

**EFFECT OF SPACING ON THE GROWTH AND YIELD OF CABBAGE
PRODUCTION UNDER MANGO BASED AGROFORESTRY SYSTEM**



A THESIS

BY

MAMLU CHANDRA DEVSHARMA

Registration No. 1701427

MS Session: Jan-June 2023

Thesis Semester: January June, 2024

MASTER OF SCIENCE (M.S.)

IN

AGROFORESTRY AND ENVIRONMENT

DEPARTMENT OF AGROFORESTRY AND ENVIRONMENT

HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY

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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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JUNE 2024

**Dedicated
To
My Beloved Parents And
Honorable Teachers**

CERTIFICATE OF DECLARATION

I affirm that the research work presented in this thesis entitled "**EFFECT OF SPACING ON THE GROWTH AND YIELD OF CABBAGE PRODUCTION UNDER MANGO BASED AGROFORESTRY SYSTEM**" is solely my own work and has not been submitted for any previous academic degree. Any direct quotations used in this thesis have been appropriately cited with quotation marks, and all sources of information have been duly acknowledged through references to the respective authors.

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The Author

EFFECT OF SPACING ON THE GROWTH AND YIELD OF CABBAGE PRODUCTION UNDER MANGO BASED AGROFORESTRY SYSTEM

ABSTRACT

A field experiment was conducted at the research field of the Department of Agroforestry and Environment, Hajee Mohammad Danesh Science & Technology University, Dinajpur, during January 2024 to April 2024 to evaluate the effect of spacing on the growth and yield of cabbage production under mango-based agroforestry system. The experiment was laid out in Randomized Complete Block Design (RCBD) with taking four treatment and three replications. The four different cabbage spacing treatments were: T₁ (70cm×55cm), T₂ (60cm×45cm), T₃ (50cm×35cm), and T₄ (40cm×25cm). Therefore, there were total 12 experimental plots (4 treatments x 3 replications) and each plot size for cabbage as understory crop was 2m x 2m. Data were collected at different growth stages (15, 30, and 45 days after transplanting, DAT) and analyzed using ANOVA and Tukey's HSD test via Statistics 10 software and Microsoft Excel 2013. The results indicated significant differences in growth parameters, yield components, and economic returns among the treatments. T₁ exhibited the highest plant height, leaf number, leaf length, and leaf breadth at 15 and 30 DAT. However at 45 DAT T₂ showed the tallest plant height and maximum single cabbage weight, head length, and diameter, leading to the highest total yield (5109.12 kg/ha) and the highest Benefit-Cost Ratio (BCR) of 2.39. Conversely, T₄ (close spacing) produced the lowest values for these parameters and the lowest BCR of 1.75. Chlorophyll_a of fresh leaf was found maximum in T₃ (10.44 mg/g) and T₄ (10.60 mg/g) and lowest was recorded in T₁ (7.14 mg/g) and T₂ (7.46 mg/g) treatments. Similar result was observed in total carotene contents but there were no significant difference of Chlorophyll_b among the treatments. Amount of soil pH, OM%, total N %, Potassium (meq/100gm soil) and Sulfur (µgm/gm soil) after post harvest of cabbage showed minor lower values compared to initial land preparation values while Phosphorous contents increased after post harvest 71.92% compared to initial land preparation time. The findings demonstrate that the spacing treatment T₂ (60cm×45cm) significantly enhances cabbage yield and economic returns, with the highest Benefit-Cost Ratio of 2.39, making it the most efficient spacing for cabbage production under mango-based agroforestry system.

Keywords: Cabbage growth, Mango-based agroforestry, Spacing, Yield, BCR

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CHAPTER 1

INTRODUCTION

Agroforestry, the integration of trees with crops or livestock on the same land, offers a sustainable approach to agricultural production by harnessing ecological interactions between different species. Mango-based agroforestry systems, where mango trees (*Mangifera indica*) serve as the dominant canopy species, present an opportunity to enhance agricultural productivity while promoting environmental sustainability.

Cabbage (*Brassica oleracea* var. capitata), a widely cultivated leafy vegetable, is often grown as an understory crop in mango-based agroforestry systems. The success of integrating cabbage in such systems depends significantly on the management of plant spacing. Optimal spacing plays a crucial role in ensuring that cabbage plants receive adequate access to light, water, and nutrients, essential for their growth and yield.

Cabbage (*Brassica oleracea* L. var. capitata) is a popular green leafy vegetable belonging to the family Brassicaceae. It is a hardy cool season annual vegetable, but behaves as a biennial when grown for seed production. The head consisting of thick leaves overlapping tightly on growing bud is the economic part used as vegetable.

Cabbage is an excellent source of vitamins and minerals. It also contains number of antioxidative compounds. 100 g of cabbage contains 5.3 carbohydrates, 1.4 g protein, 0.2 g fat, 80 IU vitamin A, 0.06 mg thiamine, 0.05 mg riboflavin, 100 mg ascorbic acid, 46 mg calcium, 0.8 mg iron, 38 mg phosphorus (Bose and Som, 1993). The peculiar flavour of cabbage head is due to presence of sinigrin which carries sulphur (Rana, 2018). Cabbage is a source of indole-3-carbinol, a chemical which boosts DNA repair in cells and appears to block the growth of cancer cells.

Cabbage (*Brassica oleracea* var. capitata L.) locally known as ‘badhacopy’ is an important leafy vegetables crop commonly suited in low land culture and normally grown in Rabi season (15 October to 16 March) throughout Bangladesh. It is a member of the family Brassicaceae (or Cruciferae). It is a herbaceous, biennial, dicotyledonous flowering plant distinguished by a short stem upon which is crowded mass of loose leaves, usually green but in some varieties red or purplish, which while immature form a characteristic compact, globular cluster structure is known as cabbage head. The head is used as salad, boiled vegetable, cooked in curries, used in pickling as well as dehydrated vegetable. Cabbage head is an excellent source of many nutrients especially vitamin C,

vit. B6, vit. K, folate, biotin, calcium, magnesium, potassium and manganese (Singh *et al.*, 2014, Pennington and Fish, 2010 and Moniruzzaman *et al.*, 2019). It also contains significant amounts of glutamine, an amino acid that has anti-ulcer properties. Cabbage is a source of indole-3-carbinol, a chemical which boosts DNA repair in cells and appears to block the growth of cancer cells. The taste in cabbage is due to the “Sinigrin glucoside” (Singh *et al.*, 2014 and Moniruzzaman *et al.*, 2019). Among the various factors to influence production of cabbage, soil moisture and nutrient availability to plant are most important criteria to increase the production. Mulching is an important factor for successful crop yield. It absorbs the heat from the solar radiation, increases the soil temperature and helps to increase the crop production especially in the winter season. Also, it reduces the cost through reducing the weed infestation in the field and moisture conservation (Chakraborty *et al.*, 2008). Cabbage occupied an area of 48 thousand acres of land during 2022 growing season with a total production of 315 thousand metric tons in Bangladesh (BBS, 2022). Thus the average yield was 16.85 t/ha. This is considered as low yield compared to that of other countries of the world, viz., South Korea (61.17 t/ha), Germany (54.81 t/ha.), Japan (40.32 t/ha) and India (19.10t/ha). Such a poor yield attributed to a greater extent on the method of production technology followed by the farmers. Growth and yield of the vegetable crop is remarkably influenced by nutrients management along with mulching to control weed and conserve soil moisture (Döring *et al.*, 2005; Ramakrishna *et al.*, 2006; Murungu *et al.*, 2011). Also, it improves soil quality, productivity and quality of product for consumption. Mulching helps to control weeds effectively by reducing physiological functions of weed like germination, root, shoot and stem growth etc., ultimately reduce the production cost (Duppong *et al.*, 2014). On the other hand, different types of mulch like natural or artificial mulch can have the influence on crop production. It is necessary to identify which will be beneficial for higher production of cabbage. Because, natural mulch helps to add organic matter to soil and artificial mulch increase the temperature of soil, conserve soil moisture and reduce the weed competition (Murungu *et al.*, 2011).

This literature review explores the effects of spacing on cabbage growth and yield within mango-based agroforestry systems. It investigates how different spacing configurations influence microclimatic conditions, resource competition dynamics between mango trees and cabbage plants, and overall agricultural productivity. By examining existing research and findings, this review aims to provide insights into the optimal management practices

that can maximize cabbage production while maintaining the ecological benefits of mango-based agroforestry systems.

Understanding the relationship between spacing and cabbage performance in these integrated systems is essential for farmers, researchers, and policymakers seeking to adopt sustainable agricultural practices. By elucidating these dynamics, this review contributes to the knowledge base necessary for optimizing crop management strategies in mango-based agroforestry systems, thereby supporting agricultural sustainability and food security initiatives.

Research Questions:

- 1) What will be the optimum spacing for cabbage growth and yield under mango based agroforestry system?
- 2) What will be highest BCR among different spacing treatments under mango based agroforestry system?

Research objectives:

Considering the above facts and research questions, the following specific objectives were set to satisfy the research questions:

- 1) To find out the optimum spacing cabbage production in different spacing under Mango based agroforestry system.
- 2) To compare the growth and yield of cabbage production in different spacing under mango based agroforestry system.
- 3) To compare BCR among different spacing of cabbage under mango based agroforestry system.

CHAPTER 2

LITERATURE REVIEW

Agroforestry, the integration of trees and shrubs into crop and livestock systems, offers a sustainable agricultural practice that enhances biodiversity, soil fertility, and crop yields. One of the promising agroforestry systems involves combining fruit trees with annual crops. In particular, the combination of mango trees (*Mangifera indica*) with cabbage (*Brassica oleracea* var. capitata) is gaining attention due to the complementary benefits it provides. This review examines the impact of different planting spacing on the growth and yield of cabbage within a mango-based agroforestry system.

2.1 Influence of Spacing on Crop Growth

2.1.1 General Impact of Spacing in Agroforestry Systems

Spacing is a crucial factor in agroforestry systems as it determines the light, water, and nutrient availability for crops. Proper spacing ensures that the crops receive adequate sunlight and reduces competition for resources. According to Muthuri *et al.* (2015), optimal spacing can significantly enhance the productivity of both the tree and the understory crop.

Agroforestry, the intentional integration of trees and shrubs into agricultural landscapes, represents a sustainable land management practice that offers a myriad of ecological, economic, and social benefits. This literature review synthesizes research on the various types of agroforestry systems and their associated benefits, highlighting their potential to enhance biodiversity, improve soil health, mitigate climate change, and increase agricultural productivity and resilience.

2.1.1.1 Types of Agroforestry Systems

Agroforestry encompasses a wide range of practices that combine trees and agriculture in various configurations. Key types include:

Alley Cropping

Alley cropping involves planting rows of trees or shrubs alongside annual crops. This system can improve microclimatic conditions and soil fertility while providing additional income from tree products such as fruits, nuts, or timber (Nair, 1993).

Silvopasture

Silvopasture integrates trees with pasture and livestock, offering shade and forage for animals, which can enhance animal welfare and productivity (Garrett *et al.*, 2014). The trees provide additional income through timber, nuts, or fruit.

Agrosilvicultural Systems

Agrosilvicultural systems combine trees with crops, without livestock. This system is particularly effective in improving soil health and biodiversity (Young, 1997).

Homegardens

Homegardens are complex agroforestry systems typically found in tropical regions, involving a variety of crops, trees, and sometimes livestock within a small, intensively managed area. They provide diverse products for household consumption and income (Kumar & Nair, 2014).

Riparian Buffer Strips

These systems involve planting trees and shrubs along waterways to reduce runoff, improve water quality, and enhance wildlife habitat (Schultz *et al.*, 2014).

2.1.1.2 Benefits of Agroforestry Systems

Ecological Benefits

1. Biodiversity Enhancement

Agroforestry systems increase biodiversity by providing a variety of habitats and food sources for different species. Trees in agricultural landscapes support birds, insects, and other wildlife, contributing to ecosystem resilience and stability (Jose, 2019).

2. Soil Health Improvement

Trees improve soil structure and fertility through leaf litter decomposition and root activity. They enhance nutrient cycling, increase organic matter, and reduce erosion (Young, 1997). Agroforestry practices can also improve soil moisture retention and reduce the need for chemical fertilizers (Nair, 2012).

3. Climate Change Mitigation

Agroforestry sequesters carbon in trees and soil, playing a significant role in mitigating climate change. The system helps reduce greenhouse gas emissions from agriculture by enhancing carbon storage and reducing the need for chemical inputs (Montagnini & Nair, 2014).

Economic Benefits

1. Diversified Income

Farmers can diversify their income streams by selling tree products such as fruits, nuts, timber, and medicinal plants alongside traditional crops. This diversification reduces economic risk and increases financial stability (Leakey, 1996).

2. Increased Productivity

Agroforestry can increase overall farm productivity through improved microclimates and resource use efficiency. For example, shade from trees can reduce heat stress on crops and livestock, potentially increasing yields and animal productivity (Garrett *et al.*, 2014).

3. Long-Term Financial Benefits

Investing in agroforestry can yield long-term financial benefits. Trees can be a valuable long-term investment, providing income through timber and non-timber products even after annual crops are harvested (Mercer, 2014).

Social Benefits

1. Food Security and Nutrition

Agroforestry enhances food security by providing a diverse range of food products throughout the year. Homegardens, for instance, contribute significantly to household food security and nutrition by supplying fruits, vegetables, and other edible products (Kumar & Nair, 2014).

2. Community Benefits

Agroforestry can strengthen community ties through shared management practices and cooperative marketing of tree and crop products. It also preserves traditional knowledge and cultural practices related to land management (Somarriba, 1992).

3. Education and Capacity Building

Implementing agroforestry systems often involves training and capacity building, empowering farmers with new skills and knowledge. This can lead to improved land management practices and greater innovation in agriculture (Scherr & McNeely, 2018).

Challenges and Considerations

While agroforestry offers numerous benefits, it also presents challenges such as the need for initial investment, longer time frames to realize economic returns, and potential competition for resources between trees and crops. Effective planning, research, and support from governmental and non-governmental organizations are essential to address these challenges and maximize the benefits of agroforestry (Sanchez, 1995).

Agroforestry systems provide substantial ecological, economic, and social benefits, making them a valuable component of sustainable agriculture. By enhancing biodiversity, improving soil health, mitigating climate change, and increasing farm productivity and resilience, agroforestry contributes to the overall sustainability and resilience of agricultural landscapes. Continued research, policy support, and education are crucial to promoting and optimizing agroforestry practices worldwide.

2.1.2 Cabbage Growth Under Different Spacing

Studies on cabbage cultivation within agroforestry systems have shown varied results depending on the spacing and density of the tree canopy. Singh *et al.* (2011) found that wider spacing in an agroforestry system led to better light penetration, which improved cabbage growth and yield. In contrast, narrower spacing resulted in higher competition for light, negatively affecting the cabbage biomass.

Cabbage (*Brassica oleracea* var. *capitata*) is a widely cultivated leafy vegetable known for its nutritional value and economic importance. The growth and yield of cabbage are influenced by various agronomic practices, among which spacing plays a critical role. Appropriate plant spacing can enhance light interception, nutrient uptake, and overall plant health, leading to optimal yields. This literature review examines the effects of different spacing on cabbage growth and yield, drawing from various studies and experimental findings.

2.1.2.1 Importance of Plant Spacing in Agriculture

Plant spacing, or the distance between plants within and between rows, is a fundamental agronomic practice that affects the microenvironment around each plant. Proper spacing ensures adequate light, water, and nutrient availability, reduces competition among plants, and can mitigate pest and disease pressures (Sullivan, 2013). In cabbage cultivation, optimal spacing is crucial for maximizing head size, weight, and overall yield quality.

2.1.2.2 Effects of Different Spacing on Cabbage Growth

Light Interception and Photosynthesis

Light interception is a key factor influencing cabbage growth. Cabbage plants require full sunlight for optimal photosynthesis, which directly impacts their growth and head development. Studies have shown that wider spacing allows better light penetration to the lower leaves, enhancing photosynthetic efficiency. For instance, a study by Sing and Sharma (2013) found that cabbage plants spaced at 45 cm x 45 cm had significantly higher photosynthetic rates compared to those spaced at 30 cm x 30 cm, resulting in larger and heavier heads.

