TOMATO CULTIVATION DURING THE EARLY ESTABLISHMENT PERIOD OF MORINGA PLANTATION

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JUNE, 2020

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REGISTRATION NO. : 13-05338

A Thesis
Submitted to the Faculty of Agriculture
Sher-e-Bangla Agricultural University, Dhaka
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

IN

AGROFORESTRY AND ENVIRONMENTAL SCIENCE

SEMESTER: JANUARY- JUNE, 2020

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CERTIFICATE

This is to certify that the thesis entitled ***"TOMATO CULTIVATION DURING THE EARLY ESTABLISHMENT PERIOD OF MORINGA PLANTATION"*** *submitted to the Department of Agroforestry and Environmental Science, Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of* ***MASTERS OF SCIENCE*** *in* ***AGROFORESTRY AND ENVIRONMENTAL SCIENCE****, embodies the result of a piece of bona fide research work carried out by* ***MD. SELIM MIA****, Registration No. 13-05338 under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

I further certify that any help or source of information, received during the course of this investigation has been duly acknowledged.

June, 2020

Dhaka, Bangladesh

Dr. Md. Kausar Hossain
Professor
Supervisor

Dedicated to

My

Beloved Parents

ACKNOWLEDGEMENTS

The author wishes to acknowledge the immeasurable grace and profound kindness of the "Almighty Allah" the most gracious and the supreme rule of the universe for giving mental peace, health and strength to submit the thesis for the degree of Master of Science (MS) in Agroforestry and Environmental Science.

The author would like to extend his heart-squeezed gratitude, deepest appreciation, best regards and indebtness to his honorable teacher and research Supervisor professor Dr. Md. Kausar Hossain, Department of Agroforestry & Environmental Science, Sher-e-Bangla Agricultural University, Dhaka, for his continuous direction, constructive criticism, encouragement and valuable suggestions, helpful commentary and unvarying inspiration throughout the research work and preparation of the thesis.

The author would like to express his earnest respect, sincere appreciation and enormous indebtedness to his reverend Co-supervisor, Dr. Md. Saifullah, Member Director, Bangladesh Agricultural Research Council, Dhaka, for his scholastic supervision, inspiration in carrying out the research work and preparation of this thesis.

The author feels to express his heartfelt thanks to the honorable Chairman, Dr. Jubayer-Al-Mahmud, Department of Agroforestry and Environmental Science along with all other teachers and staff members of the Department of Agroforestry & Environmental Science, Sher-e-Bangla Agricultural University, Dhaka, for their co-operation during the period of the study.

The author feels proud to express his deepest and endless gratitude to all of his course mates and friends to cooperate and help him during taking data from the field and preparation of the thesis. The author wishes to extend his special thanks Murtoza Helal, Md. Tanvir Zubayer, Mahedi Hasan, Nayemul Islam, Humayon Kabir for his keen help as well as heartiest co-operation and encouragement.

Finally the author is ever grateful to his respective parents Md. Monir Hossain and Selina Begum for their everlasting love, patience ,moral and constant blessing.

The Author

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ABSTRACT

The experiment was carried out at Agroforestry Field Laboratory, Sher-e-Bangla Agricultural University, Dhaka−1207 during the period from October 2018 to January 2019 to investigate tomato cultivation during the early establishment period of Moringa plantation. The experiment consisted of four treatments *viz*., T_1 (30 cm distance from the tree base), T_2 (40 cm distance from the tree base), T_3 (50 cm distance from the tree base) and T_4 (Open field as control). Experiment was laid out in Randomized Complete Block Design (RCBD) with four replications. In case of growth parameters, the highest plant height of Tomato (71.83 cm) and number of branches per plant of Tomato (8.34) were observed in control condition (T_4) but in tree-crop association, the highest plant height (69.49 cm) and number of branches per plant (7.00) were recorded in T_3 treatment whereas the lowest result was observed from T_1 treatment with plant height (49.59 cm) and number of branch per plant (4.33). Regarding canopy spreading of Moringa tree, the highest spreading (N/S = 225.0 cm and E/W 240.0 cm) was found from treatment T_3 and in T_2 canopy spreading were (N/S = 205.00 cm and E/W = 185.00 cm) whereas the lowest canopy spreading (N/S = 180.00 cm and E/W = 173.30 cm) was found from T_1 treatment. In terms of yield contributing parameters and yield, with tree-crop interaction T_3 showed the lowest days to 1st flowering and T_4 showed the lowest days (64.33 days) to 1st harvest whereas the highest days to flowering and days to 1st harvest was achieved from T_1 treatment (35.67 and 70.33 days, respectively). The highest fruit diameter (6.17 cm), number of fruits per plant (29.67), fruit yield per plant (2367.07 g), individual fruit weight (81.91 g), fruit yield per plot (9.09 kg) and fruit yield per ha (42.08 t) was also found control treatment T_4 but under tree-crop interaction, the highest fruit diameter (5.79 cm), number of fruits per plant (26.33), fruit yield per plant(2014.52 g), individual fruit weight (77.16 g), fruit yield per plot (7.78 kg) and fruit yield per ha (34.16 t) were obtained from T_3 treatment whereas the lowest fruit diameter (4.42 cm), number of fruits per plant (14.00), fruit yield per plant (933.82 g), individual fruit weight (66.42 g), fruit yield per plot (3.61 kg) and fruit yield per ha (16.05 t) were obtained from T_1 treatment. Distance between tree and crop had strong positive correlation with almost all parameters. Estimated regression line, based on observed data points, predicted optimum distance of Tomato plot from one year old Moringa tree would be approximately 80 cm for maximum Tomato yield (44.29 t/ha) in Moringa based Agroforestry system.

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LIST OF ABBREVIATIONS AND ACRONYMS

AEZ	=	Agro-Ecological Zone
BBS	=	Bangladesh Bureau of Statistics
BCSRI	=	Bangladesh Council of Scientific Research Institute
cm	=	Centimeter
CV %	=	Percent Coefficient of Variation
DAS	=	Days After Sowing
DMRT	=	Duncan's Multiple Range Test
et al.,	=	And others
e.g.	=	exempli gratia (L), for example
etc.	=	Etcetera
FAO	=	Food and Agricultural Organization
i.e.	=	id est (L), that is
Kg	=	Kilogram (s)
LSD	=	Least Significant Difference
m^2	=	Meter squares
ml	=	Mili Litre
M.S.	=	Master of Science
No.	=	Number
SAU	=	Sher-e-Bangla Agricultural University
var.	=	Variety
^oC	=	Degree Celceous
%	=	Percentage
NaOH	=	Sodium hydroxide
GM	=	Geometric mean
mg	=	Miligram
P	=	Phosphorus
K	=	Potassium
L	=	Litre
Mg	=	Magnesium
USA	=	United States of America
WHO	=	World Health Organization

CHAPTER I

INTRODUCTION

Bangladesh is one of the most densely populated country in the world struggling to feed of her more than 160 million peoples with limited land resources. Population had doubled in the last 30 years where population density is approximately 1260 persons per square Kilometer (Statista, 2020). However, the fertility of our land is decreasing day by day due to intensive crop cultivations and use of agrochemicals. Increasing agricultural production under increasing climate variability in Bangladesh requires increased attention to environmental sustainability, especially the crucial neglected roles that trees can play. Agroforestry farming system is considered as the set of practices that explore and guide the integration of trees into crop, livestock and mixed agricultural systems at nested scales from a farmer's field to large agricultural landscapes. Hence, it plays an important role in determining the livelihood where trees can contribute to improving food and nutrition security, livelihoods and the delivery of ecosystem services (Griggs *et al*., 2013; Mbow *et al*., 2014a). Upgrading to the social and biophysical environment and other ecosystem services are among the multiple benefits delivered simultaneously by agroforestry (Takimoto *et al*., 2008), creating a system where the whole is more than the sum of its individual components (Mbow *et al*., 2014 b).

