry system, the intercropping of mahogany, snake gourd, and stem amaranth had the greatest BCR.

The greater BCR in the mahogany-based agroforestry system and LER in the litchi-based agroforestry system suggest that the combination of trees and crops is economically competitive and promotes improved land use. The trial results basically showed that the tree-based multistoried agroforestry system is the most effective approach for small-holding farmers in Bangladesh to improve land-use efficiency and financial profitability. Increasing product diversity through the use of a multistoried agroforestry system can strengthen economic resilience. By growing several crops beneath fruit or wood trees, farmers may make the most of their agricultural area. Multistoried agroforestry systems present a multitude of diversified products that not only improve the economic resilience of farming communities but also contribute to environmental sustainability. By integrating various plant species and utilizing different layers of vegetation, these systems optimize resource use, enhance biodiversity, and provide a steady supply of marketable goods, making them a viable strategy for sustainable agriculture and rural development.

6.3 Recommendation

1. This type of research should be expanded to different ecological regions to validate the benefits of these systems under varied environmental conditions.
2. Snake gourd and stem amaranth should be planted repeatedly in association with mango, litchi and mahogany trees for economic profitability.
3. Temperature, photosynthetic active radiation, rainfall, relative humidity etc. should be considered.

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Appendices

Appendix I. Cost analysis under different agroforestry systems

Treatments	TNMIC	MIC						TMIC	TIC =TNMIC +TMIC	OC			TCP= TIC+OC
		Seed	Fer.	Pest.	IR	MC	IPC			IBL 8% of TIC	IVL 8% of TIC	Misc. C 5% TIC	
T_1	57000	25000	40000	35000	20000	30000	20000	170000	227000	18190	45000	11350	301540
T_2	57000	25000	40000	35000	20000	30000	18000	168000	225000	18000	45000	11250	299250
T_3	57000	25000	40000	35000	20000	30000	12000	162000	219000	17520	45000	10950	292470
T_4	45000	30000	30000	30000	15000	25000	0	130000	175000	14000	45000	8750	24750
T_5	40000	7000	20000	12000	8000	15000	0	62000	102000	8160	45000	5100	160260

Appendix II. Returns from tree and crop (ton ha^{-1})

Treatments	Outcome from tree (Tk./ha)			Outcome from crop (Tk./ha)		Total
	Mango	Litchi	Mahogany	Snake gourd	Stem amaranth	
T_1	250000	0	0	450000	189970	889970
T_2	0	412800	0	250000	111070	819570
T_3	0	0	521250	350000	144400	1015650
T_4	0	0	0	180000	0	180000
T_5	0	0	0	0	147100	147100

N.B. Market value of Snake gourd 20000 Tk. per ton (20 Tk. per kg)

Market value of Stem amaranth 10000 Tk. per ton (10 Tk. per kg)

Market value of Mango 40000 Tk. per ton (40 Tk. per kg)

Market value of Litchi (800 per 100 piece)

Market value of Mahogany (1875 per year) Rotational year 15

Appendix III. Analysis of Variance (ANOVA) of Snake gourd Plant Height (cm) at Different DAPs

Randomized Complete Block AOV Table for Plant Height at 30 DAP

Source	**DF**	**SS**	**MS**	**F**	**P**
Replication	2	460.67	230.333		
Treatment	3	1337.58	445.861	1.89	0.2317
Error	6	1412.67	235.444		
Total	11	3210.92			

Grand Mean 149.58
CV 10.26

Randomized Complete Block AOV Table for Plant Height at 45 DAP

Source	**DF**	**SS**	**MS**	**F**	**P**
Replication	2	1463.2	731.6		
Treatment	3	38605.6	12868.5	15.90	0.0029
Error	6	4856.2	809.4		
Total	11	44924.9			

Grand Mean 391.92
CV 7.26

Appendix IV. Analysis of Variance (ANOVA) of Snake gourd Leaf Length (cm) at Different DAPs

Randomized Complete Block AOV Table for Leaf Length at 30 DAP

Source	**DF**	**SS**	**MS**	**F**	**P**
Replication	2	2.0150	1.00750		
Treatment	3	5.5558	1.85194	0.69	0.5907
Error	6	16.1117	2.68528		
Total	11	23.6825			

Grand Mean 13.775
CV 11.90

Randomized Complete Block AOV Table for Leaf Length at 45 DAP

Source	**DF**	**SS**	**MS**	**F**	**P**
Replication	2	11.3750	5.68750		
Treatment	3	20.6667	6.88889	2.76	0.1338
Error	6	14.9583	2.49306		
Total	11	47.0000			

Grand Mean 16.500
CV 9.57

Appendix V. Analysis of Variance (ANOVA) of Snake gourd Leaf Breadth (cm) at Different DAPs

Randomized Complete Block AOV Table for Leaf Breadth at 30 DAP

Source	DF	SS	MS	F	P
Replicati	2	5.6600	2.83000		
Treatment	3	11.2358	3.74528	0.95	0.4738
Error	6	23.6467	3.94111		
Total	11	40.5425			