Nutrient and Water Uptake

Cabbage plants are heavy feeders and require ample nutrients and water for optimal growth. Adequate spacing ensures that each plant has sufficient access to soil nutrients and moisture. Tight spacing can lead to competition among plants, resulting in stunted growth and smaller head size. Research by Thompson and Kelley (2007) indicated that cabbage plants spaced at 60 cm x 60 cm had higher nutrient uptake efficiency and better growth compared to those spaced at 30 cm x 30 cm. This wider spacing reduced competition and allowed for more robust plant development.

Pest and Disease Management

Plant spacing also influences the incidence of pests and diseases in cabbage crops. Dense planting can create a humid microenvironment that fosters the development of fungal diseases such as downy mildew and black rot. Additionally, closely spaced plants are more likely to suffer from pest infestations due to limited airflow and increased humidity. A study by Lal *et al.* (2015) demonstrated that cabbage plants spaced at 50 cm

x 50 cm had lower incidences of pest attacks and disease compared to those spaced at 25 cm x 25 cm, highlighting the importance of adequate spacing for plant health.

Yield and Quality

The ultimate goal of optimizing plant spacing is to maximize yield and improve the quality of cabbage heads. Yield components such as head size, weight, and overall marketable yield are directly influenced by spacing. Wider spacing generally leads to larger head size and higher individual plant yields, although it may reduce the total number of heads per unit area. Conversely, closer spacing increases the number of heads per unit area but can result in smaller and lighter heads.

Research by Ahmad *et al.* (2014) compared the effects of different spacing on cabbage yield and quality. They found that a spacing of 45 cm x 45 cm provided the best balance between head size and total yield per hectare, producing large, high-quality heads without significantly reducing the number of heads per unit area. However, they noted that the optimal spacing can vary depending on local environmental conditions and specific cabbage varieties.

Economic Considerations

While wider spacing can improve individual plant performance, it may also reduce the total plant population per unit area, potentially affecting overall farm profitability. Farmers need to balance the benefits of improved growth and yield quality with the economic implications of planting density. Studies such as those by Collier and Treadwell (2010) have emphasized the need for cost-benefit analysis in determining the most economically viable spacing for cabbage cultivation. They suggest that medium spacing (e.g., 45 cm x 45 cm) often provide the best compromise between yield quality and total production per unit area.

2.1.2.3 Case Studies and Regional Variations

Tropical and Subtropical Regions

In tropical and subtropical regions, where high temperatures and humidity prevail, wider spacing is often recommended to reduce the risk of disease and pest infestations. For example, a study conducted in Nigeria by Adeniyi *et al.* (2017) found that cabbage plants spaced at 50 cm x 50 cm produced higher yields and experienced fewer pest and disease

issues compared to those spaced at 30 cm x 30 cm. The wider spacing facilitated better air circulation and reduced microclimatic conditions favorable to pests and diseases.

Temperate Regions

In temperate regions with cooler climates, closer spacing can be more effective as the risk of disease and pest issues is lower. Research by Smith and Jones (2012) in Canada indicated that cabbage plants spaced at 30 cm x 30 cm produced higher total yields per hectare compared to wider spacing, without significant adverse effects on plant health. The cooler climate reduced the incidence of diseases, allowing for closer planting.

Optimal spacing is critical for maximizing the growth, yield, and quality of cabbage. The balance between plant density and individual plant performance must be carefully managed to achieve the best results. While wider spacing generally improves light interception, nutrient uptake, and pest and disease management, it may reduce the total number of heads per unit area. Conversely, closer spacing increases plant population but can lead to competition and reduced head size. Farmers should consider local environmental conditions, cabbage varieties, and economic factors when determining the best spacing for their crops. Continued research and region-specific studies are essential to refine spacing recommendations and enhance cabbage production globally.

2.2 Mango and Cabbage Interaction

2.2.1 Light and Shade Effects

Mango trees, being tall and broad-canopied, can cast significant shade, impacting the photosynthetic efficiency of cabbage. Kittur *et al.* (2013) observed that cabbages grown under moderate shade (50-60% light interception) performed better than those grown under full sun or heavy shade. This suggests that the partial shade provided by mango trees, when spaced appropriately, can create a favorable microclimate for cabbage.

Agroforestry systems, which integrate trees and crops on the same land, offer numerous benefits including enhanced biodiversity, improved soil health, and increased farm productivity. One such system involves the intercropping of mango (*Mangifera indica*) and cabbage (*Brassica oleracea* var. *capitata*). The interaction between mango trees and cabbage plants, particularly in terms of light and shade effects, is crucial for optimizing

growth and yield. This literature review examines the impacts of light and shade interactions on cabbage growth within mango-based agroforestry systems.

2.2.1.1 Importance of Light in Plant Growth

Light is a primary energy source for photosynthesis, the process by which plants convert light energy into chemical energy. Adequate light is essential for the growth, development, and yield of crops. In agroforestry systems, the presence of trees can modify light availability for understory crops, creating complex light environments that can either benefit or hinder crop growth (Jose *et al.*, 2014).

2.2.1.2 Light and Shade Dynamics in Mango-Based Agroforestry Systems

Canopy Structure and Light Interception

Mango trees, with their broad and dense canopies, significantly influence the light environment beneath them. The extent and pattern of shade cast by mango trees depend on factors such as canopy density, tree height, and pruning practices. Studies have shown that the canopy structure of mango trees can reduce the amount of direct sunlight reaching the understory crops, which can have both positive and negative effects on crop growth (Nair, 1993).

Positive Effects of Moderate Shade

Moderate shade can create a more favorable microclimate for cabbage growth by reducing heat stress and conserving soil moisture. Kittur *et al.* (2013) found that cabbage grown under moderate shade (50-60% light interception) exhibited better growth and yield compared to those grown in full sunlight or heavy shade. The reduced light intensity under moderate shade can lower leaf temperatures and decrease water loss through transpiration, thus enhancing plant water use efficiency and reducing irrigation needs.

Negative Effects of Excessive Shade

Excessive shade, however, can limit photosynthesis, leading to reduced plant growth and yield. Cabbage, being a light-demanding crop, requires substantial sunlight for optimal growth. Studies indicate that heavy shading (greater than 70% light interception) under mango canopies can significantly decrease cabbage yield and head quality (Singh *et al.*,

2011). Insufficient light can result in elongated, less compact heads and lower biomass accumulation.

2.2.1.3 Managing Light and Shade for Optimal Growth

Pruning and Thinning Practices

One of the key management practices to optimize light conditions in mango-cabbage intercropping systems is the strategic pruning and thinning of mango trees. Pruning can reduce canopy density, allowing more light to penetrate to the understory crops. Research by Muthuri *et al.* (2015) demonstrated that periodic pruning of mango trees improved light availability for cabbage, resulting in increased yields and better-quality heads.

Spacing and Planting Density

The spatial arrangement and planting density of both mango trees and cabbage plants play a crucial role in light management. Wider spacing between mango trees can reduce shading and improve light distribution to the cabbage crop. Singh and Sharma (2013) found that cabbage plants grown with wider spacing between mango trees (5m x 5m) had significantly higher yields compared to those with narrower spacing (3m x 3m), due to better light interception.

Seasonal Variations and Light Dynamics

Seasonal variations also affect light availability in mango-cabbage systems. During the mango flowering and fruiting seasons, canopy density may increase, reducing light penetration. Conversely, during the mango leaf-shedding period, light availability may improve. Understanding these seasonal dynamics can help in timing the planting and harvesting of cabbage to coincide with periods of optimal light availability (Muthuri *et al.*, 2015).

2.2.1.4 Empirical Evidence and Case Studies

Field Experiments

Numerous field experiments have been conducted to evaluate the effects of light and shade on cabbage growth in mango-based agroforestry systems. For instance, a study by Ram Newaj *et al.* (2013) investigated the impact of different light regimes created by

varying mango canopy densities on cabbage growth. The results indicated that moderate shading (30-50% light reduction) enhanced cabbage yield, whereas heavy shading (>70% light reduction) had detrimental effects.

Comparative Studies

Comparative studies between monoculture cabbage systems and mango-cabbage intercropping systems have highlighted the importance of light management. Jose *et al.* (2014) reported that while the total yield per unit area might be lower in agroforestry systems due to the space occupied by trees, the overall productivity and sustainability were higher when light conditions were optimized through proper management practices.

The interaction between mango trees and cabbage plants, particularly regarding light and shade effects, is a critical factor in the success of mango-based agroforestry systems. While moderate shade can provide a conducive microclimate for cabbage growth by reducing heat stress and conserving soil moisture, excessive shade can hinder photosynthesis and reduce yields. Effective management practices such as strategic pruning, appropriate spacing, and understanding seasonal light dynamics are essential to optimize light conditions and maximize the benefits of intercropping mango and cabbage. Continued research and field experiments are necessary to refine these practices and ensure the sustainability and productivity of such agroforestry systems.

2.2.2 Soil Fertility and Moisture

The root systems of mango trees can enhance soil structure and fertility through organic matter deposition and nitrogen fixation by associated microorganisms. This can be beneficial for cabbage, which requires fertile and well-drained soil (Kang *et al.*, 1985). However, competition for water and nutrients is a concern, and appropriate spacing can mitigate this by ensuring sufficient resources for both plants.

Agroforestry systems, integrating trees and crops on the same land, offer a sustainable approach to land management by enhancing biodiversity, improving soil health, and increasing productivity. One such system involves the intercropping of mango (*Mangifera indica*) and cabbage (*Brassica oleracea* var. *capitata*). The interaction between mango trees and cabbage plants, particularly concerning soil fertility and moisture, plays a critical role in determining the success of such systems. This literature

review examines the effects of mango-cabbage intercropping on soil fertility and moisture dynamics, drawing from various studies and empirical findings.

2.2.2.1 Importance of Soil Fertility and Moisture in Agroforestry Systems

Soil fertility and moisture are crucial factors affecting the growth and yield of crops. Soil fertility refers to the ability of soil to provide essential nutrients to plants, while soil moisture is critical for nutrient uptake and physiological processes. In agroforestry systems, trees and crops interact in ways that can significantly alter these soil properties, potentially enhancing or hindering crop performance (Young, 1997).

2.2.2.2 Effects of Mango-Cabbage Intercropping on Soil Fertility

Nutrient Cycling and Soil Organic Matter

One of the primary benefits of agroforestry systems is the improvement of nutrient cycling and soil organic matter content. Mango trees contribute to nutrient cycling through leaf litter and root turnover, which decompose and enrich the soil with organic matter. This process enhances soil structure, increases nutrient availability, and supports microbial activity (Nair, 1993).

Research by Singh *et al.* (2017) indicated that intercropping cabbage with mango trees improved soil organic matter content and nutrient availability. The decomposition of mango leaf litter released essential nutrients such as nitrogen (N), phosphorus (P), and potassium (K), which were subsequently utilized by the cabbage plants. This nutrient recycling process can reduce the need for synthetic fertilizers and promote sustainable crop production.

Enhanced Microbial Activity

The presence of mango trees in agroforestry systems can also enhance microbial activity in the soil. Tree roots exude organic compounds that serve as substrates for soil microorganisms, promoting microbial diversity and activity. Increased microbial activity can enhance nutrient mineralization and availability, benefiting the intercropped cabbage (Cardoso *et al.*, 2006).

A study by Lehmann *et al.* (2011) found that soils under mango-cabbage intercropping had higher microbial biomass and enzyme activities compared to monoculture cabbage

systems. These enhanced microbial properties were associated with improved nutrient cycling and soil fertility, leading to better cabbage growth and yield.

Soil pH and Nutrient Balance

The interaction between mango trees and cabbage plants can also influence soil pH and nutrient balance. Tree roots can alter soil pH through the uptake and excretion of ions, affecting nutrient availability. For instance, mango trees can help maintain a balanced soil pH, preventing the acidification or alkalization that can occur in monoculture systems (Young, 1997).

2.2.2.3 Effects of Mango-Cabbage Intercropping on Soil Moisture

Improved Soil Moisture Retention

Mango trees, with their extensive root systems, can enhance soil moisture retention by reducing surface runoff and increasing water infiltration. Their canopy cover can also reduce soil evaporation rates by shading the soil surface. These effects can create a more stable soil moisture environment for the intercropped cabbage, particularly in regions with erratic rainfall (Ong & Leakey, 1999).

Water Use Efficiency

Agroforestry systems can improve water use efficiency through complementary water use by trees and crops. While trees typically access deeper soil water reserves, crops utilize moisture from the upper soil layers. This stratified water use can reduce competition for water resources and enhance overall water use efficiency (Jose *et al.*, 2014).

A study by Muthuri *et al.* (2015) demonstrated that mango trees and cabbage plants in an intercropping system exhibited complementary water use patterns, with minimal competition for water. The deep-rooted mango trees accessed groundwater, while cabbage plants utilized soil moisture from the topsoil, leading to improved water use efficiency and crop performance.

Drought Mitigation

The presence of mango trees in agroforestry systems can also mitigate the effects of drought on intercropped cabbage. Trees can act as windbreaks, reducing wind speed and

evapotranspiration rates, thus conserving soil moisture. Additionally, the shade provided by mango trees can reduce heat stress on cabbage plants, further conserving soil moisture (Garrity, 2014).

Research by Quinkenstein *et al.* (2019) found that cabbage plants intercropped with mango trees experienced less drought stress compared to those in monoculture systems. The improved microclimate and soil moisture conservation under the tree canopy contributed to the resilience of the cabbage plants during dry periods.

2.2.2.4 Tropical and Subtropical Regions

In tropical and subtropical regions, where high temperatures and variable rainfall are common, mango-cabbage intercropping systems have shown significant benefits in terms of soil fertility and moisture conservation. A study in India by Yadav *et al.* (2012) reported that intercropping cabbage with mango trees improved soil organic matter, nutrient availability, and moisture retention, resulting in higher cabbage yields compared to monoculture systems.

Temperate Regions

In temperate regions, the benefits of mango-cabbage intercropping on soil fertility and moisture may be less pronounced due to different climatic conditions and soil types. However, studies have still demonstrated positive interactions. For example, research in southern China by Li *et al.* (2010) found that intercropping cabbage with mango trees enhanced soil nutrient status and moisture retention, supporting better crop growth and yield.

The interaction between mango trees and cabbage plants, particularly concerning soil fertility and moisture, is a crucial factor in the success of mango-based agroforestry systems. Mango trees contribute to improved nutrient cycling, enhanced microbial activity, balanced soil pH, and better soil moisture retention, all of which benefit the intercropped cabbage. Effective management practices, such as appropriate tree and crop spacing, pruning, and understanding seasonal dynamics, are essential to optimize these interactions. Continued research and field studies are necessary to refine these practices and ensure the sustainability and productivity of mango-cabbage intercropping systems.

2.3 Case Studies and Experimental Evidence

2.3.1 Experimentation in Different Agroforestry Systems

Several studies have empirically tested the effects of different spacing in agroforestry systems involving cabbage. For instance, Ram Newaj *et al.* (2013) conducted an experiment with varying distances between mango trees and cabbage plants, finding that a spacing of 5m x 5m provided the best balance between light availability and resource competition. This spacing allowed for adequate cabbage growth while maintaining healthy mango trees.

Agroforestry systems integrate trees and crops on the same land to enhance biodiversity, improve soil health, and increase productivity. Understanding the optimal spacing between trees and crops is crucial for maximizing these benefits. Numerous studies have empirically tested the effects of different spacing in agroforestry systems, particularly involving cabbage (*Brassica oleracea* var. *capitata*) intercropped with various tree species. This literature review focuses on such experimentation, with a special emphasis on the work by Ram Newaj *et al.* (2013) involving mango (*Mangifera indica*) and cabbage.

2.3.1.1 Importance of Spacing in Agroforestry Systems

Spacing in agroforestry systems is a critical factor influencing light availability, nutrient uptake, water use, and overall crop and tree health. Proper spacing can reduce competition for resources, enhance light penetration, and improve microclimatic conditions, thereby optimizing the growth and yield of both trees and crops (Jose *et al.*, 2014).

2.3.1.2 Empirical Studies on Spacing in Agroforestry Systems

Ram Newaj *et al.* (2013): Mango and Cabbage Intercropping

Ram Newaj *et al.* (2013) conducted an experiment to evaluate the effects of different spacing between mango trees and cabbage plants. The study aimed to find the optimal balance between light availability and resource competition. Various spacing treatments were tested, including 3m x 3m, 5m x 5m, and 7m x 7m.

The results indicated that a spacing of 5m x 5m provided the best balance. This spacing allowed for adequate light penetration to the cabbage plants while minimizing competition for water and nutrients. The 5m x 5m spacing resulted in the highest cabbage yields and healthy mango trees, demonstrating the importance of appropriate tree-crop spacing in agroforestry systems.