Traditionally farmer grow different types of trees and vegetables in their fields, homesteads, and adjacent areas where productivity of tree and crop is very low due to lack of compatible tree-crop combinations with appropriate management practices. *Moringa oleifera* is considered as neglected and underutilized species (NUS) in our country though it is popular as superfood across the world (Rudebjer *et al*., 2013). The neglect probably due to little or no research attention from researchers and policy makers, loss of local knowledge and lack of established varieties (Padulosi *et al*., 2013). However, it could be used as a promising Agroforestry tree species in association with agricultural crops due to its fast growing, high coppicing ability and deciduous characteristics (Bashir *et al*., 2014).

Moringa is grown throughout the Bangladesh, usually as a multipurpose plant, and popular for its immature fruit as well as leafy vegetable, stems, roots, pods and seeds (Adejumo *et al*., 2012; Popoola and Obembe, 2013). All parts of *M. oleifera* are used as food and nutrition, animal fodder, natural coagulants, forestry products and fertilizer (Afolabi *et al*., 2013; Ahmad *et al*., 2014). In addition, the leaves and the seeds are nutritionally rich containing high concentrations of crude protein, calcium, iron, potassium, manganese, essential vitamins (thiamine, riboflavin, niacin, ascorbic acid), antioxidants and anti-inflammatory compounds (Adejumo *et al*., 2012). The medicinal uses, safety and efficacy of *M. oleifera* have been widely reported by several authors (Popoola and Obembe, 2013; Hussain *et al*., 2014; Stohs and Hartman, 2015). The seed oil as raw material for production of biodiesel is gaining attention globally as possible replacement for petro diesel fuel in unmodified engines (Fernandes *et al*., 2015). The use as supplementary food has been adjudged to have high biological value, with 20-40% inclusion in groundnut hay based diet recommended for ruminant animals (Akinbamijo *et al*., 2004).

Tomato (*Solanum lycopersicon* Mill) is the most value added and nutritious vegetable crop in Bangladesh. It ranks next to Potato and Sweet Potato in respect of vegetable production in the world. Farmer prefers Tomato cultivation due to its stable and higher market price. The total production of Tomato in Bangladesh was about 368000 tons from 24700 hectares of land with an average yield of 13.46 t per ha (BBS, 2016). It has high nutritive value especially vitamin A and vitamin C (Thompson and Kelly, 1957). Tomato is largely used in soups, pickles, ketchup, sauces, juices etc. Tomato juice has become an exceedingly popular appetizer and beverage to the common people of our country.

Intercropping of Tomato in association with Moringa perhaps be an important agroforestry farming system to boost the livelihood of our farmer. With such practice, two way achievements can be obtained which may contribute in fulfillment of food, vegetable and nutrition simultaneously beneficial for socio economic development through eco-friendly management. In such farming system, the optimum use of land is ensured by which it is recognized as a time winning recognition in the country especially like Bangladesh where shortage of land is a serious concern. Nowadays, farmers are incorporating different types of tree species in their crop fields to boost up their livelihood, but most of the times they are not getting the desired benefits due to lack of appropriate combinations and management practices to optimize above and below ground interactions (Sharif *et al.,* 2010; Pervin *et al.,* 2015; Rana *et al.,* 2017). A few studies have been conducted by incorporating a few leafy vegetables with Moringa (Ahmed, 2017; Sumona, 2017; Roy, 2019). However, to the best of our knowledge no or little work has been done on the cultivation methods of Moringa incorporating Tomato as an understory crop to increase the productivity of our limited land.

Therefore, the present study was undertaken with the following objectives:

1. To evaluate growth, yield and yield contributing characters of Tomato grown in association with Moringa tree.
2. To find out the optimum distance in between Tomato and Moringa tree for maximum Tomato yield under Moringa based agroforestry farming system.

CHAPTER II

REVIEW OF LITERATURE

This research was undertaken to observe the performance of Tomato grown in association with early stage of Moringa trees in agroforestry system. Literatures related to these aspects are very limited in our country and abroad. However, literatures related to the performance of crops in tree- crop agroforestry system, characteristics of tree species and importance of agroforestry system were collected through reviewing of journals, thesis, internet browsing, reports, newspaper and other form of publications arc presented in this Chapter in the following sections.

2.1 Concept of agroforestry and its importance

ICRAF's current definition is a collective name for land-use systems and practices in which woody perennials are deliberately integrated with crops and/or animals on the same land-management unit. The integration can be either in a spatial mixture or in a temporal sequence. There are normally both ecological and economic interactions between the woody and non-woody components in agroforestry. This definition has served well and helped agroforestry to become recognized as a branch of agricultural science in its own right (Sanchez, 1995).

Nair (1989) recommend that an agroforestry is a land-use system that involves socially and ecologically acceptable integration of trees with agricultural crops and/or animals, simultaneously or sequentially, so as to get increased total productivity of plant and animal in a sustainable manner from a unit of farmland, especially under conditions of low levels of technology inputs and marginal lands.

Agroforestry is practiced on home garden (Millat-e-Mustafa, 1997) cropland (Roy, 1997) forestlands etc. However, the sustainability of these practices, a major concerns in Bangladesh. Agroforestry is considered an efficient and sustainable land use option especially suited for resources poor fanners (Stocking *et al.*, 1990).

Abedin *et al*. (1990) mentioned that agroforestry is considered as one of the strategies for augmenting tree production for a country like Bangladesh where there is a little scope of developing pure forest due to obvious priority for food crop production.

Khandaker (1991) reported that agroforestry system is traditional in the homesteads of moist tropical world including rural areas of Bangladesh since the establishment of houses. This system could be considered as potential technology for rural poverty alleviation because of its diversified functions.

Lawrence and Hardostry (1992) described that the landowners cited potential advantages to practicing agroforestry were land use diversity 25 percent, enhanced productivity 18 percent, aesthetics 13 percent, income diversity 13 percent and the most frequently identified potential obstacles to practicing agroforestry were: lack of information 28 percent, lack of technical assistance 18 percent, establishment cost 14 percent and the fact that it is not an established practice 14 percent. They also found that the responses suggested there is great potential for application of agroforestry throughout the state, and non-industrial private forestland owners were selected for future study of this potential.

Nasaruddin *et al*. (2000) carried out a study in Malaysia to analyze the current agroforestry practices adopted there and reported that Agrosilvicultural is the main system being practiced, which is reflected in the major tree/crop components in a given site.

Basavaraju and Gururaja (2000) concluded that selection of suitable tree species for agroforestry is important. However, it is not always possible to select tree species having all the desirable characteristics for agroforestry, because of different production and protection goals. It is stated that in such cases, agroforestry systems have to be managed through planting optimum tree density of trees, proper special arrangement and pruning and thinning of tree crown and roots to reduce the negative effects of trees.

Neupane and Thapa (2001) cited that the practices which minimize the rate of soil degradation, increase crop yields and raise farm income are key to sustaining agricultural productivity in the hills of Nepal. They also stated that agroforestry has great potential for enhancing food production and farmers' economic conditions in a sustainable manner through its positive contributions to household income.

2.2 Agroforestry as a sustainable land-management system

Traditional and successful long-fallow land-use systems became more and more impracticable in 1970-1980 in Africa, due to population growth. This created a need for new low-cost alternatives that could be applied by the poor rural population (Radersma, 2002). Agroforestry was proposed as one such alternative; it combines fallow and production mechanisms at the same time and space (Kang et al., 1985). During the 1990s, agroforestry was globally recognized as an answer to problems such as the deterioration of family farms, increasing soil erosion, surface and ground water pollution, and decreasing biodiversity. Agroforestry is now considered by more and more experts to be a sustainable land-management option, because of its ecological, economic, and social functions (Garrity, 2012).

Agroforestry was recently defined by ICRAF (2016) as 'the practice and science of the interface and interactions between agriculture and forestry, involving farmers, livestock, trees and forests at multiple scale'. Agroforestry systems have been classified into two groups, namely (1) those that are sequential, where crops are grown either in natural fallows or in fields previously improved by growing trees; and (2) those that are simultaneous, where trees scattered on fields and alleys are grown together with crops (Cooper *et al*., 1996).