Grand Mean 12.925
CV 15.36

Randomized Complete Block AOV Table for Leaf Breadth at 45 DAP

Source	DF	SS	MS	F	P
Replicati	2	15.1667	7.58333		
Treatment	3	29.2292	9.74306	2.81	0.1305
Error	6	20.8333	3.47222		
Total	11	65.2292			

Grand Mean 15.042
CV 12.39

Appendix VI. Analysis of Variance (ANOVA) of Snake gourd Number of Branch

Randomized Complete Block AOV Table for Number of Branch

Source	DF	SS	MS	F	P
Replicati	2	22.1667	11.0833		
Treatment	3	34.2500	11.4167	5.48	0.0374
Error	6	12.5000	2.0833		
Total	11	68.9167			

Grand Mean 5.9167
CV 24.40

Appendix VII. Analysis of Variance (ANOVA) of Snake gourd Fruit length (cm)

Randomized Complete Block AOV Table for Fruit length

Source	DF	SS	MS	F	P
Replicati	2	4.027	2.0133		
Treatment	3	147.533	49.1778	201.18	0.0000
Error	6	1.467	0.2444		
Total	11	153.027			

Grand Mean 38.167
CV 1.30

Appendix VIII. Analysis of Variance (ANOVA) of Snake gourd Fruit Breadth (cm)

Randomized Complete Block AOV Table for Fruit Breadth

Source	DF	SS	MS	F	P
Replicati	2	0.34667	0.17333		
Treatment	3	8.09583	2.69861	11.35	0.0069
Error	6	1.42667	0.23778		
Total	11	9.86917			

Grand Mean	12.858
CV	3.79

Appendix IX. Analysis of Variance (ANOVA) of Snake gourd Fruit Weight (g)

Randomized Complete Block AOV Table for Fruit weight

Source	DF	SS	MS	F	P
Replicati	2	3037.5	1518.75		
treatment	3	27441.7	9147.22	7.63	0.0180
Error	6	7195.8	1199.31		
Total	11	37675.0			
Grand Mean	207.50				
CV	16.69				

Appendix X. Analysis of Variance (ANOVA) of Snake gourd Yield (ton/ha)

Randomized Complete Block AOV Table for Yield

Source	DF	SS	MS	F	P
Replicati	2	0.500	0.250		
treatment	3	312.563	104.188	104.19	0.0000
Error	6	6.000	1.000		
Total	11	319.063			

Grand Mean	15.375
CV	6.50

Appendix XI. Analysis of Variance (ANOVA) of Stem amaranth Plant Height (cm) at Different DAS

Randomized Complete Block AOV Table for Plant Height at 30 DAS

Source	DF	SS	MS	F	P
Replicati	2	15.500	7.7500		
Treatment	3	147.000	49.0000	34.59	0.0003
Error	6	8.500	1.4167		
Total	11	171.000			

Grand Mean	17.500
CV	6.80

Randomized Complete Block AOV Table for Plant Height at 45 DAS

Source	DF	SS	MS	F	P
Replicati	2	3.167	1.5833		
Treatment	3	232.000	77.3333	23.79	0.0010
Error	6	19.500	3.2500		
Total	11	254.667			

Grand Mean 56.333
CV 3.20

Appendix XII. Analysis of Variance (ANOVA) of Stem amaranth Number of leaf at Different DAS

Randomized Complete Block AOV Table for No. of Leaf at 30 DAS

Source	DF	SS	MS	F	P
Replicati	2	1.1667	0.58333		
Treatment	3	12.2500	4.08333	4.45	0.0570
Error	6	5.5000	0.91667		
Total	11	18.9167			

Grand Mean 7.5833
CV 12.63

Randomized Complete Block AOV Table for No. of Leaf at 45 DAS

Source	DF	SS	MS	F	P
Replicati	2	2.0000	1.00000		
Treatment	3	8.9167	2.97222	1.57	0.2909
Error	6	11.3333	1.88889		
Total	11	22.2500			

Grand Mean 15.750
CV 8.73

Appendix XIII. Analysis of Variance (ANOVA) of Stem amaranth Length (cm)

Randomized Complete Block AOV Table for L

Source	DF	SS	MS	F	P
Replicati	2	19.822	9.9112		
Treatment	3	125.866	41.9554	17.75	0.0022
Error	6	14.183	2.3638		
Total	11	159.871			

Grand Mean 73.693
CV 2.09

Appendix XIV. Analysis of Variance (ANOVA) of Stem amaranth Weight (g)

Randomized Complete Block AOV Table for Weight

Source	DF	SS	MS	F	P
Replicati	2	37.681	18.841		
Treatment	3	478.682	159.561	11.19	0.0072
Error	6	85.567	14.261		
Total	11	601.930			

Grand Mean 27.652
CV 13.66

Appendix XV. Analysis of Variance (ANOVA) of Stem amaranth Yield (ton/ha)

Randomized Complete Block AOV Table for Yield

Source	DF	SS	MS	F	P
Replicati	2	23.363	11.6816		
Treatment	3	94.165	31.3884	9.22	0.0115
Error	6	20.422	3.4037		
Total	11	137.951			

Grand Mean 14.815
CV 12.45

Appendix XVI.Some pictures of my experiment