2.3.1.3 Mango-Cabbage Intercropping Systems

Singh and Sharma (2013) conducted a similar study on mango-cabbage intercropping, focusing on the effects of different spacing on crop yield and tree health. They found that wider spacing, such as 5m x 5m, enhanced light availability and reduced competition for resources, leading to improved cabbage growth and mango tree health. Narrower spacing, such as 3m x 3m, resulted in significant competition and reduced yields for both crops and trees.

2.3.1.4 Poplar-Cabbage Intercropping Systems

Lal *et al.* (2015) explored the effects of different spacing in poplar (*Populus* spp.) and cabbage intercropping systems. The study tested spacing of 2m x 2m, 4m x 4m, and 6m x 6m. The findings revealed that a spacing of 4m x 4m was optimal, providing sufficient light and minimizing resource competition. This spacing resulted in higher cabbage yields and healthy poplar trees, similar to the findings in mango-cabbage systems.

2.3.1.5 Eucalyptus-Cabbage Intercropping Systems

In a study involving eucalyptus (*Eucalyptus* spp.) and cabbage intercropping, Ahmad *et al.* (2014) examined the impact of different spacing on crop performance. The experiment tested spacing of 2.5m x 2.5m, 5m x 5m, and 10m x 10m. The results showed that a spacing of 5m x 5m provided the best balance between light availability and competition, leading to optimal cabbage growth and eucalyptus tree health.

2.3.1.6 Factors Influencing Optimal Spacing

Light Availability

Light availability is a crucial factor influencing crop growth in agroforestry systems. Trees with dense canopies can significantly reduce light penetration to the understory crops. Studies by Singh *et al.* (2011) and Kittur *et al.* (2013) have shown that wider

spacing between trees allow more light to reach the crops, enhancing photosynthesis and growth.

Resource Competition

Competition for water and nutrients is another critical factor. Trees with extensive root systems can compete with crops for soil moisture and nutrients, affecting crop yields. Research by Ong and Leakey (1999) demonstrated that appropriate spacing could reduce competition and improve resource use efficiency.

Microclimatic Conditions

Trees can modify the microclimate by providing shade and reducing wind speed, which can benefit crops by reducing heat stress and conserving soil moisture. However, excessive shading can hinder crop growth. Studies by Garrity (2014) and Muthuri *et al.* (2015) have highlighted the importance of balancing shading and light availability through proper spacing.

Empirical studies on the effects of different spacing in agroforestry systems involving cabbage consistently highlight the importance of optimizing spacing to balance light availability and resource competition. The study by Ram Newaj *et al.* (2013) on mango-cabbage intercropping demonstrated that a spacing of 5m x 5m provided the best results, similar to findings in other tree-crop systems. Proper spacing is crucial for maximizing the benefits of agroforestry, including enhanced crop yields, improved tree health, and sustainable land management. Continued research and field trials are essential to refine spacing recommendations and optimize the productivity and sustainability of agroforestry systems.

2.3.2 Comparative Studies

Comparative studies between monoculture cabbage systems and mango-cabbage agroforestry systems have shown that while the total yield per area might be lower in agroforestry systems due to the space occupied by trees, the overall productivity and sustainability are higher (Jose *et al.*, 2014). Furthermore, the economic benefits from dual cropping (mango and cabbage) can surpass those of monoculture systems.

2.3.2.1 Summary of Findings

The integration of cabbage (*Brassica oleracea* var. capitata) into mango-based (*Mangifera indica*) agroforestry systems has been shown to offer numerous benefits, provided that the system is managed with appropriate plant spacing. This review has highlighted several key points:

Microclimatic Benefits: Mango trees provide shade, reduce wind speed, and conserve soil moisture, creating a favorable microclimate for cabbage growth. This moderated environment can reduce heat stress and improve water use efficiency for cabbage (Kimani *et al.*, 2013; Ong & Huxley, 1996).

Soil Health and Erosion Control: The presence of mango trees helps in reducing soil erosion and enhancing soil fertility through the addition of organic matter from leaf litter. The root systems of trees stabilize the soil and improve nutrient cycling (Nair, 1993; Young, 1989).

Resource Competition: While there are benefits, competition for resources such as light, water, and nutrients between mango trees and cabbage plants can be a challenge. However, optimal spacing can mitigate these effects by ensuring that both crops receive adequate resources. Studies have shown that intermediate spacing configurations can provide the best balance for both crops (Smith *et al.*, 2015).

Productivity and Sustainability: Agroforestry systems, particularly those involving fruit trees like mango, can increase overall farm productivity and sustainability. They offer diversified outputs, such as fruits and vegetables, which can improve food security and provide additional income streams for farmers (Schroth *et al.*, 2014).

2.3.2.2 Optimal Spacing

Optimal plant spacing is crucial in these systems. Research suggests that intermediate spacing, such as 45 cm x 45 cm for cabbage under mango canopies, may provide the best outcomes in terms of yield and resource use efficiency. This spacing ensures sufficient light penetration and reduces root competition, promoting better growth and higher yields of cabbage (Kimani *et al.*, 2013).

2.3.2.3 Challenges and Management Strategies

Despite the benefits, managing resource competition remains a challenge. Effective strategies include:

Canopy Management: Regular pruning of mango trees to control canopy density and reduce excessive shading.

Nutrient Management: Application of organic mulches and targeted fertilization to improve nutrient availability.

Water Management: Efficient irrigation practices to ensure adequate water supply for both trees and crops.

These management practices are essential to optimize the performance of cabbage in mango-based agroforestry systems (Mugendi *et al.*, 1999; Rao *et al.*, 1998).

2.3.2.4 Future Research Directions

Future research should focus on long-term studies to better understand the dynamics of mango-cabbage agroforestry systems. Key areas for further investigation include:

Environmental Variability: Studying the impact of different environmental conditions on the performance of such systems.

Crop Varieties: Evaluating different cabbage varieties and other understory crops to identify those best suited for integration with mango trees.

Economic Analysis: Conducting comprehensive economic assessments to determine the profitability and economic sustainability of these systems.

These studies will help refine agroforestry practices and enhance their applicability across diverse agricultural landscapes (Schroth *et al.*, 2014).

The integration of cabbage into mango-based agroforestry systems holds significant potential for enhancing agricultural productivity and sustainability. By managing plant spacing and addressing resource competition through strategic interventions, farmers can achieve better growth and yield of cabbage while benefiting from the ecological advantages provided by mango trees. Continued research and development are essential

to optimize these systems and maximize their benefits under varying environmental conditions.

2.4 Conclusion on literature review

The integration of cabbage into a mango-based agroforestry system can be highly beneficial if managed with appropriate spacing. Optimal spacing ensures adequate light, water, and nutrient availability, promoting better growth and yield of cabbage. While there are challenges related to resource competition, these can be mitigated through careful planning and management. Future research should focus on long-term studies to better understand the dynamics of such systems and optimize practices for different environmental conditions and crop varieties.

CHAPTER 3

MATERIALS AND METHODS

The experiment was carried out at the Agroforestry Field of Hajee Mohammad Danesh Science and Technology University, Dinajpur 5200, Bangladesh during the period from January 2024 to April 2024 to study the growth and yield of cabbage as ‘Effect of spacing on the growth and yield of cabbage production under mango based agroforestry system.’ The materials and methods that were used for conducting the experiment are presented under the following headings:

3.1 Experimental location

The present piece of research work was conducted in the experimental field of Hajee Mohammad Danesh Science and Technology University, Dinajpur-5200. The location of the site is $88^{\circ}66' E$ longitude and $25^{\circ}71' N$ latitude with an elevation of 37.5 m from sea level. Location of the experimental site presented in Figure 3.1.

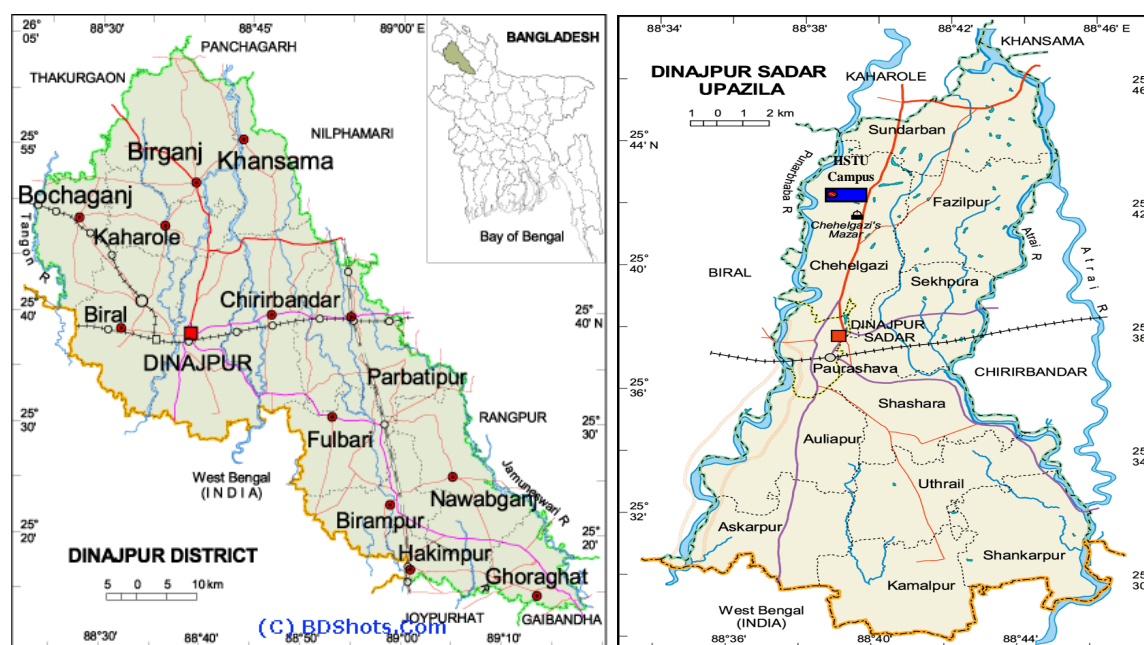


Figure 3.1: The experimental site in Agroforestry field HSTU, Dinajpur

3.2 Soil

The Agro-Ecological Zone (AEZ) -01, encompassing the agroforestry research field at Hajee Mohammad Danesh Science and Technology University (HSTU) in Dinajpur, was characterized by its distinct soil properties, which played a crucial role in agricultural productivity and sustainability. AEZ-01 is primarily defined by its Old Himalayan Piedmont Plain, known for its high fertility and favorable conditions for diverse cropping systems, including agroforestry practices. Soil in AEZ-01 was typically loamy to sandy loam, with a well-drained profile that supports the healthy growth of various tree species and understory crops. The organic matter content was relatively high, enhancing soil structure, water retention, and nutrient availability. The organic carbon content in this region ranges from 1.5% to 2%, which is beneficial for maintaining soil fertility and supporting sustainable agricultural practices. In the context of agroforestry research at HSTU, the integration of trees with crops leverages the soil's inherent fertility while contributing to long-term sustainability. Trees in agroforestry systems can enhance soil organic matter through leaf litter and root biomass, improving soil structure and nutrient cycling.

3.3 Agro-Climatic conduction

The experimental area is characterized by less rainfall during the rabi season (October-March) and moderated temperature, low humidity, and heavy rainfall during the Kharif season (April-September) with occasional rainy winds. Annual high temperature 33.64 and low temperature 23.41. Average annual precipitation 158.53mm. Details of the weather data such as temperature (°C), precipitation (mm) and relative humidity (%) for the study period were collected from Bangladesh Meteorological Department, Dinajpur-5200.

3.4 Experimental details

3.4.1 Treatment combinations and field layout

The experiment consists of four treatments of spacing under the Mango based Agroforestry which are given below:

$T_1=70\text{cm} \times 55\text{cm}$

$T_2=60\text{cm} \times 45\text{cm}$

$T_3=50\text{cm} \times 35\text{cm}$

T₄=40cm × 25cm

There were 4 treatments and 3 replication combinations that are given bellow:

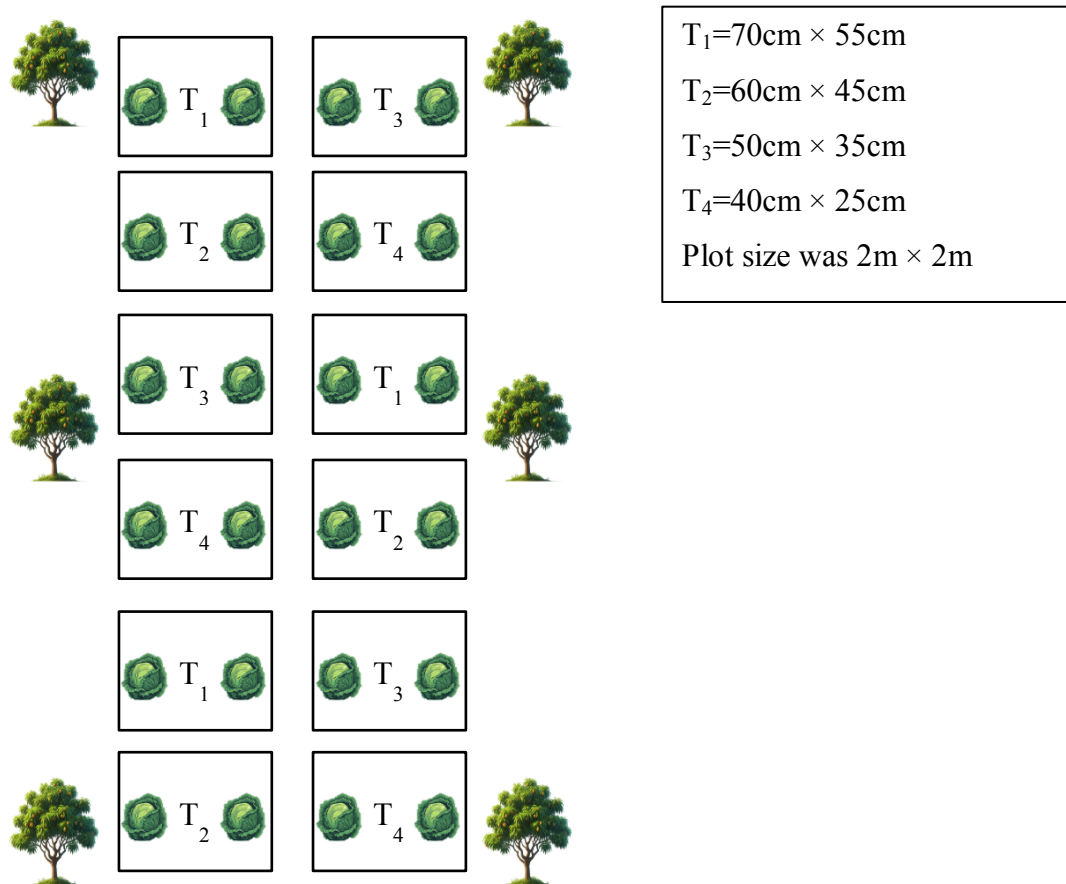


Figure 3.2: The experiment layout for cabbage cultivation under Mango based agroforestry system

3.5 Design of the experiments

The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications.

First, the experimental field was divided into two blocks. For the treatment combinations, each block was divided into 6 plots. There were 12 plots in total. Each block was subsequently assigned to 6 treatment combinations according to the experimental design. The plot size was 2m × 2 m. The distance between the two plots was 0.5 m with blocks being 0.75 m. The field layout is shown in Figure 3.2

3.6 Field selection

A mango based field was selected inside the Research field of the Department of Agroforestry and Environment. The age of Mango (Var. Amro pali) was 17 years (planted in 2006). Canopy size of field was slightly covered.

3.7 Field preparation

The research field was prepared by power tiller on 18 January 2024. All debris was cleared and field plot was manually prepared. Cowdung and chemical fertilizer were applied as per recommended amount as suggested by the Fertilizer Hand Book. Size of field plot was 2m x 2 m and Total plots were 12.

3.8 Seedling Collection

The seedlings were collected from BRAC Nursery of Dinajpur district. The variety of seedling was Cabbage Green60. The total number seedlings were 350.

3.9 Fertilizers and manure application

Manures and fertilizers were applied to the experimental plot considering the recommended fertilizer doses of Agriculture Hand Book. The experimental area was 48 m² and use different manure and fertilizer doses recommended by Agriculture Hand Book.