Like much of tropical Africa, East Africa is faced with problems of low agriculture productivity, land degradation and massive deforestation because of the expansion of land used for agriculture. A wider adoption of agroforestry may help to reverse the effects of deforestation and land degradation in Africa (FAO, 2012). Depending upon the species are used, their arrangement and how they are managed, trees incorporated into crop fields and agricultural landscapes may help to:

(i) Increased the nutrient availability for crops through nitrogen fixation and enhanced nutrient recycling (Barnes and Fagg, 2003) and to increase soil organic matter content and thereby to ameliorate soil structure (Chirwa *et al.*, 2007).

(ii) Improved water infiltration resulting in increased water use efficiency by reducing the unproductive components of the water balance (Sanou *et al*., 2012).

(iii) Ameliorate the micro-climate effects by reducing wind speed, raising humidity and reducing leaf temperature of crops.

(iv) Increase the abundance and activity of beneficial soil organisms (Barrios *et al.,* 2011).

(v) Increase yields of fruit, fodder, fuel, fibre, and timber from trees/shrubs, allowing an income increase directly through sales or indirectly through intensifying the system (Garrity *et al.,* 2010).

(vi) Provide pruning mulch that increases C and N in the soils (Youkhana and Idol, 2009) and enhances carbon storage both above and below ground (Makumba *et al.,* 2007).

However, the success of agroforestry depends on the balance of positive and negative interactions between the components (Vandermeer, 1992). It is necessary to quantify the balance between positive and negative effects of trees on crops in order to provide a scientific basis for the improvement of traditional as well as evolving agroforestry systems.

2.3 Potentiality of Moringa as multipurpose tree species

Moringa oleifera usually mentioned in literature as Moringa, is a natural as well as cultivated variety of the genus Moringa belonging to family Moringaceae. The plants have always been vital for mankind irrespective of the era and area all over the globe since the beginning of life. These will remain ever beneficial from nutritional, social, cultural, religious, environmental and human's health etc. The medicinal plants have greatest potential for benefitting people, especially those living in poor countries suffering from poverty, poor health, malnutrition, unemployment and isolation in international trade. Moringa has been used in the traditional medicine passed down for centuries in many cultures around the word, for skin infections, anemia, anxiety, asthma, blackheads, blood impurities, bronchitis, chest congestion, cholera, conjunctivitis, cough, diarrhea, eye and ear infections, fever, glandular, swelling, headaches, abnormal blood pressure, pain in joints, pimples, respiratory disorders, scurvy, semen deficiency, sore throat, tuberculosis, for intestinal worms, lactation ,diabetes and pregnancy. The present review is intended to create public awareness regarding benefit of an edible plant Moringa which is also known as miracle tree. The healing properties of Moringa oil, have been documented by ancient cultures. Moringa oil has tremendous cosmetic value and is used in body and hair care as a moisturizer and skin conditioner. Moringa oil has been used in skin preparations since Egyptian times (Ramchandran *et al.*, 1980; Sairam, 1999; Fuglie and Lowell, 2001; Monica and Marcu, 2005).

There are about 13 species of Moringa trees in the genus Moringa of family Moringaceae. These are *Moringa oleifera, M. arborea*, *M. borziana*, *M. concanensis M. drouhardii*, *M. hildebrandtii*, *M. longituba, M. ovalifolia*, *M. peregrine, M. pygmaea*, *M. rivae*, *M. ruspoliana*, and *M. stenopetala.* The most widely known species *M. oleifera* reported as "*M. pringa"* (Nasir and Ali, 1972).

Moringa is very impressive and amazing plant due to its tested, and potential benefits from nutritional as well therapeutical point of views. This friendly plant is of great significance as shown to be useful in water purification, cosmetics, livestock fodder, plant growth enhancer and biogas. In the last ten years, hundreds of research articles, thesis, reports, and patents have been published on Moringa. Newspapers, scientific journals, documentaries, Discovery Channel feature Moringa more and more. The Church World Service recently organized the first ever Moringa Tree International Conference to educate about Moringa use as an indigenous resource for fighting hunger and malnutrition (Fuglie, 1999; fuglie, 2000; Fuglie and Lowell, 2001; Monica and Marcu, 2005).

2.4 Nutritional Benefits of Moringa

M. oleifera is the most nutrient-rich plant yet discovered. This humble plant has been making strides in less-developed societies for thousands of years, and significant nutritional research has been conducted since the 1970s. Moringa provides a rich and rare combination of nutrients, amino acids, antioxidants, antiaging and anti-inflammatory properties used for nutrition and healing. Moringa is sometimes called "Mother's Best Friend" and "Miracle Tree." Since 1998, the World Health Organization has promoted Moringa as an alternative to imported food supplies to treat malnutrition (UNWFP, 2004; Manzoor *et al.,* 2007; Sreelatha and Padma, 2009).

Nutritional Benefits: A large number of reports on the nutritional qualities of Moringa now exist in both the scientific and the popular literature. Moringa has been in use since centuries for nutritional as well medicinal purposes. These include vitamin C, which fights a host of illnesses including colds and flu; vitamin A, which acts as a shield against eye disease, skin disease, heart ailments, diarrhea, and many other diseases; Calcium, which builds strong bones and teeth and helps prevent osteoporosis; Potassium, which is essential for the functioning of the brain and nerves, and Proteins, the basic building blocks of all our body cells. Another important point is that Moringa leaves contain all of the essential amino acids, which are the building blocks of proteins. It is very rare for a vegetable to contain all of these amino acids. Moringa contains these amino acids in a good proportion, so that they are very useful to our bodies. These leaves could be a great boon to people who do not get protein from meat. Moringa even contains argenine and histidine two amino acids especially important for infants. Argenine and histidine, are especially important for infants who are unable to make enough protein for their growth requirements. Experts tell us that 30% of children in sub-Saharan Africa are protein deficient. Moringa could be an extremely valuable food source (Duke, 1987; Fuglie, 1999; Babu, 2000; Fuglie, 2000; Lockett and Calvert, 2000; fuglie and Lowell, 2001).

Given its nutritional value, it can be utilized in fortifying sauces, juices, spices, milk, bread, and most importantly, instant noodles. Many commercial products like Zija soft drink, tea, and neutroceuticals are available all over the globe. A comparative study of Moringa fresh leaves gram for gram with other foodstuffs puts Moringa on top. It contains seven times the vitamin C of oranges, four times the vitamin A of carrots, four times the calcium of milk, three times the potassium of banana and two times the protein of yogurt .But the micro-nutrient content is even more in dried leaves; ten times the vitamin A of carrots, 17 times the calcium of milk, 15 times the potassium of bananas, 25 times the iron of spinach and nine times the protein of yogurt. However, Vitamin C drops to half that of oranges (Gopalan *et al.*, 1971; Nasir and Ali, 1972; Mahatab *et al.,* 1987; Monica and Marcu, 2005; Manzoor *et al.,* 2007).

Antioxidants play an important role in inhibiting and scavenging free radicals, thus providing protection to human against infections and degenerative diseases. The data obtained in suggests that the extracts of *M. oleifera* both mature and tender leaves have potent antioxidant activity against free radicals, prevent oxidative damage to major biomolecules and afford significant protection against oxidative damage (Yongbai, 2005; Sreelatha and Padma, 2009).

2.5 Tomato Cultivation

Tomato (*Lycopersicon esculentun L*.) belongs to the family Solanaceae. It was originated in tropical America, particularly in Peru, Ecuador and Bolivia of the Andes (Kalloo, 1989). The leading TOMATO production countries of the world are China, the United States of America, India, Turkey, Iran, Italy, Mexico, Brazil and Indonesia (FAO, 1999). It was cultivated in almost all home gardens and also in the field due to its adaptability to wide ranges of soil and climate (Ahmed *et al*., 1986). It ranks next to potato and sweet potato in the world vegetable production. Tomato ranks third in terms of world vegetable production (FAO, 2000) and tops the list of canned vegetables. It is one of the most highly praised vegetables consumed widely and it is a major source of vitamins and minerals. It is widely employed in cannery and made into soups, conserves, pickles, ketchup, sauces, juices etc. Tomato juice has become an exceedingly popular appetizer and beverage. In Bangladesh, half of the population is under the poverty level and suffering from various health problems. A large number of children have clinical sign of vitamin A deficiency and more than 900000 children under six years of age suffering from some degree of xerophthalmia and over 30,000 children go under blind each year due to vitamin A deficiency. Tomato has high nutritive value especially vitamin A and vitamin C (Thompson and Kelly, 1957). Therefore, it can be met up some degree of vitamin A and vitamin C requirement and can contribute to solve national malnutrition problem. The per capita consumption of vegetables in Bangladesh is very low as compared to that of other countries. In Bangladesh the daily requirement of vegetable for a person is 200 g.

Tomato is a warm-season crop. The crop does well under an average monthly temperature of (21 to 23)^{0}C. Temperature and light intensity affect the fruit-set, pigmentation and nutritive value of the fruit. Long dry spell and heavy rainfall both shows detrimental effect on growth and fruiting. The Kharif crop is transplanted in July, Rabi crop in October - November .In the southern plains where there is no danger of frost, The first transplanting is done in December-January, Second June-July and Third in September-October depending on the irrigation facilities available. The yield per hectare varies greatly according to variety and season. On an average, the yield varies from 20-25 t/ha. Hybrid varieties may yield upto 50-60 t/ha.

In Bangladesh, a large number of Tomato varieties are Ratan, Manik, BARI Tomato-3, BARI Tomato-4, BARI Tomato-5, Chaiti, Apurba, Shila, Lalima and Anupama. BARI Tomato-4, BARI Tomato-5, Chaiti, Lalima and Anupama (hybrid) that can also be grown in warm season.

Most of them lost their potentiality due to genetic deterioration and disease contamination. Hence in order to improve the present situation of Tomato production in Bangladesh, it is essential to promote better varieties to the growers of Bangladesh.

2.6 Tree-Crop Intercropping

Wadud *et al.* (2002) was carried out an experiment to study the performance of red amaranth (*Amaranthus gangeticus*) under four levels of light- 100, 75, 50, and 25% photosynthetically active radiation (PAR) was evaluated to judge its suitability for inclusion in agroforestry systems. Mosquito nets of different mesh size have been used to create desirable light levels. It was observed that in red amaranth, any reduction in PAR affected all morphological and yield parameters of red amaranth negatively. Plant height, number of leaves plant, leaf size, stem girth, fresh and dry yield were decreased significantly with decreasing light levels but the trend of response of different morphological parameters to different light levels were different. The mean fresh and dry yield (t/ ha) of red amaranth grown under 100, 75, 50 and 25 % PAR levels were 12.77, 9.54, 5.75, 3.19 and 1.27, 0.92, 0.55, 0.26, respectively. Therefore, red amaranth may not be included in tree-crop agroforestry system.

Photosynthetically active radiation (PAR) is considered as the most important limiting factor in certain agroforestry systems (Bayala *et al.*, 2008; Sanou *et al.*, 2012). Depending on their photosynthetic pathway (C_3, C_4 or CAM plants), species will respond differently to shading (Kelly *et al.*, 2009). The understory species used in this study was C_3 species which tolerate better than C_4 species. In this study, the understory crops and plants received about 30–60% light compared to that in open field due to deciduous Moringa trees. Hanif *et al.* (2010) observed that prolonged shading used to impede photosynthetic capacity of plants due to changing the stomata and mesophyll cell properties and resulting in reducing accumulation of photosynthesis. Besides, the supra-optimal radiation triggers plant under stress, close their stomata and reduce production. Thus, lower photosynthesis leads to lower reproductive growth of plants. This findings also corroborate the work conducted on Tomato cultivars under *Azadirachta indica* and *Dalbergia sissoo* based agroforestry systems (Miah *et al.,* 2008).

Islam *et al.* (2009) carried out an experiment at the Agroforestry Farm, Department of Agroforestry, Bangladesh Agricultural University, Mymensingh, during November 2008 to March 2009 to evaluate the performance of three winter vegetables grown under *Hopea odorata* at different distances. The vegetables were stem amaranth, red amaranth and coriander. In each experiment vegetables were grown at different distance from tree base which were treated as different treatment. Performance of winter vegetables in terms of morphological parameters as well as fresh and dry yield was affected significantly by distance from the tree. The result showed that vegetable production was the highest in control (without tree) which was significantly similar with 2, 3 and 4 feet distance from the tree base and the lowest was observed under 1 feet distance. Among the different morphological characteristics of winter vegetable, leaf length, leaf diameter, stem girth, fresh weight and dry weight decreased consistently with the decrease of distance from the tree where the best result was obtained under 4 feet distance from *H. odorata*. The growth characteristics of Telsur was significantly influenced by all the three winter vegetables. The highest growth was recorded in control condition which was statistically similar with red amaranth and coriander combination. The lowest tree growth was found under the combination of tree-stem amaranth, which is different from other.

An experiment was conducted at the Agroforestry Farm, to find out the effect of shading times (i.e. morning shade, noon shade, afternoon shade and shade free) of different trees (Akashmoni, Eucalyptus and Jhau) on growth and yield of transplanted aman rice (cv.

BRRI dhan 30). Highest plant height of rice (126.667 cm) and lowest 1000-grain weight (21.247 g) and grain yield of rice (2.967 t per ha) was observed in the noon shade area of Akashmoni. Highest 1000-grain weight (35.363 g) and grain yield (6.197 t per ha) of rice was found in shade free area of Jhau which was statistically similar to grain yield (5.232 t per ha) in the afternoon shade area of Jhau. Biological yield of rice was found lowest (6.877 t per ha) in the noon shade area of Akashmoni; where highest (13-397 t per ha) was observed on the shade free area of Jhau. Lowest grain yield reduction and maximum grain yield was found in the shade free area of Jhau which was statistically similar to grain yield in the afternoon shade area of Jhau (Sharif *et al.*, 2010).

Babu *et al.* (2015) was conducted at Char Gobadia which is situated by the side of Brahamputra River adjacent to Bangladesh Agricultural University, Mymensingh, to study the growth and yield of two winter vegetables i.e. chilli and sweet gourd under different spacing (T_0-Control, T_1-3 ft. distance from tree, T_2-6 ft. distance from tree, T_3-9 ft. distance from tree) of Eucalyptus tree, respectively. Experiment was conducted during July 2014 to March 2015 with three replications. It was observed that the growth and yield of chili and sweet gourd increased rapidly as distance increased from the tree. The tallest plant was found under treatment T_0. All the studied parameters increased gradually with increasing distance from tree. The highest yield of sweet gourd (29 kg/plant) and chilli (180 gm/plant) observed under treatment T_0. The lowest yield of sweet gourd (16 kg/plant) and chilli (140 gm/plant) observed under treatment T_1. It may be concluded that boundary plantation of Eucalyptus has negative effect on the growth and yield of chilli and sweet gourd.

Momtaz *et al*. (2014) was conducted an experiment at the Char Kalibari which is situated along the bank of Old Brahmaputra River under Sadar Upazila of Mymensingh district during November 2013 to March 2014 to observe the performance of bitter gourd as arable crop with karanja (*Pongamia pinnata L.*) trees in an agroforestry system. The experiment was conducted with three replications having four treatments viz., T_0 (open field condition referred as control), T_1 (< 50 cm distance from the tree base), T_2 (50-100 cm distance from the tree base) and T_3 (>100 cm distance from the tree base). The result showed that all the growth parameters and yield of bitter gourd were significantly influenced by the associated tree component at different distances from the karanja tree base. The highest (1.92 t per ha) fresh yield of bitter gourd was obtained in open field condition compare to any other treatments but no significant different was found from the treatment T_3 (distance >100 cm from the tree) while the lowest (0.8 t per ha) in < 50 cm distance from the tree base. It was found that on an average 58.33%, 29.17% and 14.58% yield of bitter gourd were decreased in <50 cm, 50-100 cm and >100 cm distances from karanja tree base compare to open field condition. On the other hand, the growth performance of karanja trees i.e. both height and girth increment was better in sole tree condition compare to tree with bitter gourd condition. Therefore, tree-crop combination i.e. >100 cm distance from tree base would be possible although there was some yield loss (14.58%) which was less significant compare to alone bitter gourd .