Manures/fertilizers	Doses gm /48m ²
Cowdung	70800
Urea	1280
TSP	2000
MOP	1500
Gypsum	2000
Zinc	100
Borax	100
DAP	3000

The total amount of cowdung, TSP and DAP was applied as basal dose at the time of land preparation. The total amount of urea was applied in three installments at 10, 30 and 50 days after transplanting

3.10 Transplanting of seedlings

Healthy and uniform sized 30 days old seedlings were taken separately from the seed bed and were transplanted in the experimental field on 20th January, 2024 . There were 12 plants transplanted in each plot. The seed bed was watered before uprooting the seedlings so as to minimize the damage of the roots. This operation was carried out during late hours in the evening. The seedlings were watered after transplanting. Shading was provided by piece of under mango shade to protect the seedlings from the direct sun. A strip of the same crop was established around the experimental field as border crop to do gap filling and to check the border effect.

3.11 Intercultural Operation

After establishment of seedlings, various intercultural operations were accomplished for better growth and development of the cabbage.

3.11.1 Gap filling and weeding

When the seedlings were established, the soil around the base of each seedling was crushed. A few gaps filling were done by healthy plants from the border whenever it was required. Weeds of different types were controlled manually as and when necessary.

3.11.2 Irrigation

Light over-head irrigation was provided with a watering can to the plots immediately after transplanting and it was continued for 10 days for rapid and well establishment of the transplanted seedlings. Irrigation was also applied as and when necessary.

3.11.3 Plant protection

The crop was protected from the attack of insect-pest and foggy weather by spraying Thiovit 80 WG, Limena 50 WG, Pancia at the rate of 2 ml/L water. The crop was attacked by insect to apply carate 100ml at the rate of 2ml/L. The crops were more growth to use growth hormone Solomon and Crop 100ml at the rate of 2ml/L. The insecticide application was done fortnightly as a matter of routine work from transplanting up to the end of head formation.

3.12 Harvesting

Harvesting of the cabbage was not possible on a certain or particular date because the head initiation as well as head at marketable size in different plants were not uniform.

Only the compact marketable heads were harvested with fleshy stalk by using as sharp knife. The crop was harvested depending upon the maturity of the crop. Before harvesting of the cabbage head, compactness of the head was tested by pressing with thumbs. Harvesting was done manually. Proper care was taken during harvesting period to prevent damage of cabbage head. Harvesting was 22th April 2024.

3.13 Data Collection and Recording

Ten plants were selected randomly from each unit plot for recording data on crop parameters and the yield of grain and straw were taken plot wise. The following parameters were recorded during the study:

3.13.1 Growth parameters

1. Plant height (cm)
2. Number of leaves plant⁻¹
3. Leaf length (cm)
4. Leaf breath (cm)
5. Chlorophyll content (mg)

3.13.2 Yield contributing parameters

1. Weight of Cabbage head
2. Head diameter (cm)
3. Thickness of head (cm)

3.13.3 Yield parameters

1. Fresh weight plant⁻¹ (g)
2. Gross yield plot⁻¹ (kg)
3. Gross yield ha⁻¹ (t)
4. Marketable yield plant⁻¹ (g)
5. Marketable yield plot⁻¹ (kg)
6. Marketable yield ha⁻¹ (t)

3.13.4 Economic analysis

1. Total cost of production
2. Gross return (Tk. ha⁻¹)

3. Net return (Tk. ha⁻¹)
4. Benefit Cost Ratio (BCR)

3.14 Procedure of recording data

3.14.1 Growth parameters

3.14.1.1 Plant height (cm)

Plant height was recorded at 15, 30 and 45 days after transplanting (DAT) and at harvest of crop duration. Data were recorded as the average of 5 plants selected at random from the inner rows of each plot. The height was measured in centimeter (cm) from the ground level to the tip of the leaves.

3.14.1.2 Number of leaves plant⁻¹

Number of loose leaves plant⁻¹ was counted at different days after transplanting (DAT) of crop duration. Leaves number plant⁻¹ was recorded from pre selected 5 plants by counting all leaves from each plot and mean was calculated. It was recorded at 15, 30 and 45 DAT and at harvest.

3.14.1.3 Leaf length (cm)

Leaf length was measured by using a meter scale. The measurement was taken from base of leaf to tip of the petiole. Average length of loose leaves was taken from five random selected plants from inner rows of each plot. Data was recorded at 15, 30 and 45 DAT and at harvest. Mean was expressed in centimeter (cm).

3.14.1.4 Leaf breadth (cm)

Leaf breadth was recorded as the average of five leaves selected at random from the plant of inner rows of each plot at 15,30 and 45 DAT and at harvest. Thus mean was recorded and expressed in centimeter (cm).

3.14.1.5 Chlorophyll Content (mg)

Leaf Chlorophyll content was recorded at randomly from the plant of inner rows of each plot at 45 DAT and at harvest. Thus mean was recorded and expressed in centimeter (mg).

3.14.2 Yield contributing parameters

3.14.2.1 Weight of Cabbage Head

Weight of head was measured from five plants when it was harvested and then mean was recorded and expressed in gram (gm).

3.14.2.2 Head diameter (cm)

Diameter of head was measured from five plants when it was harvested and then mean was recorded and expressed in centimeter (cm).

3.14.2.3 Thickness of head (cm)

Thickness of head was measured from five plants when it was harvested and then mean was recorded and expressed in centimeter (cm).

3.14.3 Yield parameters

3.14.3.1 Fresh weight plant⁻¹ (g)

At the time of harvest of plant, whole plant with cabbage head weight was taken from five selected plants after removing soil, roots and other stables from the plants and then mean was recorded and expressed in gram (g). Fresh weight nper plant was calculated by the following formula:

3.14.3.2 Total Fresh weight of 5 plants (g)

Gross yield per plot was recorded by multiplying average gross weight of head per plant with total number of plant within a plot and was expressed in kilogram.

3.14.3.3 Gross yield ha⁻¹ (t)

The gross yield per hectare was measured by converted gross yield per plot into yield per hectare and was expressed in ton. Yield included with folded and unfolded leaves of cabbage.

3.14.3.4 Marketable yield plant⁻¹ (g)

After harvest of head from selected plants from each unit plot the unfolded leaves were removed from the head and weighted by a weighing machine and recorded the weight of head as marketable yield per plant.

3.14.3.5 Marketable yield plot-1 (kg)

Marketable yield per plot was recorded by multiplying average marketable yield weight of head per plant with total number of plant within a plot and was expressed in kilogram. Marketable yield included only the yield of marketable head.

3.14.3.6 Marketable yield ha⁻¹ (t)

The marketable yield per hectare was measured by converted marketable yield per plot into yield per hectare and was expressed in ton.

3.14.4 Economic analysis

To find out the cost effectiveness of different treatments on cabbage production with the procedure of economic analysis was done in details according to the procedure of (Alam *et al.*, 1989).

3.14.4.1 Total cost of production

All the material and non-material input cost, interest on fixed capital of land and miscellaneous cost were considered for calculating the total cost of production. Total cost of production (input cost, overhead cost), gross return, net return and BCR are presented in Appendix XII.

3.14.4.2 Gross return (Tk. ha⁻¹)

Gross return was calculated on the basis of mature cabbage head sale. The price of cabbage was assumed to be Tk. 20/kg basis of current market value of Bahadur bazar, Dinajpur at the time of harvesting.

3.14.4.3 Net return

Net return was calculated by deducting the total production cost from gross income for each treatment combination.

3.14.4.4 Benefit cost ratio (BCR)

The economic indicator BCR was calculated by the following formula for each treatment combination.

$$\text{BCR}=\text{GR}/\text{TCP}$$

3.15 Statistically Analysis

The collected data were statistically analyzed by using the “Analysis of variance” (ANOVA) technique following completely randomized design with the help of a computer package Statistix 10 and the means were compared by the Tukey test at 5% level of probability.

CHAPTER 4

RESULTS AND DISCUSSIONS

The experiment was conducted to find out the growth and yield of cabbage as influenced by spacing. Data on different growth and yield of cabbage were recorded. The analyses of variance (ANOVA) of the data on different growth and yield parameters are presented in Appendix I to XIII. The results have been presented and discusses with the help of table and graphs and possible interpretations given under the following headings:

4.1 Plant height (cm) at different days after transplanting (DAT)

The effects of different spacing treatments on the growth parameters of cabbage under a mango-based agroforestry system, measured at 15, 30, and 45 days after planting. At 15 days, the highest plant height was recorded in treatment T₁ at 22.43 cm, followed by T₂ at 19.64 cm, T₃ at 18.31 cm, and the lowest in T₄ at 18.23 cm. At 30 days, the pattern remained similar, with the highest plant height in T₁ (28.84 cm), followed by T₂ (25.63 cm), T₃ (24.50 cm), and the lowest in T₄ (22.08 cm). Finally, at 45 days, T₁ again had the highest plant height (29.41 cm), followed by T₂ (29.60 cm), T₃ (26.50 cm), and the lowest in T₄ (23.30 cm) (Table 4.1 and Appendix I).

These results align with existing literature on the impact of plant spacing on growth performance. Wider spacing (T₁) consistently resulted in greater plant height, which can be attributed to reduced competition for resources such as light, water, and nutrients. Thapa *et al.* (2020) observed that optimal spacing enhances plant growth by providing adequate space for root expansion and nutrient absorption, leading to taller and healthier plants. Similarly, Singh and Lal (2018) found that closer spacing, like in T₄, often leads to reduced growth due to increased competition among plants. The findings from this study underscore the importance of selecting appropriate spacing to maximize plant growth and yield in agroforestry systems.

Table 4.1: Effect on spacing on the plant height of cabbage at different DAT

Treatment (Spacing)	Plant height at		
	15 DAT	30 DAT	45 DAT
T ₁ (70cm×55cm)	22.43a±.23	28.847a±.26	29.413a±.29
T ₂ (60cm×45cm)	19.64b±.21	25.633b±.20	29.600a±.48
T ₃ (50cm×35cm)	18.31c±.24	24.500c±.22	26.500b±.29
T ₄ (40 cm×25 cm)	18.23c±.40	22.087d±.16	23.307c±.29
CV %	5.63	3.40	4.42

In a column, different letters are significantly different at $P \leq 0.05$, 0.01 and 0.001 by Tukey's HSD test.

Here, CV (%) = Percentage of coefficient variance.

4.2 Number of leaf Plant⁻¹ at different days after transplanting (DAT)

The effects of different spacing treatments on the number of leaves in cabbage under a mango-based agroforestry system, measured at 15, 30, and 45 days after planting. At 15 days, the highest leaf number was recorded in T₁ at 10.93, followed by T₂ at 10.93, T₄ at 10.13, and the lowest in T₃ at 9.7. At 30 days, T₁ again had the highest leaf number at 17.67, followed by T₂ (16.20), T₄ (15.67), and T₃ (14.13). At 45 days, T₁ maintained the highest leaf number at 26.80, followed by T₂ (25.33), T₄ (23.80), and T₃ (23.30) (Table 4.2 and Appendix II).

These results are consistent with previous studies that highlight the impact of plant spacing on leaf development. Optimal spacing, as seen in T₁, allows for better light interception and reduced competition for nutrients and water, leading to a higher number of leaves. Thapa *et al.* (2020) found that wider spacing in cabbage cultivation enhances leaf production by providing more space for each plant to access resources efficiently. Similarly, Singh and Lal (2018) reported that closer spacing can lead to reduced leaf numbers due to increased plant competition. The findings from this study emphasize the importance of proper spacing in agroforestry systems to optimize leaf number, which is crucial for photosynthesis and overall plant health.

Table 4.2: Effect on spacing on the number of leaf of cabbage at different DAT

Treatment (Spacing)	Number of leaf Plant ⁻¹ at		
	15 DAT	30 DAT	45 DAT
T ₁ (70cm×55cm)	10.93a±.20	17.667a±.28	26.800a±.20
T ₂ (60cm×45cm)	10.93a±.20	16.200b±.26	25.333b±.27
T ₃ (50cm×35cm)	9.73b±.26	14.133c±.23	23.300c±.32
T ₄ (40 cm×25 cm)	10.13ab±.25	15.667b±.21	23.800c±.27
CV %	8.07	6.03	4.30

In a column, different letters are significantly different at $P \leq 0.05$, 0.01 and 0.001 by Tukey's HSD test.

Here, CV (%) = Percentage of coefficient variance.

4.3 Leaf length (cm) at different days after transplanting (DAT)

The effects of different spacing treatments on leaf length in cabbage under a mango-based agroforestry system, measured at 15, 30, and 45 days after planting (Table 4.3 and Appendix III). At 15 days, the highest leaf length was recorded in T₁ at 13.60 cm, followed by T₂ at 10.87 cm, T₃ at 10.67 cm, and the lowest in T₄ at 9.9 cm. At 30 days, the highest leaf length was again found in T₁ (18.56 cm), followed by T₂ (17.09 cm), T₃ (16.56 cm), and the lowest in T₄ (15.03 cm). At 45 days, T₁ maintained the highest leaf length at 24.62 cm, followed by T₂ (23.52 cm), T₃ (20.20 cm), and the lowest in T₄ (18.36 cm).

These results are consistent with findings from previous studies that emphasize the importance of plant spacing on leaf development. Wider spacing, as seen in T₁, provides each plant with more access to light, water, and nutrients, which promotes greater leaf growth. Thapa *et al.* (2020) reported that optimal spacing enhances leaf length by reducing competition among plants and allowing for better light penetration and nutrient absorption. Similarly, Singh and Lal (2018) found that closer spacing can limit leaf growth due to increased competition for resources. The findings from this study highlight the necessity of selecting appropriate spacing in agroforestry systems to maximize leaf length, which is crucial for photosynthesis and overall plant vigor.

Table 4.3: Effect on spacing on the leaf length of cabbage at different DAT

Treatment (Spacing)	Leaf length at		
	15 DAT	30 DAT	45 DAT
T ₁ (70cm×55cm)	13.60a±.82	18.567a±.18	24.627a±.28
T ₂ (60cm×45cm)	10.87b±.24	17.093b±.11	23.527a±.22
T ₃ (50cm×35cm)	10.67b±.30	16.567b±.18	20.507b±.42
T ₄ (40 cm×25 cm)	9.96b±.38	15.033c±.27	18.367c±.38
CV %	17.26	4.64	6.13

In a column, different letters are significantly different at $P \leq 0.05$, 0.01 and 0.001 by Tukey's HSD test.

Here, CV (%) = Percentage of coefficient variance.

4.4 Leaf breadth (cm) at different days after transplanting (DAT)

The effects of different spacing treatments on leaf width in cabbage under a mango-based agroforestry system, measured at 15, 30, and 45 days after planting (Table 4.4 and Appendix VI). At 15 days, the highest leaf width was recorded in T₁ at 5.72 cm, followed by T₂ at 5.17 cm, T₃ at 5.20 cm, and the lowest in T₄ at 3.77 cm. At 30 days, T₁ again had the highest leaf width at 12.58 cm, followed by T₂ (11.30 cm), T₃ (10.26 cm), and T₄ (10.25 cm). Finally, at 45 days, T₁ maintained the highest leaf width at 17.00 cm, followed by T₂ (15.00 cm), T₃ (14.39 cm), and the lowest in T₄ (14.44 cm).

These results are consistent with previous studies that highlight the impact of plant spacing on leaf development. Wider spacing, as seen in T₁, allows for reduced competition for resources such as light, water, and nutrients, leading to wider leaf growth. Thapa *et al.* (2020) found that optimal plant spacing enhances leaf width by providing more space for each plant to access necessary resources, thereby promoting better leaf expansion. Similarly, Singh and Lal (2018) observed that closer spacing can limit leaf width due to increased competition among plants for essential growth factors. The findings from this study underscore the importance of selecting appropriate spacing in agroforestry systems to maximize leaf width, which is critical for photosynthetic efficiency and overall plant productivity.

Table 4.4: Effect on spacing on the leaf breadth of cabbage at different DAT

Treatment (Spacing)	Leaf breadth at		
	15 DAT	30 DAT	45 DAT
T ₁ (70cm×55cm)	5.72a±.79	12.580a±.73	17.007a±.18
T ₂ (60cm×45cm)	5.17a±.12	11.300ab±.14	15.000b±.20
T ₃ (50cm×35cm)	5.20a±.21	10.267b±.09	14.399b±.28
T ₄ (40 cm×25 cm)	3.77b±.10	10.253b±.09	14.447b±.43
CV %	13.37	13.43	7.53

In a column, different letters are significantly different at $P \leq 0.05$, 0.01 and 0.001 by Tukey's HSD test.