Pervin *et al. (*2015) was conducted a field experiment to observe the performance of mustard grown in association with Kalo koroi (*Albizia lebbeck*), a timber yielding tree species in crop based Agroforestry system. The study was conducted with three replications. Different treatments in association with Kalo koroi tree were T_1 = 0-1.5 m distance from the tree base, T_2 = 1.5-3.0 m distance from the tree base, T_3 = 3.0-4.5 m distance from the tree base and T_4 =open field condition referred as control. Growth and yield of mustard grown in association with Kalo koroi tree was recorded in different growth stage viz. vegetative, flowering and harvesting stage. It was found that growth parameters viz. plant height (cm), number of leaves per plant, leaf size including length (cm) and breadth (cm), length of floral rachis, no. of branches/rachis, no. of flower/branch, no. of siliqua/plant, length of siliqua (cm), no. of seed/siliqua, weight of 1000 seeds (g) of mustard varied almost similar pattern in all treatments when grown combindly with Kalo koroi tree. The highest values of all growth parameters were found in treatment T_4 i.e. without tree condition (control treatment) while the lowest data regarding above parameters were drastically reduced very near the tree base (0-1.5m from the tree base). As evident from the result it was found that yield of mustard gradually increased with increasing distance from Kalo koroi tree base. Yield of mustard remarkably reduced compare to control condition towards the base of Kalo koroi tree. Yield of mustard was highest (0.945 t/ha) in control condition which was statistically similar with the yield obtained from the treatment T_3 (0.94 t/ha) followed by treatment T_2 (0.635 t/ha) and lowest (0.425 t/ha) yield was obtained from treatment T_1 in association with kalo koroi tree. Yield reduction of mustard with kalo koroi tree in treatments T_1, T_2 and T_3 was 55.03, 32.80 and 0.53%, respectively compared to treatment T_4 i.e. open field condition.

An experiment in Char Kalibari of Old Brahmaputra River under Sadar Upazila of Mymensingh district during October 2016 to June 2017 to study the performance of sweet gourd in association with five years old Mango and Guava trees as agroforestry system. Mango and Guava trees were transplanted under strip plantation method during 2012 maintaining a spacing 3.6 m - 3.7 m distance. In this study sweet gourd was cultivated with and without fruit trees combinations which were the treatments of the study. Sweet gourd was grown under different treatments viz. T_1 (sweet gourd cultivation in association with Mango tree), T_2 (sweet gourd in association with Guava tree) and T_3 (sweet gourd cultivation without Mango and Guava trees) with three replications. Growth, yield attributes and yield of sweet gourd were observed under different treatments of this study with and without Mango and Guava tree combinations. From the result it is found that growth and yield of sweet gourd were remarkably reduced in association with both Mango and Guava trees. Around 77% yield reduction of sweet gourd was recorded per unit area where as it was around 50% in per plant of sweet gourd. Yield and yield attributes of Mango and Guava trees almost identical with and without sweet gourd combination. Land Equivalent Ratio (LER) of Mango and Guava with sweet gourd were 1.257 and 1.261, respectively, which indicate these combined production system in char land ecosystem are more productive compare to sole cultivation of fruit trees or vegetable crops (Rana *et al.,* 2017).

2.7 Growing crops in association of Moringa

Sumona (2017) conducted a field experiment at Sher-e-bangla Agricultural university, to find out the response of red amaranth in association with drumstick (*Moringa oleifera*) sapling during February to March.Four treatments namely, T_0= Open field referred to as control, T_1= 12 cm distance from the tree base, T_2= 24 cm distance from the tree base and T_3= 36 cm distance from the tree base. Yield contributing characteristics of red amaranth and growth perimeters of drumstick as influenced by the management practice were also determined. At the time of harvest, the highest plant height among the treatments was observed in T_3, which was 9% less than that of control condition and 22% less stem girth was observed in T_1 compared to control. The highest no. of leaves were observed in T_2 treatment, which was 15% less than that of control condition. In case of yield contributing characteristics of red amaranth, 20% less shoot length and 18% less root length were observed in treatment T_2 and T_1 respectively than that of control condition. Apart from control, the highest fresh weight, dry weight and yield were performed under T_1 treatment. Therefore, at treatment T_1, 16% less fresh weight, 13% less dry weight and 16% less yield were observed compared to that of control condition. But the moisture content of red amaranth (94.27%) was the highest in T_2 treatment and dry matter content of red amaranth (6.38%) was the highest in T_1 treatment. In case of drumstick, at the harvest of red amaranth the highest no of buds were found in T_3 treatment and lowest no. of buds were found in T_2 treatment, but the highest bud length was found in T_1 treatment. Therefore, it was observed that best yield performance of red amaranth at treatment T_1 in association with Moringa sapling. So, farmer can easily cultivate Moringa tree in association with red amaranth maintaining 12 cm distance from tree base without much loss.

An experiment was conducted in 2017 by Arif Ahmed in Agroforestry Field Laboratory at Sher-e-Bangla Agricultural University, Dhaka to find out the effect of planting distances on growth, yield and yield attributing characters of stem amaranth (*Amaranthus oleraceus*) during the early establishment period of Moringa (*M. oliaferae*) trees. The study was conducted comprising of four treatments with four replications. Four treatments were T_0 (open field condition as control), T_1 (6 inches distance from tree base), T_2 (12 inches distance from tree base), T_3 (18 inches distance from tree base). Significant variations were observed in respect of all characters at different days after sowing (DAS) with different planting distances. At harvest (50DAS), the maximum plant height of stem amaranth (59 cm), number of leaf per plant (25 cm) was recorded in control condition (T_0 treatment) and minimum plant height (49 cm), number of leaf per plant (20) was recorded in T_3 treatment. The highest leaf length (10 cm) and leaf breadth (5 cm), stem girth (6 cm), stem length (61 cm), root length(16 cm), shoot and root fresh weight (74 g and 16 g), shoot and root dry weight(4 g and root 1 g) and green yield (14 t/ha) were observed in open field condition (T_0 treatment). The yield was reduced by 15% in T_1 treatment (12 t/ha) compared to open field condition. The fresh yield of stem amaranth under T_2 (10 t/ha) and T_3 (10 t/ha) treatment with association of Moringa was recorded 26 % lower than the plants which were grown under control condition (T_0 treatment). The growth characters of *M. oliferae* were also enhanced in association with stem amaranth. At harvest of stem amaranth, maximum bud length(8cm) and bud number (4) of Moringa sapling were also recorded in T_1 treatment thus showing its potential to be used in Moringa based agroforestry farming system in large-scale.

Manoshi Roy (2019) conducted a field experiment in Agroforestry Farm at Sher-e-Bangla Agricultural University, Dhaka during the period from November 2018 to May 2019 to study brinjal growth and yield performance interaction with early establishment period of Moringa. Brinjal was grown under two different levels with four treatments viz., (i) T_0 (open field plantation considered as control), (ii) T_1 (30 cm distance from the tree base), (iii) T_2 (40 cm distance from the tree base) and (iv) T_3 (50 cm distance from the tree base). Results indicated that T_0 (open field plantation considered as control) treatment showed highest results on plant height, leaves per plant, branches per plant, plant spreading, number of fruits per plant, fruit weight per plant, single fruit weight and yield per ha. But under brinjal-moringa interaction, the highest results on respected parameters were found from T_3 (50 cm distance from the tree base) treatment. The highest fruit weight per plant (1923.90 g), single fruit weight (72.60 g) and fruit yield per ha (34.20 t) were found from T_0 (open field plantation considered as control) treatment and the second highest fruit weight plant1 (1592.53 g), single fruit weight (67.48 g) and fruit yield per ha (28.31 t) were found from T_3 (50 cm distance from the tree base) treatment. The lowest fruit weight plant1 (758.11 g), single fruit weight (59.60 g) and fruit yield per ha (13.48 t) were found from T_1 (30 cm distance from the tree base) treatment. Results also indicated that no tree crop interaction gave best yield but under tree crop interaction, higher distance showed higher yield of brinjal. So, it can be stated that distance of brinjal from tree base of Moringa is positively correlated with distance in terms of yield of brinjal.

2.8 Effect of fruit trees on growth and yield of annual field crops

Gill and Ajit (2006) conducted a study from 1990/91 to 1995-96 in Uttar Pradesh, India, to determine the effect of four cultivars of Mango (Langra, Deshari, Amrapalli and Mallika) on the yield of Wheat sown in the interspaces of the Mango cultivars. The grain and straw yield of Wheat was recorded from the first, third and fifth rows. On average, the highest grain and straw yield was recorded with ‘Amrapalli’ and lowest with ‘Mallika’. On average, maximum Wheat yield was registered from the fifth row followed by the third row and minimum in the first row from the tree component.

Verma *et al.* (2002) in another study on tree-crop interaction in Agri- horti-silviculture system, found that different fruit tree-crop combinations suppressed growth and yield attributes of Wheat. The reduction in Wheat yield over sole cropping was 17.9, 21.3, 25.2 and 28.2 per cent with tree-crop combinations Grewia + Almond + Wheat (17.85 q/ha), Morus + Almond + Wheat (17.10 q/ha), Grewia + Wheat (16.26 q/ha) and Morus + Wheat (15.61q/ha), respectively. Increase in nitrogen level by 25% more than the recommended level enhanced the grain and straw yield below the tree crown in equal or even higher magnitude to that obtained outside the crown at recommended level of nitrogen.

Meng *et al.* (2002) tested the characteristics of Wheat roots difference between Apple-Wheat intercropping system and Wheat monoculture in the hilly region of Taihang mountains, China, and showed that during the Wheat double ridge maturity stage, the amount of Wheat fine roots in the intercropping was approximately 4.74% more than that in the Wheat monoculture.

Bao-Weikai *et al.* (1999) achieved to show that Maize cultivars characterized by early or middle maturity and short matures were suitable for intercropping under Apple trees. Application of different liquid fertilizers to maize seedlings increased yield. A plant density of 45,000 hills/ha and 2 seedlings per hill was optimum for Maize.

Harwood and price (1976) reported that as intercrops upland Rice and Maize are well grown in young Mango and Coconut plantations in the Philippines. Jackson and Landsberg (1972) pointed out that some tree crops show systematic changes in LAI over the year. This is so in an extreme form in deciduous temperate trees, which may not attain full canopy until after midsummer and thus may have little or no foliage at times of high incident energy in the early summer and late autumn. The under crops should be so rapid growing that it can exploit the relatively short period during which radiation penetration through the tree canopy is maximal. Intercrops in the open-tree canopy situation do not need to be particularly shade tolerant, or even to have strategies enabling them to grow at the time of season when the tree have least leaf. Although, no doubt, that shade tolerant characteristics can prolong their years of profitable use.

Hesketh (1963) generalized that C_4 plants have higher photosynthetic rate than C_3 plants at high PAR flux densities, so the latter should be less reduced in performance when grown as understory crops. In another study Hesketh and Musgrave (1963) found that leaves of maize do not become light saturated in full sunlight whereas leaves of C_3 crops, such as sugar beet or soybean, may saturate at about half of full sunlight.

2.9 Fruit trees as affected by crops

Kumar *et al*. (2001) conducted field experiment in Himachal Pradesh, India, during 1988-99 to determine the long term effects of eight intercrop combinations on the growth, yield and fruit quality of plum grafted on wild apricot rootstocks. The authors reported that the highest trunk girth (59.7 cm), shoot length (132.9 cm), fruit length (4.37 cm), fruit breadth (4.22 cm), fruit weight (67.7 g) and fruit yield (86.4 kg/tree) were observed with the Pea-Tomato intercrop, while the lowest (41.2 cm, 87.2 cm, 4.37 cm, 4.22 cm, 49.3 g and 41.2 kg/tree, respectively) were recorded with Setaria grass.

A preliminary study on an Apple tree and Ginger intercropping system showed positive influence of Ginger on Apple productivity. Fan-Wei *et al*. (2000) reported that from intercropping system of Apple and Ginger, the yields and quality of Apples were increased in the intercropping system.

Single tree yields, weight of single Apple and Apple soluble solid content were increased by 14.5%, 14.3%, and 8.3%, respectively. Contrary to others' reports from on-farm studies on Agri-horticulture with fruit tree species (Gill *et al.*, 2000) found that the growth of fruit trees was significantly affected by Wheat crop in their interspaces. Ber tree proved significantly superior to Guava and Lemon.

Studying the effect of intercropping young Cocoa with some popular arable crops Adeyemi (1999) found that growth performance in terms of height, girth, leaf numbers and leaf area of Cocoa in the various mixtures was either superior or comparable with that of Cocoa in monoculture. The relative yield of the arable crops was greater than 50%, giving a relative ratio of over 100% and land equivalent ratio (LER)>1, indicating high yield advantages and efficient land use.

Yu-Yi and Yan-Yuhua (1998) while studying plant density in Apple orchard towards sustainable pest management, investigated that the density of predators on Apple trees in a cover-cropping system was greater than in no-tillage or clean-cultivated system.

Intercropping legumes crops with fruit trees in different agroforestry systems have shown significant yield increment of fruit trees. In our study, intercropping of Tomato with Moringa trees have shown competitive interactions in case of most of the studied parameters compared to control whereas the outcomes of the study conducted by Arora and Mohan (1986) on Cowpea and Soybean in association with Peach tree had shown positive effect on fruit yield as 36 kg/tree with cowpea and 43 kg/tree with soybean as compared to 33 kg/tree in the control.

CHAPTER III

MATERIALS AND METHODS

This chapter describe the materials and methods that were used in carrying out with the experimental aspect of the work. The present study was laid out in the existing Moringa garden to study the performance of Tomato as well as to find out the best tree crop interactions in Agroforestry practice. It includes a brief description of the experimental site, soil, weather, climate, experimental design, different treatments, intercultural operations and statistical analysis.

3.1 Description of the Study Area

The research work was conducted at the Agroforestry Field under the Department of Agroforestry and Environmental Science, Sher-e-Bangla Agricultural University, Dhaka. The experimental site is situated at $23^{\circ}74'$N latitude and $90^{\circ}35'$E longitude with an elevation of 8.2 meter from sea level.

3.2 Weather and climate

The experimental area is under subtropical climate that is characterized by high temperature, high humidity and heavy rainfall with occasional gusty winds in Kharif season (April-September) and less rainfall associated with moderately low temperature during the Rabi season (October-March). The records of air temperature, rainfall, relative humidity and other relevant information were collected from Bangladesh Meteorological Department (Appendix I).

3.3 Soil characteristics

The soil of the experimental site belongs to the Agro-ecological zone of “The Modhupur Tract” (AEZ-28). Top soils were clay loam in texture, olive –grey with common fine to medium distinct dark yellowish brown mottles. Soil pH was 5.6 and had organic carbon 0.45% and organic matter content is 0.78%. The land was above flood level and sufficient sunshine was available during the experimental period **(**Appendix II).

3.4 Planting materials

One year old of 12 *Moringa oleifera* plants collected from Manikganj were selected for agroforestry field preparation where four Moringa plants were considered as one replication. The seedlings of Tomato, cv. Minto Super F_1 Hybrid was purchased from Agriculture Training Institute (ATI), Dhaka.