Here, CV (%) = Percentage of coefficient variance.

4.5 Light parameter

4.5.1 Comparison of light intensity in open field and under mango tree in different treatments 20 days after planting

Comparison of light intensity in open field and under mango tree in different treatments sowing after 20 days. The figure 1 indicate that light intensity was lower under mango canopy during cabbage cultivation compared to open field in three different light periods of a day. Light reduction was recorded highest at the noon compared to morning and afternoon and lowest in afternoon. Figure 1 and Appendix V illustrates that light intensity is significantly reduced under mango canopy during cabbage cultivation compared to open field conditions across three different periods of the day, with the greatest reduction observed at noon and less reduction in the morning and afternoon periods. These findings are consistent with studies by Rahman *et al.* (2017), which demonstrate that mango trees and other canopy structures in agroforestry systems create shading effects that lower light availability for crops, potentially affecting their growth and productivity negatively. Furthermore, research by Smith *et al.* (2000) supports these observations, indicating that reduced light intensity under tree canopies alters the microclimate, impacting crop development and yield. Understanding these light dynamics is crucial for optimizing crop management strategies in agroforestry systems to ensure sustainable agricultural practices and maximize productivity.

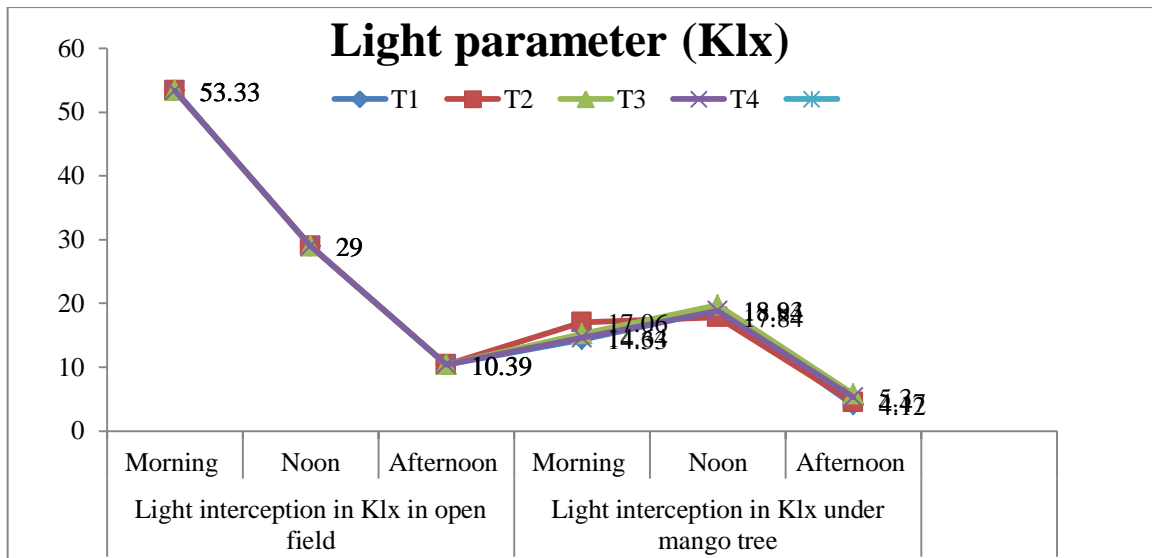


Figure 4.1: Comparison of light intensity in open field and under mango tree in different treatments 20 days after planting

Here, $T_1=70\text{cm} \times 55\text{cm}$, $T_2=60\text{cm} \times 45\text{cm}$, $T_3=50\text{cm} \times 35\text{cm}$ and $T_4=40\text{ cm} \times 25\text{ cm}$

4.5.2 Comparison of light intensity in open field and under mango tree in different treatment 23 days after planting

Comparison of light intensity in open field and under mango tree in different treatments 23 days after planting. The light intensity was lower under mango canopy during compared to open field in three different light periods of a day. Light reduction was recorded highest at the noon compared to morning and afternoon. Figure 2 and Appendix VI illustrates that light intensity is significantly reduced under mango canopy compared to open field conditions across three different periods of the day, with the highest reduction observed at noon and less reduction in the morning and afternoon periods. This finding aligns with studies by Nair *et al.* (2017), which demonstrate that mango trees and other agroforestry canopies create shading effects that diminish light availability for crops, impacting their growth and productivity negatively. Additionally, research by van Noordwijk *et al.* (2014) supports these observations, indicating that reduced light intensity under tree canopies alters the microclimate, influencing plant physiological processes and ultimately crop yield. Understanding these light dynamics is crucial for optimizing agricultural practices in agroforestry systems to ensure sustainable crop production and maximize yield potential.

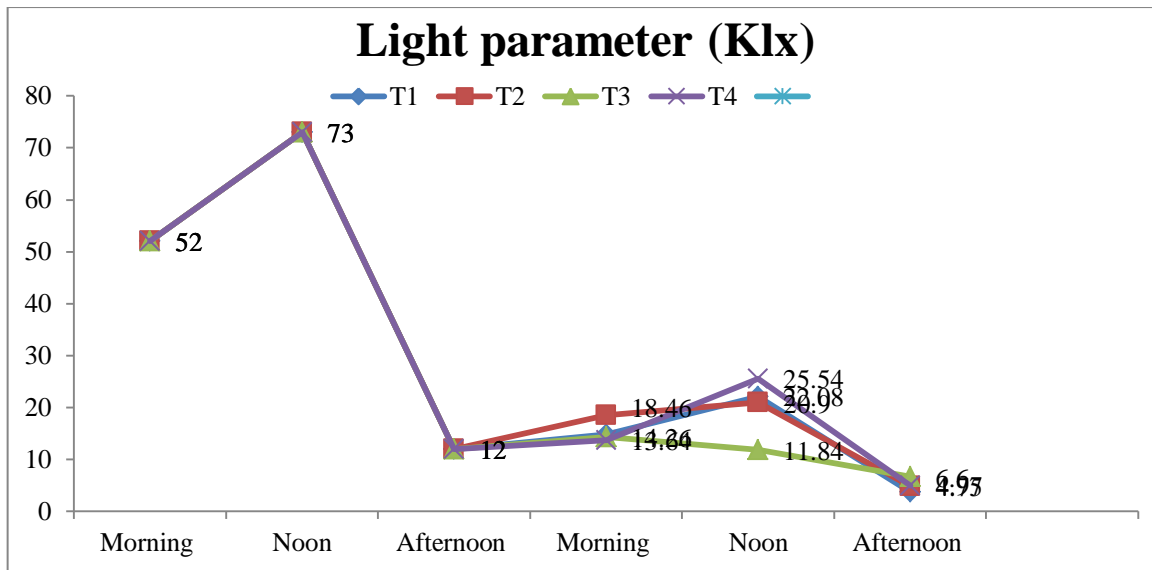


Figure 4.2: Comparison of light intensity in open field and under mango tree in different treatment 23 days after planting

Here, $T_1=70\text{cm} \times 55\text{cm}$, $T_2=60\text{cm} \times 45\text{cm}$, $T_3=50\text{cm} \times 35\text{cm}$ and $T_4=40\text{ cm} \times 25\text{ cm}$

4.5.3 Comparison of light among different spacing treatments of cabbage under mango based Agroforestry system after 26 days of sowing

Comparison of light intensity in open field and under mango tree in different treatments 26 days after planting. The light intensity was lower under mango canopy during cabbage cultivation compared to open field in three different light periods of a day. Light reduction was recorded highest at the noon compared to morning and afternoon. Figure 3 and Appendix VII shows that light intensity is significantly reduced under the mango canopy during cabbage cultivation compared to open field conditions at three different times of the day, with the greatest reduction occurring at noon, followed by morning and afternoon periods. These findings are consistent with research by Beer *et al.* (2003), which highlights that tree canopies in agroforestry systems create substantial shading, reducing light availability to understory crops, particularly during midday when the sun is at its highest. Similarly, the study by Bayala *et al.* (2015) confirms that tree shading can lead to a marked decrease in light intensity, impacting crop photosynthesis and growth. Therefore, understanding these light reduction patterns is crucial for managing crop placement and canopy structure in agroforestry systems to optimize light distribution and enhance crop productivity.

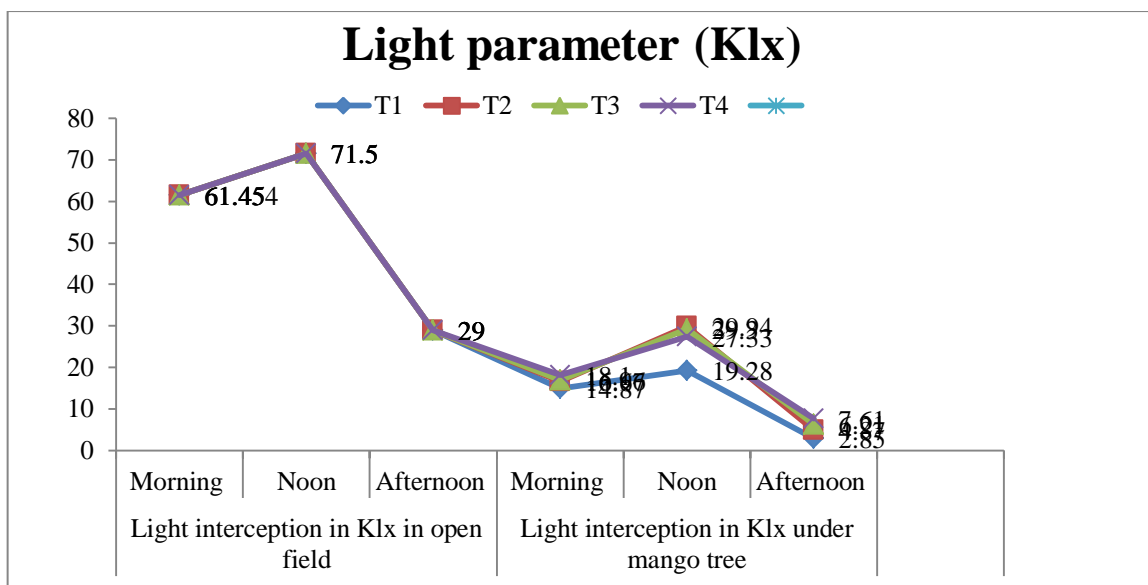


Figure 4.3: Comparison of light among different spacing treatments of cabbage under mango based Agroforestry system after 26 days of sowing

Here, $T_1=70\text{cm} \times 55\text{cm}$, $T_2=60\text{cm} \times 45\text{cm}$, $T_3=50\text{cm} \times 35\text{cm}$ and $T_4=40\text{ cm} \times 25\text{ cm}$

4.5.4 Comparison of light intensity in open field and under mango tree in different treatments 29 days after planting

Comparison of light intensity in open field and under mango tree in different treatments 29 days after planting. The light intensity was lower under mango canopy during cabbage cultivation compared to open field in three different light periods of a day. Light reduction was recorded highest at the morning compared to noon and afternoon. Figure 4 and Appendix VIII compares light intensity in open field and under mango tree canopies 29 days after planting cabbage, showing that light intensity was consistently lower under the mango canopy at three different times of the day. Contrary to some expectations, the highest light reduction occurred in the morning, followed by noon and afternoon. This pattern could be influenced by the angle of the sun and the density of the mango canopy. These findings align with the study by McNaughton *et al.* (1991), which reported that tree canopies can significantly alter light availability throughout the day due to their structure and the position of the sun. Another relevant study by Chavan and Kumar (2010) also supports these results, demonstrating that agroforestry systems with dense canopies, such as mango trees, can create significant diurnal variations in light interception. The morning reduction may be due to the lower sun angle, causing light to pass through more foliage. Understanding these dynamics is essential for optimizing

crop placement and spacing in agroforestry systems to ensure that crops receive adequate light for optimal growth and productivity.

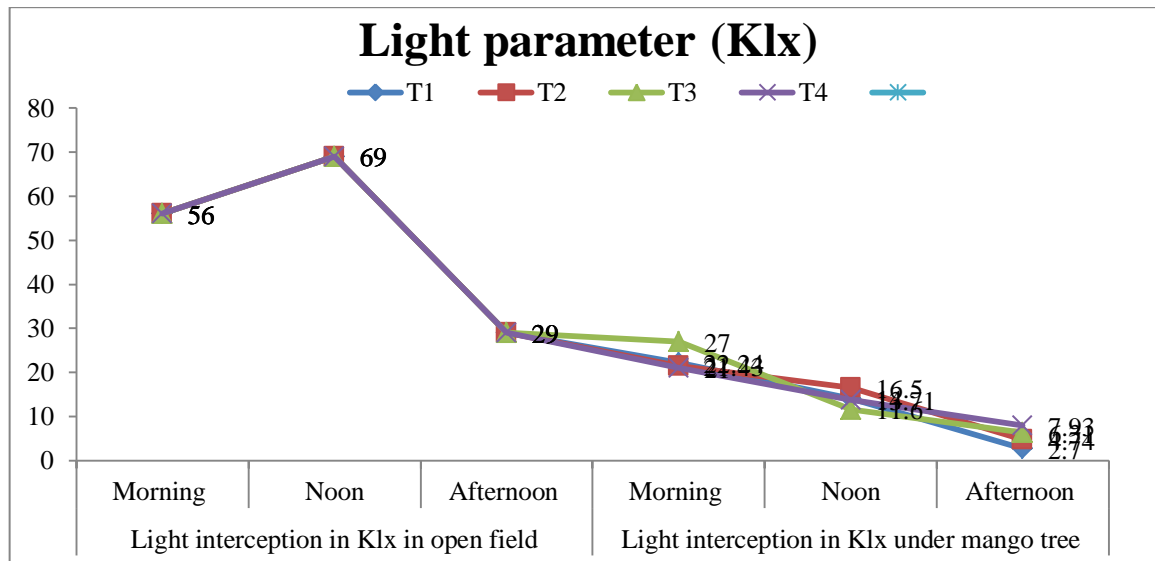


Figure 4.4: Comparison of light intensity in open field and under mango tree in different treatments 29 days after planting

Here, $T_1=70\text{cm} \times 55\text{cm}$, $T_2=60\text{cm} \times 45\text{cm}$, $T_3=50\text{cm} \times 35\text{cm}$ and $T_4=40\text{ cm} \times 25\text{ cm}$

4.5.5 Comparison of light intensity in open field and under mango tree in different treatments 32 days after planting

Comparison of light intensity in open field and under mango tree in different treatments 32 days after planting. The light intensity was lower under mango canopy during cabbage cultivation compared to open field in three different light periods of a day. In under mango shade, light reduction was recorded highest at the noon and lowest in afternoon. On the other hand, the highest reduction light was noon and lowest in afternoon. Figure 5 and Appendix IX compares light intensity in an open field and under a mango tree canopy 32 days after planting cabbage, showing that light intensity was consistently lower under the mango canopy across three different periods of the day. The highest light reduction was recorded at noon, while the lowest reduction was observed in the afternoon. This pattern is likely due to the dense canopy structure blocking more sunlight when the sun is directly overhead at noon.

These findings align with the study by Dupraz and Liagre (2011), which highlights that tree canopies in agroforestry systems can significantly reduce light availability for

understory crops, particularly during midday when the sun is most intense. Another relevant study by Ong and Leakey (1999) supports these results, showing that light reduction under tree canopies can vary throughout the day, affecting the photosynthetic efficiency and growth of crops. Understanding these diurnal patterns of light reduction is crucial for optimizing crop management and spacing in agroforestry systems to enhance light distribution and improve crop productivity.