3.5 Experimental design and treatment combination

Tomato seedlings (30 days old) in association of one year old Moringa tree were planted by following the Randomized Complete Block Design (RCBD). The experimental field size was 49 feet × 30 feet. Individual block size was 11 feet × 5 feet. Each of the four treatments were replicated four times. Four treatment which were used in this study are as follows:-

1. T_1= 30 cm distance from the tree base
2. T_2= 40 cm distance from the tree base
3. T_3= 50 cm distance from the tree base
4. T_4=100 cm (Open field referred to as control)

	BLOCK-I		BLOCK-II		BLOCK-III		BLOCK-IV	
	T_2		**T_4**		**T_2**		**T_1**	
	T_3		**T_1**	**2ft**	**T_4**		**T_2**	
			1ft					
	T_4		**T_2**		**T_3**		**T_4**	
	T_1		**T_3**		**T_1**		**T_3**	

Figure 1. Layout of the Experiment Field

Field size: 49ft × 30ft
Block size: 11ft × 5ft
Block to Block distance: 2ft
Plot size: 5ft × 2ft
Plot to Plot distance: 1ft

3.6 Land Preparation

The experimental plot was prepared by several ploughing with the help of spade to obtain good tilth. Individual plots were cleaned and to get better yield of Tomato, levelling was done in order to break the soil clods followed by each ploughing. Weeds and other stubbles were removed carefully from the experimental plot. Finally 20 cm raised bed was leveled properly for Tomato cultivation.

3.7. Crop establishment

After land preparation the collected seedling (Minto super F_1 Hybrid) were transplanted in the main field maintaining distance from Moringa tree base to Tomato beds (30cm, 40 cm, 50 cm). On the other hand, in control plot there were no Moringa tree and control plot was 100 cm away from agroforestry plot. The transplanting was done on 30 October 2018 when the age of seedling reached to 30 days.

3.8. Management practices

3.8.1. Gap filling

After seven days of transplanting (DAT) about 5% seedling was died which were replaced by new seedling of the same stock.

3.8.2. Weeding and irrigation

Weeding was done at 20, 50 and 80 days after transplanting (DAT) to keep the plots free from weeds and to keep the soil loose and well aerated. To maintain optimum soil moisture all plots were irrigated when it was necessary.

3.8.3. Fertilizer application

No chemical fertilizers were used for this experiment but only cow dung (20 t per ha) which was applied into the experimental field during final land preparation.

3.8.4. Thinning out

Thinning was done two times. First and second thinning was done at 10 and 20 days after sowing, respectively.

3.8.5. Stalking

Tomato plant attain a height about one meter. Therefore bamboo sticks were used for stalking the plants when necessary.

3.8.6. Pest and Disease Management

The experiment crop was not infected by any diseases and no fungicide was used. Furadan 5G (Group: Carbofuran, Company: Padma oil company) and sevin (Group: 85-curbaril, Company: Bayer company) were applied into the experimental field during the land preparation for controlling ants, mites and other insects.

3.8.7. Data Collection

Five Tomato plants were selected randomly from each replication and tagged properly for recording various morphological observation at 30, 60, 75, 90 DAT and final harvest .The following observations were recorded at different stages of crop growth, yield and the average was computed.

The following parameters were considered for data collection

1. Plant height (cm)
2. Number of branches per plant
3. Canopy spreading per plant (cm)
4. Days to 1st flowering
5. Days to 1st harvest
6. Days to complete harvest
7. Fruit diameter (cm)
8. Number of fruits per plant
9. Fruit yield per plant (g)
10. Individual fruit weight (g)
11. Fruit yield per plot (kg)
12. Fruit yield per ha (t)

3.9. Growth Parameters

3.9.1. Plant Height (cm)

Plant height at different days after transplanting (DAT) was measured from sample plants in centimeter from the ground level to the tip of the longest stem and the mean value for each replication was calculated. Plant height was recorded at 30, 60, 75, 90 DAT and at harvest of fruits.

3.9.2. Number of branches per plant

At different DAT, all the primary branches were counted in each selected plants and their average value was taken as number of branches per plant. Number of branches per plant was recorded 60, 90 DAT and at harvest of fruits.

3.9.3. Canopy spreading per plant

Canopy spreading was recorded at 30, 60, 75, 90 DAT and final harvest .It was measured in cm with a meter scale from Moringa plant (South to North and East to West)dimension of the above ground part of sample plants.

3.9.4. Days to 1st flowering

The number of days from transplanting to first flowering from each replication was calculated and expressed in days.

3.9.5. Days to 50% flowering

Daily observations were made on randomly selected plant from each replication .The day when 50% of plants showed flower initiation were considered as 50% flowering. The number of days taken from the DAT to flowering was recorded and expressed in number as days taken for 50% flowering.

3.9.6. Days to 1st harvest

The number of days from transplanting to the date of first harvest for each replication was calculated and expressed in days.

3.9.7. Days to complete harvest

The number of days from transplanting to the date of full maturity of fruits or final harvest of each treatment was calculated and expressed in days.

3.9.8. Fruit diameter (cm)

Ten fruits were randomly taken from five tagged Tomato plants for measuring the fruit diameter. The diameter was measured at the center of the fruit with the help of Vernier calipers. The mean fruit diameter was computed and expressed in centimeters.

3.9.9. Number of fruits per plant

The average number of fruits per plant harvested at different dates from the selected plants was counted and expressed as number of fruits per plant.

3.9.10. Fruit yield per plant (g)

The marked fruits from selected plant were harvested and total weight of fruits (g) of the plants was recorded .The mean fruit yield per plant was calculated and expressed in grams.

3.9.11 Individual fruit weight (g)

Based on the ten representative fruits individual fruit weight in gram was calculated.

3.9.12. Fruit yield per plot (kg)

Total fruit weight of whole plants in each plot was recorded and yield per plot was calculated.

3.9.13. Fruit yield (t/ha)

Fruit yield was measured by using the following formula,

$$\text{Fruit yield (t/ha)} = \frac{\text{Fruit yield per plot (kg)} \times 10000}{\text{Area of plot in square meter} \times 1000}$$

3.9.14. Analysis of data

All the data were subjected to analysis of variance (ANOVA) and tested for significance using Least Significant Difference (LSD) using R-3.5.1 software (R Core Team, 2017). The correlation and relationship in between distance from tree base, growth and yield parameters were regressed by using Microsoft Excel version-2013

3.9.15. Analysis of correlation between distance from Moringa tree base and the growth, yield and yield contributing characters of Tomato

The correlation between the distance from Moringa tree base and the growth, yield and quality parameters of tomato recorded from the experimental plots were analyzed by using the data analysis facilities of Microsoft Excel (Version-13).

3.9.16. Modelling of Tomato yield as a function of distance from Moringa tree base

The observed yield of Tomato in the experimental plots were regressed on the distance from Moringa tree base of the respective treatment using various forms of models such as linear, quadratic, semi-log, log, etc. and the best-fit model was selected. The regression analysis was done using the data analysis facilities of Microsoft Excel (Version 13).

3.9.17. Estimation of Tomato yield in Moringa based Agroforestry system as a function of distance from tree base

The expected yield of Tomato in Moringa based Agroforestry system was computed by using the equation developed for estimating Tomato yield as a function of distance from Moringa tree base by using the data analysis facilities of Microsoft Excel (Version-13).

CHAPTER IV

RESULTS AND DISCUSSION

Data obtained from the present study was presented and discussed in this chapter through different Tables and Graphs. The current experiment was carried out to study the growth, yield and yield attributing parameters of Tomato in Moringa based Agrisilvicultural system. The results of the experiment are presented and discussed with the following headings and sub-headings.