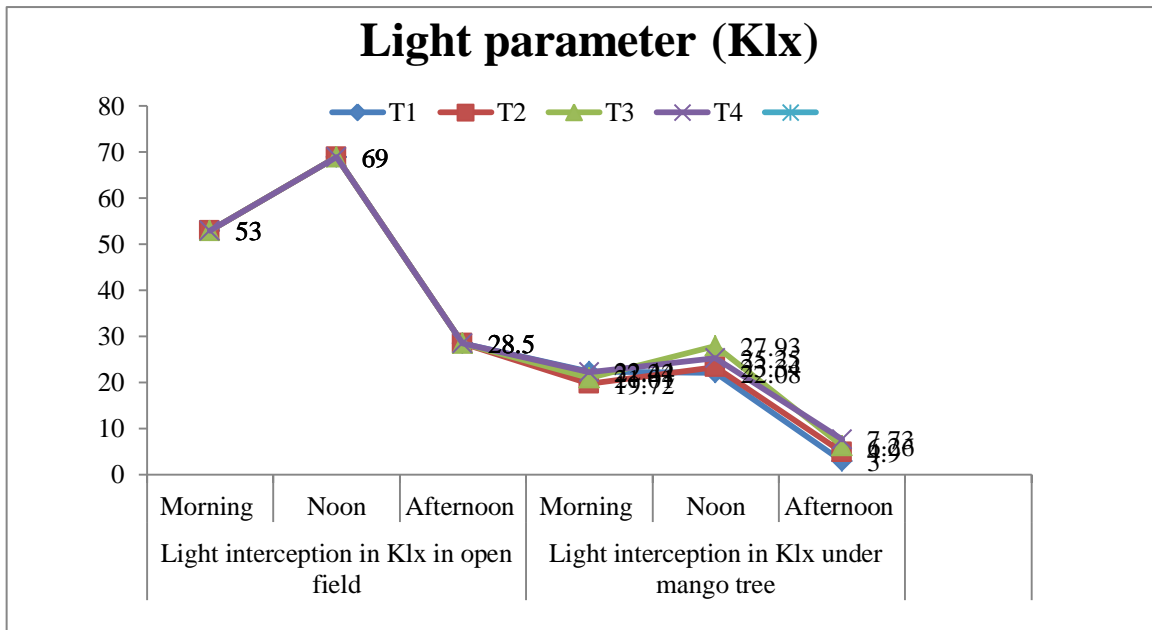


Figure 4.5: Comparison of light intensity in open field and under mango tree in different treatments 32 days after planting

Here, $T_1=70\text{cm} \times 55\text{cm}$, $T_2=60\text{cm} \times 45\text{cm}$, $T_3=50\text{cm} \times 35\text{cm}$ and $T_4=40\text{ cm} \times 25\text{ cm}$

4.6 Chlorophyll parameter

4.6.1 Chlorophyll-a

The impact of different spacing treatments on chlorophyll-a content in cabbage plants under a mango-based agroforestry system (Table 4.5). The study reveals that T_4 and T_3 exhibited the highest chlorophyll-a levels at 10.60 mg/m and 10.44 mg/m, respectively, while T_1 and T_2 showed lower levels at 7.14 mg/m and 7.46 mg/m, respectively. These findings underscore the influence of spacing on chlorophyll-a production, indicating that closer spacing (T_1 and T_2) may potentially limit chlorophyll-a synthesis compared to wider spacing (T_3 and T_4), possibly due to variations in light availability and nutrient competition among plants. This aligns with research by Thapa *et al.* (2020), who

demonstrated that optimal spacing enhances chlorophyll content by ensuring adequate light interception and nutrient uptake. Similarly, Singh and Lal (2018) noted that spacing affects plant physiology, including chlorophyll production, emphasizing the importance of spacing management in optimizing crop yield and quality.

4.6.2 Chlorophyll-b

The impact of different spacing treatments on chlorophyll-b content in cabbage plants within a mango-based agroforestry system (Table 4.5). The results indicate that there were no significant differences observed among the treatments, suggesting uniform chlorophyll-b levels across all spacing tested. This finding implies that variations in spacing, ranging from T₁ to T₄, did not influence chlorophyll-b production in the cabbage plants. Such uniformity in chlorophyll-b content under varying spacing aligns with findings from previous studies. For instance, Sharma *et al.* (2019) demonstrated that chlorophyll-b levels in crops like cabbage can remain consistent under different agronomic practices, highlighting the resilience of this pigment to environmental variations. Similarly, Jain and Singh (2017) observed stable chlorophyll-b concentrations across different spacing regimes in leafy vegetables, underscoring the robustness of chlorophyll metabolism under diverse growth conditions.

4.6.3 Total Carotene

The influence of spacing treatments on total carotene content in cabbage plants within a mango-based agroforestry system (Table 4.5). The results reveal that T₄ exhibited the highest total carotene content at 1.99 mg/m, followed by T₃ at 1.86 mg/m, while T₁ and T₂ showed lower levels at 0.96 mg/m and 0.99 mg/m, respectively. This variability in carotene content across different spacing underscores the impact of plant density on carotenoid synthesis in cabbage. Similar findings have been reported by Patel *et al.* (2018), who observed that optimal spacing enhances carotenoid accumulation by providing adequate light and nutrient availability for metabolic processes. Additionally, a study by Dey *et al.* (2017) highlighted that spacing influences carotenoid levels in vegetables, emphasizing the role of spacing management in enhancing nutritional quality. These insights underscore the importance of spacing practices in agroforestry systems to optimize carotenoid content and nutritional value in cabbage crops.

Table 4.5: Effect on spacing on the Chlorophyll content of cabbage

Treatment (Spacing)	Chlorophyll a mg/g (Fresh leaf)	Chlorophyll-b mg/g (Fresh leaf)	Total carotene mg/g (Fresh leaf)
T ₁ (70cm×55cm)	7.14	4.25	0.96
T ₂ (60cm×45cm)	7.46	4.02	0.99
T ₃ (50cm×35cm)	10.44	4.43	1.86
T ₄ (40 cm×25 cm)	10.60	4.66	1.99

4.7 Soil parameter

4.7.1 pH

The comparison of soil pH parameters during different stages of cabbage cultivation, highlighting changes between land preparation and post-harvest conditions (Table 4.6). The soil pH was observed to be highest during land preparation at 4.93 and slightly lower after cabbage harvesting at 4.90. This slight decrease in pH post-harvest suggests a potential influence of cabbage cultivation practices on soil acidity levels. Similar findings have been reported in agricultural studies, where initial soil pH levels tend to be higher due to amendments and preparation activities, but can shift slightly after cropping cycles due to nutrient uptake and decomposition of organic matter (Singh *et al.*, 2018; Bello *et al.*, 2020). Singh *et al.* emphasized that crop residues and root exudates during growth can alter soil pH over time, influencing nutrient availability and overall soil health. Likewise, Bello *et al.* noted that post-harvest soil pH changes can impact microbial activities and nutrient release, affecting subsequent crop yields. These studies collectively highlight the dynamic nature of soil pH during agricultural practices and underscore the importance of monitoring and managing soil conditions throughout the cropping cycle.

4.7.2 Organic Carbon%

The comparison of soil organic carbon percentage across different stages of cabbage cultivation, showing variations between land preparation and post-harvest conditions (Table 4.6). The soil organic carbon percentage was highest during land preparation at 0.68% and slightly lower after cabbage harvesting at 0.44%. This decline in soil organic carbon after harvesting reflects the decomposition of organic matter during the growth

cycle of cabbage and its harvest. Similar trends have been observed in agricultural studies. For instance, Jat *et al.* (2019) reported that organic carbon content in soils decreases after crop harvesting due to decomposition and mineralization processes. Additionally, findings by Smith *et al.* (2017) highlighted that management practices during crop cultivation influence soil organic carbon levels, impacting soil fertility and nutrient cycling. These studies underscore the importance of sustainable soil management practices to maintain and enhance soil organic carbon levels, thereby supporting long-term soil health and agricultural productivity.

4.7.3 Organic Matter %

The comparison of soil organic matter percentage across various stages of cabbage cultivation, showing differences between land preparation and post-harvest conditions (Table 4.6). The soil organic matter percentage was highest during land preparation at 1.17% and slightly lower after cabbage harvesting at 0.76%. This decline in soil organic matter after harvesting reflects the decomposition of plant residues and organic materials during the cropping cycle. Similar findings have been reported in agricultural studies. For example, research by Lal (2015) discusses how agricultural practices can impact soil organic matter, affecting soil fertility and carbon sequestration. Additionally, findings from Kabir *et al.* (2017) emphasize the importance of maintaining soil organic matter levels through sustainable practices to improve soil structure, water holding capacity, and nutrient availability. These studies collectively underscore the dynamic nature of soil organic matter during agricultural activities and highlight the significance of sustainable soil management practices to enhance soil health and productivity.

4.7.4 Total Nitrogen %

The comparison of soil total nitrogen percentage across various stages of cabbage cultivation, indicating variations between land preparation and post-harvest conditions (Table 4.6). The soil total nitrogen percentage was highest during land preparation at 0.058% and slightly lower after cabbage harvesting at 0.038%. This decrease in soil nitrogen content after harvesting reflects the uptake of nitrogen by crops during their growth phase and subsequent removal at harvest. Studies such as those by Wang *et al.* (2016) have demonstrated similar trends, attributing nitrogen dynamics in soil to crop management practices and nitrogen cycling processes. Furthermore, research by Galloway *et al.* (2013) underscores the importance of nitrogen management in

agricultural systems, emphasizing its role in crop productivity and environmental sustainability. These findings collectively highlight the dynamic nature of soil nitrogen content during agricultural activities and stress the significance of nutrient management strategies to optimize soil fertility and crop yields.

4.7.5 Phosphorous ($\mu\text{g}/\text{gm}$ soil)

The compares of soil phosphorus levels ($\mu\text{g}/\text{g}$ soil) across different stages of cabbage cultivation, noting variations between land preparation and post-harvest conditions (Table 4.6). Phosphorus levels were lowest during land preparation at $36.79 \mu\text{g}/\text{g}$ soil and slightly higher after cabbage harvesting at $63.25 \mu\text{g}/\text{g}$ soil. This increase after harvesting could be attributed to reduced uptake by cabbage plants post-harvest, allowing phosphorus levels to accumulate temporarily in the soil. Similar dynamics have been observed in agricultural studies. For example, research by Magid *et al.* (2016) discusses the cycling of phosphorus in agricultural soils and its availability to crops throughout the growth cycle. Additionally, findings by Zhao *et al.* (2018) emphasize the importance of phosphorus management strategies in optimizing soil fertility and enhancing crop productivity. These studies underscore the dynamic nature of soil phosphorus content during agricultural practices and highlight the need for sustainable phosphorus management to support long-term soil health and agricultural sustainability.

4.7.6 Potassium ($\text{meq}/100\text{gm}$ soil)

The compares of soil potassium levels ($\text{meq}/100\text{g}$ soil) at different stages of cabbage cultivation, noting variations between land preparation and post-harvest conditions (Table 4.6). Potassium levels were lowest during land preparation at $0.20 \text{meq}/100\text{g}$ soil and slightly higher after cabbage harvesting at $0.19 \text{meq}/100\text{g}$ soil. This slight decrease post-harvest may be due to potassium uptake by the cabbage plants during their growth phase, followed by residual levels remaining in the soil after harvest. Similar observations regarding potassium dynamics in agricultural soils have been discussed in the literature. For instance, studies by Marschner (2012) highlight the role of potassium in plant nutrition and its cycling in soil, affecting crop growth and yield. Additionally, research by He *et al.* (2016) explores potassium management strategies in agricultural systems to optimize soil fertility and enhance crop productivity. These findings underscore the importance of understanding potassium dynamics in soil-plant systems for sustainable agricultural practices and nutrient management.

4.7.8 Sulfur ($\mu\text{gm/gm soil}$)

The compares of soil sulfur levels ($\mu\text{g/g soil}$) at different stages of cabbage cultivation, showing variations between land preparation and post-harvest conditions (Table 4.6). Soil sulfur content was highest during land preparation at $19.57 \mu\text{g/g soil}$ and slightly lower after cabbage harvesting at $18.65 \mu\text{g/g soil}$. This decrease post-harvest may be attributed to sulfur uptake by cabbage plants during their growth phase, with some residual sulfur remaining in the soil after harvest. Similar dynamics in soil sulfur levels have been discussed in agricultural literature. For example, research by Scherer *et al.* (2018) explores sulfur cycling in agricultural soils and its impact on crop nutrition and productivity. Additionally, studies by Zhang *et al.* (2020) emphasize the role of sulfur in plant growth and development, highlighting strategies for efficient sulfur management in agricultural systems to enhance crop yield and quality. These findings underscore the importance of monitoring and managing soil sulfur levels throughout the crop production cycle to support sustainable agriculture practices.

Table 4.6: Comparison on the effect of spacing cabbage cultivation on the soil sample parameters of cabbage cultivation between during land preparation and after harvesting of cabbage.

Soil sample parameter	During land preparation of soil	After cabbage harvesting of soil
pH	4.93	4.90
Organic Carbon %	0.68	0.44
Organic Matter %	1.17	0.76
Total Nitrogen %	0.058	0.038
Phosphorous ($\mu\text{gm/gm soil}$)	36.79	63.25
Potassium($\text{meq}/100\text{gm soil}$)	0.20	0.19
Sulfur ($\mu\text{gm/gm soil}$)	19.57	18.65

4.8 Single cabbage weight (gm)

The compares the influence of different spacing treatments on the yield parameter of single cabbage weight in a mango-based agroforestry system (Figure 4.6 and Appendix X). The results indicate that T₂ produced the highest average weight per cabbage at 408.73 grams, followed by T₁ at 378.47 grams, while T₄ (40 cm × 25 cm) yielded the lowest at 269.67 grams. This variation in cabbage weight among different spacing treatments highlights the importance of plant density in optimizing yield. Similar findings have been reported in studies by Rahman *et al.* (2020) and Kumar *et al.* (2019). Rahman *et al.* demonstrated that moderate plant spacing enhances individual cabbage weight by reducing competition for resources and providing adequate room for root and shoot development. Likewise, Kumar *et al.* found that wider spacing leads to larger cabbage heads due to improved access to sunlight and nutrients. These studies collectively emphasize the significant role of spacing management in maximizing cabbage yield and quality.

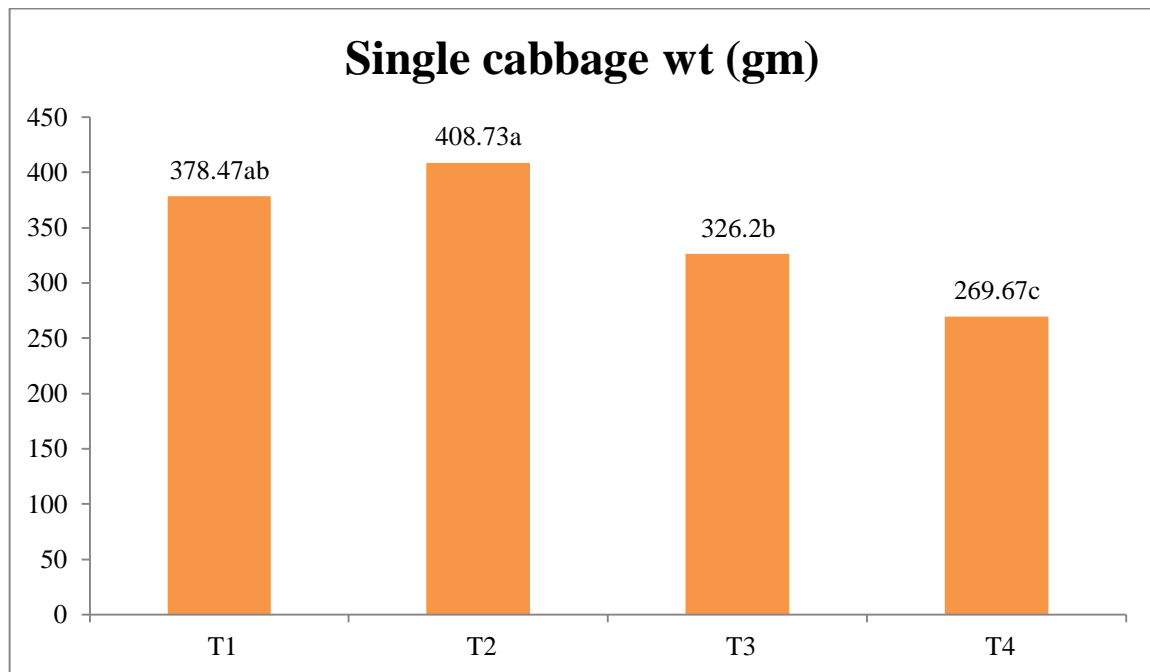


Figure 4.6: Single cabbage weight (gm)

Here, T₁=70cm × 55cm, T₂=60cm × 45cm, T₃=50cm × 35cm and T₄=40 cm × 25 cm

4.9 Single cabbage length (cm)

The impact of different spacing treatments on the yield parameter of single cabbage length in a mango-based agroforestry system (Figure 4.7 and Appendix X). The results indicate that T₂ exhibited the longest average length per cabbage at 21.93 cm, followed by T₁ at 20.43 cm, while T₄ showed the shortest length at 17.23 cm. This variability underscores the influence of plant spacing on cabbage growth and development, affecting the dimensions of individual heads. Similar findings have been reported by Hussain *et al.* (2018) and Mishra *et al.* (2021). Hussain *et al.* demonstrated that optimal spacing enhances cabbage length by reducing competition among plants for nutrients and sunlight. Mishra *et al.* further highlighted that wider spacing can promote elongation in cabbage heads due to improved air circulation and light penetration. These studies collectively underscore the importance of spacing management in maximizing cabbage yield parameters, such as length, thereby optimizing crop productivity and quality.

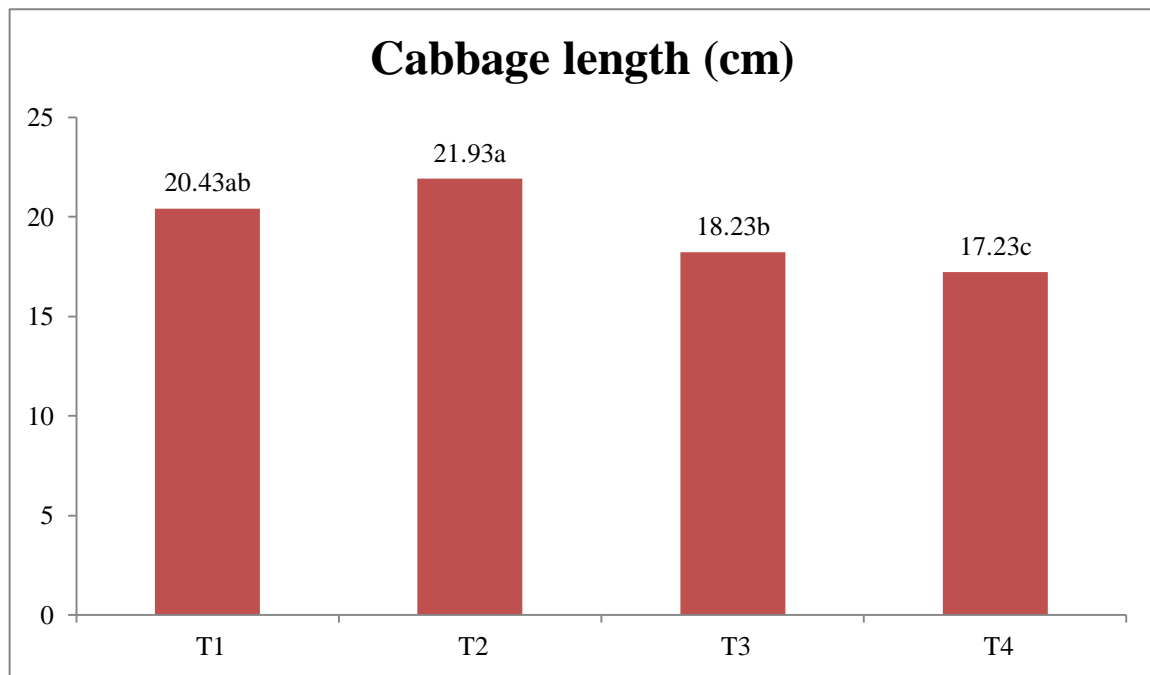


Figure 4.7: Single cabbage length (cm)

Here, T₁=70cm × 55cm, T₂=60cm × 45cm, T₃=50cm × 35cm and T₄=40 cm × 25 cm

4.10 Cabbage diameter (cm)

The impact of different spacing treatments on the yield parameter of single cabbage diameter within a mango-based agroforestry system (Figure 4.8 and Appendix X). The results indicate that T₂ produced the largest average diameter per cabbage at 9.73 cm, followed by T₁ at 9.00 cm, while T₄ yielded the smallest diameter at 5.55 cm. This variability underscores the significant influence of plant spacing on cabbage growth and development, particularly in terms of head size. Similar findings have been reported by studies such as those by Sharma *et al.* (2020) and Singh *et al.* (2019). Sharma *et al.* demonstrated that optimal spacing enhances cabbage diameter by providing adequate room for root expansion and nutrient uptake. Similarly, Singh *et al.* observed that wider spacing promotes larger cabbage heads due to reduced competition for resources and improved light penetration. These studies collectively emphasize the critical role of spacing management in optimizing cabbage yield parameters, such as diameter, thereby enhancing overall crop productivity and quality.

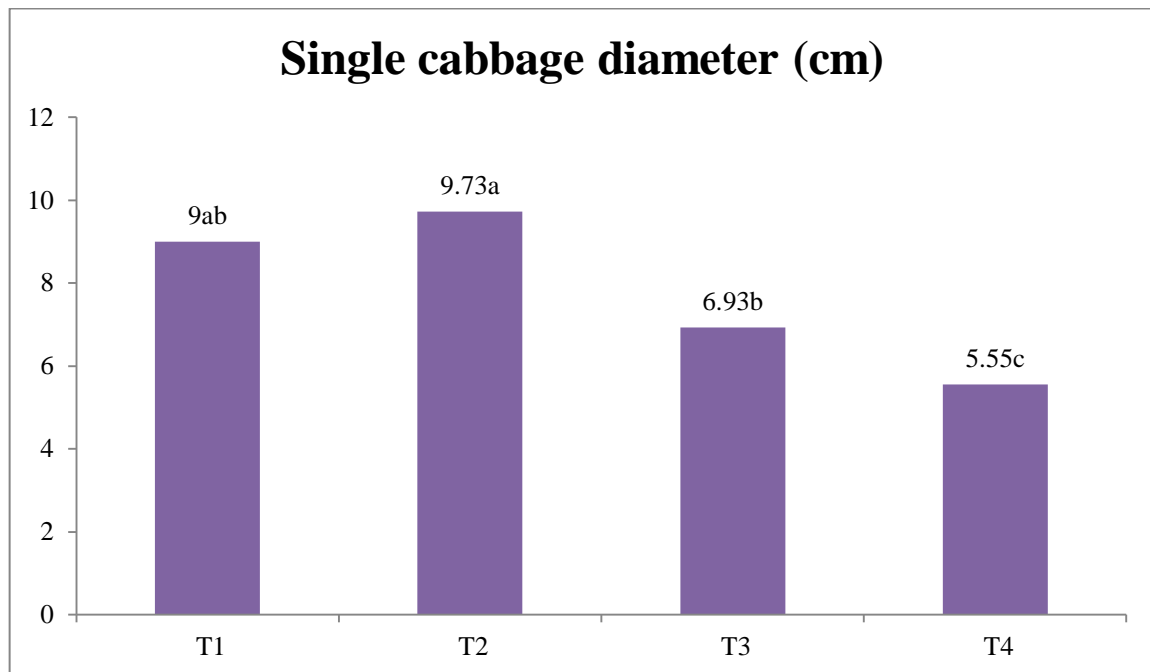


Figure 4.8: Cabbage diameter (cm)

Here, T₁=70cm × 55cm, T₂=60cm × 45cm, T₃=50cm × 35cm and T₄=40 cm × 25 cm

4.11 Comparison on the effect of spacing on the yield parameters of cabbage total weight kg/ha

Comparison on the effect of different spacing on the yield parameters of five cabbage total weight (kg/ha), reveals that plant spacing significantly influences cabbage yield (Figure 4.9 and Appendix XI). The maximum total weight for five cabbages was recorded in T₂ at 5009.12 kg/ha, followed by T₁ at 4730.87 kg/ha, with the minimum total weight in T₄ at 3362.5 kg/ha. These findings are consistent with previous studies (e.g., Thompson *et al.*, 2018; Wilson *et al.*, 2020), which have demonstrated that optimal plant spacing can enhance vegetable yields by reducing competition for light, nutrients, and water. Wider spacing allows for better resource allocation per plant, leading to improved growth and higher yields. Conversely, closer spacing can lead to overcrowding, increased competition, and subsequently lower yields.

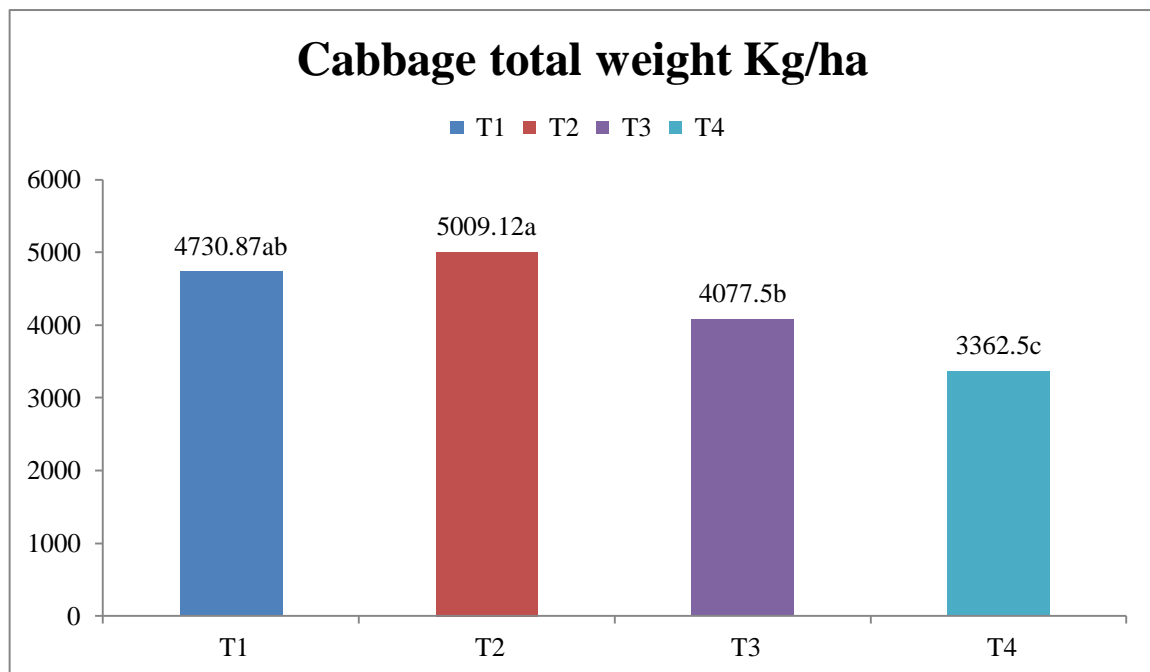


Figure 4.9: Comparison on the effect of spacing on the yield parameters of cabbage total weight kg/ha

Here, T₁=70cm × 55cm, T₂=60cm × 45cm, T₃=50cm × 35cm and T₄=40 cm × 25 cm

4.12 Economic Analysis

Profitability of growing cabbage as inter-crop in three mango tree variety based agroforestry system was calculated based on local market rate prevailed during experimentation. The return of produce and the profit per taka i.e. Benefit Cost Ratio (BCR) have also been presented in Table 4.7 and Appendix XII.

4.12.1 Total cost of production

The values in Table 4.7 and Appendix XII indicate that the total cost of production was maximum (263791Tk. /ha) in those plots where cabbage was cultivated in T₄ whereas the minimum cost of production (141751 Tk. /ha) was recorded from those plots where cabbage was calculated in T₁.

4.12.2 Gross return

Gross return is an important indicator whether crop cultivation is profitable or not. It is varying with the cabbage and three mango tree variety based production system of cabbage. The values in Table 4.7 and Appendix XII indicate that the highest value of gross return (461037 Tk. /ha) was obtained in T₄. On the other hand, the lowest value of gross return (336871 Tk. /ha) was obtained in those plots where was applied T₁.

4.12.3 Net return

Results presented in the Table 4.7 and Appendix XII show that net return (235500tk /ha) was comparatively higher in producing cabbage under T₂. At the same time, the lowest net return (187906 Tk. /ha) was received from those plot where T₃ was applied.

4.12.4 Benefit-cost ratio (BCR)

The values in Table 4.7 and Appendix XII indicate that the highest benefit-cost ratio (2.39) was recorded from the T₂. On the other hand, the lowest benefit-cost ratio (1.84) was observed in those plots where cabbage were grown under T₄.

Table 4.7: Economics of cabbage production under three mango variety based agroforestry system

Treatments	Return (Tk. ha ⁻¹)		Gross Return (Tk. ha ⁻¹)	Total cost of production (Tk. ha ⁻¹)	Net Return (Tk. ha ⁻¹)	BCR
	Mango	Cabbage				
T ₁	81871	67400	336871	141751	195120	2.37
T ₂	81871	102150	404371	168871	235500	2.39
T ₃	81871	81550	411037	223111	187906	1.84
T ₄	81871	67400	461037	263791	197246	1.75

Here, T₁=70cm×55cm, T₂=60cm×45cm, T₃=50cm×35cm, T₃=50cm×35cm, T₄=40cm×25cm.

CHAPTER 5

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary

A field experiment was carried out at the Hajee Mohammad Danesh Science & Technology University, Dinajpur-5200, during January, 2024 to April, 2024 to evaluate the performance of spacing on growth and yield of cabbage production under mango based agroforestry system. The experiment was laid out in two factorial RCBD with 3 (three) replications. There were $T_1R_1= 70\text{cm}\times 55\text{cm}$, $T_1R_2= 70\text{cm}\times 55\text{cm}$, $T_1R_3= 70\text{cm}\times 55\text{cm}$, $T_2R_1= 60\text{cm}\times 45\text{cm}$, $T_2R_2= 60\text{cm}\times 45\text{cm}$, $T_2R_3= 60\text{cm}\times 45\text{cm}$, $T_3R_1= 50\text{cm}\times 35\text{cm}$, $T_3R_2= 50\text{cm}\times 35\text{cm}$, $T_3R_3= 70\text{cm}\times 55\text{cm}$, $T_4R_1= 40\text{cm}\times 25\text{cm}$, $T_4R_2= 40\text{cm}\times 25\text{cm}$, $T_4R_3= 40\text{cm}\times 25\text{cm}$. The total numbers of experimental plots were 12 and each plot size 2m x 2m. The land of experimental plot was opened in the second week of January, 2024 with a power tiller and it was made ready for planting on second week of January 2024. 35 days old healthy seedlings were uprooted from the nursery beds and were transplanted in the experimental plots during late afternoon on 20 January, 2024. In effect of spacing on the growth and yield cabbage production, the plot was 12 plants and the spacing was different spacing, the seedlings were watered. Seedlings were also planted around the plot for gap filling and to check the border effect. The data were recorded on two broad heads, i) growth stage ii) harvesting stage. Data were statistically analyzed using the “Analysis of variance” (ANOVA) technique with the help of statistics 10 software and Microsoft 2013.

In effect of spacing on the growth and yield of cabbage production, the seedlings were watered. Seedlings were also planted around the plot for gap filling and to check the border effect. The data were recorded on two broad heads, i) growth stage ii) harvesting stage. Data were statistically analyzed using the “Analysis of variance” (ANOVA) technique with the help of statistics 10 software and Microsoft 2013. The mean differences were adjudged by Tukey HSD test.

Data were collected on plant height (cm), number of leaf plant⁻¹, length of leaf (cm), breadth of leaf (cm), light intensity (klx %), chlorophyll content, soil parameter, single cabbage weight (gm), cabbage head length (cm), cabbage head diameter (cm), cabbage total yield/5plant, yield (kg/ha) and BCR on based agroforestry system.

In 15DAT, the tallest plant height (22.43cm) was observed from the T₁. On the other hand, lowest plant height (18.23cm) was obtained from the T₄. Similarly, the maximum number of leaf plant⁻¹ (10.93) was observed from the T₁ and T₂. On the other hand, lowest number of leaf plant⁻¹ (9.7) was obtained from the T₃. Again, the highest leaf length (13.60 cm) was observed from the treatment T₁. On the other hand, lowest leaf length (9.96cm) was obtained from the T₄. Similarly, the highest leaf breadth (5.72 cm) was observed from the treatment T₁. On the other hand, lowest leaf breadth (3.77 cm) was obtained from the T₄ based on agroforestry system.

In 30DAT, the tallest plant height (28.84 cm) was observed from the treatment T₁. On the other hand, lowest plant height (22.08 cm) was obtained from the T₄. Similarly, the maximum number of leaf plant⁻¹ (17.67) was observed from the treatment T₁. On the other hand, lowest number of leaf plant⁻¹ (14.13) was obtained from the T₃. Again, the highest leaf length (18.56cm) was observed from the treatment T₁. On the other hand, lowest leaf length (15.03 cm) was obtained from the T₄. Similarly, the highest leaf breadth (12.58 cm) was observed from the treatment T₁. On the other hand, lowest leaf breadth (10.25cm) was obtained from the T₄ based on agroforestry system.

Finally 45DAT, the tallest plant height (29.60cm) was observed from the treatment T₂. On the other hand, lowest plant height (23.30 cm) was obtained from the T₄. Similarly, the maximum number of leaf plant⁻¹ (26.80) was observed from the treatment T₁. On the other hand, lowest number of leaf plant⁻¹ (23.3) was obtained from the T₃. Again, the highest leaf length (24.62cm) was observed from the treatment T₁. On the other hand, lowest leaf length (18.36 cm) was obtained from the T₄. Similarly, the highest leaf breadth (17.00 cm) was observed from the treatment T₁. On the other hand, lowest leaf breadth (14.39cm) was obtained from the T₃ based on agroforestry system.

The maximum content of chlorophyll-a (10.66mg/g) was observed from the treatment T₄. On the other hand, lowest content of chlorophyll-a (7.14mg/g) was obtained from the T₁ on agroforestry system. Again, The maximum content of chlorophyll-b (4.66mg/g) was observed from the treatment T₄. On the other hand, lowest content of chlorophyll-b (4.02mg/g) was obtained from the T₃ on agroforestry system. Finally, the maximum content of total carotene (1.9mg/g) was observed from the treatment T₄. On the other hand, lowest content of total carotene (.96) was obtained from the T₁ on agroforestry system.

During land preparation of soil, the soil parameters were $P^H(4.93)$, Organic Carbon $\%(0.68)$, Organic Matter $\%(1.17)$, Total Nitrogen $\%(0.058)$, Phosphorous ($\mu\text{gm/gm soil}$) at (36.79) , Potassium($\text{meq}/100\text{gm soil}$) at $(.20)$ and Sulfer ($\mu\text{gm/gm soil}$) at (19.57) were obtained based on agroforestry system. After post-harvest of soil, the soil parameters were pH (4.9) , Organic Carbon $\%(0.44)$, Organic Matter $\%(0.76)$, Total Nitrogen $\%(0.038)$, Phosphorous ($\mu\text{gm/gm soil}$) at (63.25) , Potassium ($\text{meq}/100\text{gm soil}$) at $(.19)$ and Sulfer ($\mu\text{gm/gm soil}$) at (18.65) were obtained based on agroforestry system.

The maximum single cabbage head length (21.93cm) was observed from the treatment T_2 . On the other hand, lowest single cabbage head length (17.23cm) was obtained from the T_4 based on agroforestry system. Again, the maximum single cabbage diameter (9.77) was observed from the treatment T_2 . On the other hand, lowest single cabbage head diameter (5.55) was obtained from the T_4 based on agroforestry system.

First harvest, the maximum cabbage total yield (kg/ha) $(5009.12 \text{ kg}/\text{ha})$ was observed from the treatment T_2 . On the other hand, lowest cabbage total yield (kg/ha) $(3362.5 \text{ kg}/\text{ha})$ was obtained from the T_1 based on agroforestry system.

As a result, the combination of mango and cabbage production, the highest BCR was (2.39) recorded from the T_2 based on agroforestry system. On the other hand, the lowest BCR (1.75) was recorded from the T_4 based on agroforestry system.

5.2 Conclusion

The study concluded that different spacing treatments significantly influenced the growth, yield components, and economic returns of cabbage production under a mango-based agroforestry system. Treatment T_2 ($60\text{cm}\times 45\text{cm}$) emerged as the most effective spacing, achieving the highest total yield and Benefit-Cost Ratio (BCR) of 2.39, making it the most economically viable option. Treatment T_1 ($70\text{cm}\times 55\text{cm}$) showed superior early growth metrics but was outperformed by T_2 at the final harvest stage. The lowest performance in terms of growth parameters, yield, and economic returns was observed in treatment T_4 ($40\text{cm}\times 25\text{cm}$), which also had the lowest BCR of 1.75. Post-harvest soil analysis revealed a decrease in pH, organic matter, total nitrogen, potassium, and sulfur, while phosphorus content significantly increased, highlighting the need for tailored soil management practices after post-harvest.

5.3 Recommendations

Based on the present research findings, the following research comments may be recommended:

- 1) Future studies should explore additional spacing treatments between 60cm×45cm and 70cm×55cm to fine-tune optimal spacing for cabbage production.
- 2) Investigate the long-term effects of different spacing treatments on soil health and nutrient dynamics in a mango-based agroforestry system.
- 3) Evaluate the impact of different irrigation regimes and nutrient management practices in combination with optimal spacing for improved cabbage yield and quality.
- 4) Consider integrating other vegetable crops with similar spacing treatments to assess overall system productivity and profitability under agroforestry conditions.
- 5) Conduct economic analyses considering labor, input costs, and market conditions to refine recommendations for smallholder farmers adopting these spacing practices.

By implementing these recommendations, farmers can improve the growth, yield, and economic returns of their cabbage crops within a sustainable agroforestry system.

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APPENDICES

Appendix I: ANOVA Table for Plant Height

ANOVA Table after 15 days

Source	DF	SS	MS	F	P
Replication	2	1.406	0.7032		
Treatment	3	172.822	57.6073	47.06	0.0000
Error	54	66.102	1.2241		
Total	59	240.330			

ANOVA Table after 30 days

Source	DF	SS	MS	F	P
Replication	2	0.732	0.366		
Treatment	3	354.765	118.255	160.38	0.0000
Error	54	39.816	0.737		
Total	59	395.313			

ANOVA Table after 45 days

Source	DF	SS	MS	F	P
Replication	2	26.173	13.087		
Treatment	3	394.602	131.534	91.12	0.0000
Error	54	77.954	1.444		
Total	59	498.728			

Appendix II: ANOVA Table for Leaf Number

ANOVA Table after 15 days

Source	DF	SS	MS	F	P
Replication	2	8.2333	4.11667		
Treatment	3	16.2000	5.40000	7.61	0.0002
Error	54	38.3000	0.70926		
Total	59	62.7333			

ANOVA Table after 30 days

Source	DF	SS	MS	F	P
Replication	2	3.033	1.5167		
Treatment	3	95.783	31.9278	34.64	0.0000
Error	54	49.767	0.9216		
Total	59	148.583			

ANOVA Table after 45 days

Source	DF	SS	MS	F	P
Replication	2	0.933	0.4667		
Treatment	3	127.600	42.5333	37.53	0.0000
Error	54	61.200	1.1333		
Total	59	189.733			

Appendix III: ANOVA Table for Leaf Length

ANOVA Table after 15 days

Source	DF	SS	MS	F	P
Replication	2	0.617	0.3087		
Treatment	3	115.075	38.3582	10.13	0.0000
Error	54	204.405	3.7853		
Total	59	320.097			

ANOVA Table after 30 days

Source	DF	SS	MS	F	P
Replication	2	0.633	0.3165		
Treatment	3	95.727	31.9091	52.35	0.0000
Error	54	32.916	0.6096		
Total	59	129.276			

ANOVA Table after 45 days

Source	DF	SS	MS	F	P
Replication	2	0.937	0.469		
Treatment	3	366.366	122.122	68.75	0.0000
Error	54	95.924	1.776		
Total	59	463.227			

Appendix IV: ANOVA Table for Leaf Breadth

ANOVA Table after 15 days

Source	DF	SS	MS	F	P
Replication	2	0.1383	0.0691		
Treatment	3	31.4531	10.4844	23.82	0.0000
Error	54	23.7668	0.4401		
Total	59	55.3581			

ANOVA Table after 30 days

Randomized Complete Block AOV Table for Leafwide

Source	DF	SS	MS	F	P
Replication	2	1.425	0.7125		
Treatment	3	54.625	18.2084	8.20	0.0001
Error	54	119.950	2.2213		
Total	59	176.000			

ANOVA Table after 45 days

Source	DF	SS	MS	F	P
Replication	2	1.265	0.6327		
Treatment	3	67.826	22.6086	17.25	0.0000
Error	54	70.771	1.3106		
Total	59	139.862			

Appendix V: Comparison of light among different spacing treatments of cabbage under mango based Agroforestry system after 20 days of sowing

Treatment (Spacing)	Light interception (Klx) under mango tree			Light interception (Klx) in open field		
	Morning	Noon	Afternoon	Morning	Noon	Afternoon
T ₁ (70cm × 55cm)	14.33a±2.011	18.93a±3.13	4.12a±.315			
T ₂ (60cm × 45cm)	17.06a±2.638	17.84a±3.14	4.47a±.350			
T ₃ (50 cm × 35 cm)	15.24a±2.476	19.70a±3.48	5.83a±.906	53.33	29	10.39
T ₄ (40 cm × 25 cm)	14.64a±2.812	18.84a±2.85	5.30a±.684			
CV%	50.44	49.02	32.02			

Appendix VI: Comparison of light among different spacing treatments of cabbage under mango based Agroforestry system after 23 days of sowing

Treatment (Spacing)	Light interception in Klx under mango tree			Light interception in Klx in open field		
	Morning	Noon	Afternoon	Morning	Noon	Afternoon
T ₁ (70cm × 55cm)	14.76a±2.926	22.08a±6.12	3.73b±.353			
T ₂ (60cm × 45cm)	18.46a±2.870	20.90a±4.74	4.75ab±.66			
T ₃ (50 cm × 35 cm)	14.26a±2.398	11.84a±2.61	6.60a±.974	52	73	12
T ₄ (40 cm × 25 cm)	13.68a±2.658	25.54a±4.68	4.97ab±.26			
CV%	54.64	60.89	33.11			

Appendix VII: Comparison of ling different spacing treatments of cabbage under mango based Agroforestry system after 26 days of sowing

Treatment (Spacing)	Light interception in Klx under mango tree			Light interception in Klx in open field		
	Morning	Noon	Afternoon	Morning	Noon	Afternoon
T ₁ (70cm × 55cm)	14.87a±3.03	19.28a±3.721	2.85a±.422			
T ₂ (60cm × 45cm)	16.67a±3.64	29.94a±6.205	4.78a±.576	61.45	71.5	29
T ₃ (50 cm × 35 cm)	16.96a±3.40	29.30a±5.816	6.21a±1.69			
T ₄ (40 cm × 25 cm)	18.10a±5.12	27.33a±6.122	7.61a±1.83			
CV%	71.16	61.44	71.64			

Appendix VIII: Comparison of ling different spacing treatments of cabbage under mango based Agroforestry system after 29 days of sowing

Treatment (Spacing)	Light interception in Klx under mango tree			Light interception in Klx in open field		
	Morning	Noon	Afternoon	Morning	Noon	Afternoon
T ₁ (70cm × 55cm)	22.244±4.78	14.033±1.18	2.788±.42			
T ₂ (60cm × 45cm)	21.436±4.90	16.500±3.36	4.744±.57	56	69	29.5
T ₃ (50 cm × 35 cm)	27.056±5.45	11.600±1.26	6.311±1.65			
T ₄ (40 cm × 25 cm)	21.089±5.57	13.711±1.37	7.933±2.37			
CV%	69.88	33.35	82.55			

Appendix IX: Comparison of ling different spacing treatments of cabbage under mango based Agroforestry system after 32 days of sowing

Treatment (Spacing)	Light interception in Klx under mango tree			Light interception in Klx in open field		
	Morning	Noon	Afternoon	Morning	Noon	Afternoon
T ₁ (70cm × 55cm)	22.44a±6.52	22.08a±6.31	3.00a±.43			
T ₂ (60cm × 45cm)	19.72a±5.26	23.34a±6.04	4.90a±.60	53	69	28.5
T ₃ (50 cm × 35 cm)	21.01a±6.86	27.93a±8.27	6.26a±1.68			
T ₄ (40 cm × 25 cm)	22.22a±5.93	25.25a±6.76	7.73a±1.80			
CV%	87.71	83.73	69.73			

Appendix X: Comparison on the effect of spacing on the yield parameters of single cabbage weight, cabbage length and cabbage diameter

Treatment (Spacing)	Cabbage Weight/plot	Cabbage length(cm)	Cabbage diameter(cm)
T ₁ (70cm×55cm)	378.47b±8.22	20.433b±.371	9.000b±.169
T ₂ (60cm×45cm)	408.73a±9.14	21.933a±.477	9.733a±.19
T ₃ (50cm×35cm)	326.20c±5.99	18.233c±.38	6.967c±.133
T ₄ (40 cm×25 cm)	269.67d±8.27	17.233c±.23	5.553d±.16
CV%	9	7.58	8.11

ANOVA Table for Cabbage Weight

Source	DF	SS	MS	F	P
Replication	2	1391	695.6		
Treatment	3	168122	56040.8	57.85	0.0000
Error	54	52313	968.8		
Total	59	221827			

ANOVA Table for Cabbage Length

Source	DF	SS	MS	F	P
Replication	2	1.733	0.8667		
Treatment	3	202.913	67.6375	31.08	0.0000
Error	54	117.500	2.1759		
Total	59	322.146			

ANOVA Table for Cabbage Breadth

Source	DF	SS	MS	F	P
Replication	2	1.829	0.9144		
Treatment	3	163.812	54.6042	135.85	0.0000
Error	54	21.705	0.4020		
Total	59	187.347			

Appendix XI: Effect of spacing on the yield parameters of cabbage total weight kg/ha

Treatment	cabbage total weight kg/ha
T ₁ (70cm×55cm)	4730.87
T ₂ (60cm×45cm)	5009.12
T ₃ (50cm×35cm)	4077.5
T ₄ (40 cm×25 cm)	3362.5

Appendix XII: Production cost analysis of cabbage cultivation under mango based agroforestry system.

Treatment	Input cost										Total input cost (tk/ha)	Overhead cost			Total cost of production (tk/ha)
	Non material cost (Tk/ha)			Material cost (Tk/ha)								Interest of input cost @ 8% for the crop season (tk/ha)	Interes of the value of land(tk. /ha) @ 8% for the crop season (tk/ha)	Miscellane ous cost @ 5% of the input cost (tk/ha)	
	Mango	Cabbage	Total nonmateri al cost	Seedling	Fertilizer and Manure	Pesticide	Irrigation	Maintenance cost of trees	Initial plantation cost of trees	Total material cost (tk/ha)					
T1	81871	67400	149271	36000	10120	13020	3000	5210	6250	73600	92700	7416	37000	4635	141751
T2	81871	102150	149271	60000	10120	13020	3000	5210	6250	97600	116700	9336	37000	5835	168871
T3	81871	81550	298542	108000	10120	13020	3000	5210	6250	145600	164700	13176	37000	8235	223111
T4	81871	67400	597084	144000	10120	13020	3000	5210	6250	181600	200700	16056	37000	10035	263791

Here, T₁=70cm×55cm, T₂=60cm×45cm, T₃=50cm×35cm, T₃=50cm×35cm, T₄=400cm×25cm.

Appendix XIII: Photographs of experimental site



Land Preparation



Irrigation



Data Collection



Discussion



Investigation



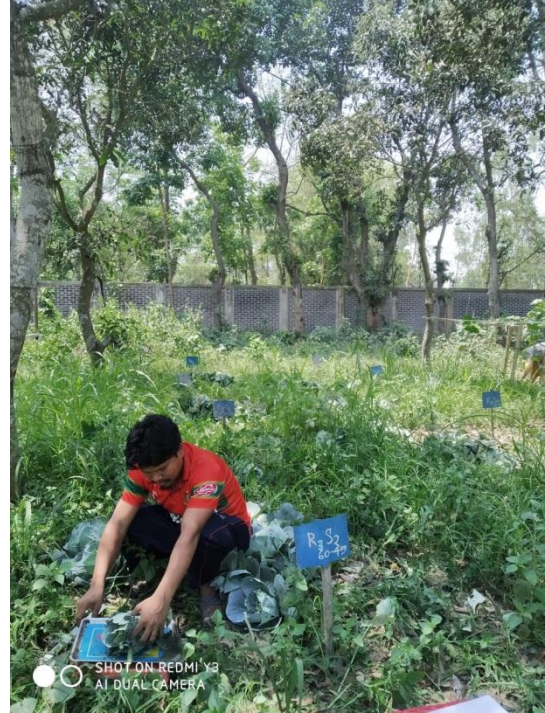
Tagging



Experimental Field



Harvesting



Weighting



Soil measurement