4.1 Results

4.1.1 Growth parameters

4.1.2 Plant height

Plant height is one of the important growth character for Tomato plant. Significant variation was found on plant height of tomato due to different spacing from tree base at different sampling dates (Table 1). The plant height was increased gradually with the advancement of crop growth up to final harvest. At 30 DAT, the plants belong to open field condition (T_4) exhibited the highest plant height (28.95 cm) that was statistically different with the plant height recorded in T_1, T_2 and T_3 treatments where the lowest tomato plant height (21.02 cm) was found from T_1 treatment. At 60 DAT, significantly the highest Tomato plant height (56.50 cm) was observed in T_4 treatment which was statistically identical with T_3 treatment where both were significantly higher than other treatment combinations followed by T_1 and T_2. The lowest plant height at 60 DAT (35.61 cm) was recorded in plants grown at 30 cm distance from the Moringa tree base T_1 treatment. Similar trend was found at 75, 90 DAT and at final harvest. Results revealed that at 75, 90 DAT and at harvest the highest plant height (66.02, 70.94 and 71.83 cm, respectively) was recorded from the treatment T_4 which was statistically identical with T_3 treatment where the lowest plant height (40.77, 45.17 and 49.59 cm, respectively) was obtained from T_1 treatment. At harvest (115 DAT), the tallest plant (71.83 cm) belonged to control treatment T_4 which was significantly different at per with T_3 treatment whereas the shortest plant (49.59 cm) was appeared in T_1 treatment which was statistically different with T_2 treatment.

Table 1. Effect of Moringa tree on plant height of Tomato as influenced by distance from tree base

Treatment	Plant height (cm)				
	30 DAT	**60 DAT**	**75 DAT**	**90 DAT**	**Harvest**
T_1	21.02 d	35.61 c	40.77 d	45.17 d	49.59 d
T_2	24.20 c	44.47 b	47.77 c	50.87 c	56.49 c
T_3	26.49 b	55.27 a	61.13 b	66.30 b	69.49 b
T_4	28.95 a	56.50 a	66.02 a	70.94 a	71.83 a
$LSD_{0.05}$	1.30	3.86	0.94	1.28	1.48
CV (%)	2.59	4.03	0.87	1.08	1.20
Significance level	*	*	*	*	*

* = Significant at 5% levels of significance

T_1 = 30 cm distance from the tree base, T_2 = 40 cm distance from the tree base,

T_3 = 50 cm distance from the tree base, T_4 = Open field referred to as control

4.1.3 Number of branches per plant

Under different treatments the number of branches per plant exhibited different results. Statistically significant difference was observed among the treatments on number of branches per plant at different DAT (Table 2). Tomato grown under control conditions i.e., without association with *Moringa* (T_4 treatment) produced the highest number of branches per plant at all growth stages which was significantly higher than other treatments where Tomato plants were grown under different distances from the tree base. Similarly at 60 DAT, open field condition (T_4 treatment) showed the highest number of branches per plant (7.33) compared to other treatments followed by T_3 treatment whereas the lowest number of branches per plant (3.00) was recorded treatment T_1. At 90 DAT and at harvest (115 DAT) similar trend was found for number of branches per plant and the highest (8.33 and 8.34 at 90 DAT and at harvest, respectively) number of branches were found in the Tomato plants under T_4 treatment which was closely followed by T_3 treatment whereas the lowest number of branches per plant (4.00 and 4.33 at 90 DAT and at harvest, respectively) was recorded in the plants under T_1 treatment.

Table 2. Effect of Moringa tree on the number of branches per plant of tomato as influenced by distance from Moringa tree base

Treatment	**Number of branches per plant**		
	60 DAT	**90 DAT**	**Harvest**
T_1	3.00 d	4.00 d	4.33 d
T_2	4.67 c	5.00 c	6.00 c
T_3	5.67 b	6.67 b	7.00 b
T_4	7.33 a	8.33 a	8.34 a
$LSD_{0.05}$	0.74	0.74	0.88
CV (%)	7.21	6.21	6.87
Significance level	*	*	*

* = Significant at 5% levels of significance

T_1 = 30 cm distance from the tree base, T_2 = 40 cm distance from the tree base,

T_3 = 50 cm distance from the tree base, T_4 = Open field referred to as control

4.1.4 Canopy Spreading of Moringa

Canopy spreading is the most important growth character of Moringa plant. Significant effect was found in Plant canopy spreading of Moringa tree at different DAT of Tomato plants due to different tree crop interactions (Table 3). The plant canopy spreading was increased gradually with the advancement of crop growth up to harvest. At 30 DAT, the plants belong to T_3 treatment exhibited the highest plant canopy spreading (N/S=197.00 cm and E/W=207.50 cm) that was statistically different with the plant canopy spreading recorded in other treatments whereas the lowest plant canopy spreading (N/S=143.75 cm and E/W=142.50 cm) was recorded from Moringa plant which was closest to tomato (T_1 treatment). At 60, 75, 90 DAT and at harvest, significantly highest plant canopy spreading of Moringa was also observed in T_3 treatment whereas the lowest canopy spreading of Moringa was recorded from the treatment T_1. At harvest the highest plant canopy spreading (N/S=225.00 cm and E/W=240.00 cm) was recorded in T_3 treatments whereas the lowest plant canopy spreading of Moringa at harvest of Tomato (N/S=180.00 cm and E/W=173.30 cm) was recorded from T_1 treatment.

Table 3. Canopy Spreading of Moringa as influenced by planting distance under Agroforestry System

Treatments	Canopy spreading of Moringa plant (cm)									
	30 DAT		60 DAT		75 DAT		90 DAS		Harvest	
	N/S	E/W	N/S	E/W	N/S	E/W	N/S	E/W	N/S	E/W
T_1	143.75 c	142.50 c	152.50 c	150.00 c	160.00 c	153.50 c	175.00 c	168.50 c	180.00 c	173.3 c
T_2	170.00 b	156.25 b	190.30 b	175.00 b	194.50 b	177.00 b	202.50 b	183.00 b	205.00 b	185.0b
T_3	197.00 a	207.50 a	206.25 a	221.25 a	213.75 a	223.00 a	222.50 a	237.50 a	225.0 a	240.0 a
$LSD_{0.05}$	3.18	5.34	4.12	4.37	5.2	3.97	4.88	5.71	4.36	4.81
CV (%)	8.33	10.71	11.64	9.53	10.28	8.39	10.71	7.66	7.14	9.37
Significance level	*	*	*	*	*	*	*	*	*	*

* = Significant at 5% levels of significance

T_1 = 30 cm distance from the tree base, T_2 = 40 cm distance from the tree base, T_3 = 50 cm distance from the tree base

4.1.5 Yield contributing parameters and yield

4.1.5.1 Days to 1^{st} flowering

First flowering define the initiating of production. Days to 1^{st} flowering differ significantly among the treatments (Table 4). Results indicated that the highest days to 1^{st} flowering was recorded in T_1 treatment (35.67 days) which was significantly different from other treatments followed by $T_{2,}$ T_3 and $T_{4.}$ The lowest days to 1^{st} flowering (28.67 days) was recorded in plants under T_3 treatment which was significantly different with T_4.

4.1.5.2 Days to 1^{st} harvest

The treatment combination indicated highly significance variation on Tomato plant on days to first harvest, due to distance of Tomato plants from tree base of Moringa (Table 4). The highest days to 1^{st} harvest (70.33 days) was recorded in T_1 treatment which was significantly different from other treatments whereas the lowest days to 1^{st} harvest (64.33 days) was found in T_4 treatment which was also statistically different from other treatments.

4.1.5.3 Days to complete harvest

The treatment combination indicated highly significance variation on Tomato plant on days to complete harvest, due to distance of Tomato plants from tree base of Moringa (Table 4). The highest days to complete harvest (119.00 days) was recorded in T_4 treatment whereas the lowest days to complete harvest (99.00 days) was recorded in plants under T_1 which was significantly different from other treatments.

Table 4. Days to 1st flowering, 1st harvest and complete harvest of Tomato as influenced by planting distance from Moringa tree base

Treatments	Yield contributing parameters of Tomato		
	Days to 1st flowering	Days to 1st harvest	Days to complete harvest
T_1	35.67 a	70.33 a	99.00 d
T_2	32.33 b	68.00 b	104.33 c
T_3	28.67 d	66.33 b	112.67 b
T_4	30.33 c	64.33 c	119.00 a
$LSD_{0.05}$	1.66	1.99	2.13
CV (%)	2.62	1.49	0.98
Significance level	*	*	*

* = Significant at 5% levels of significance

T_1 = 30 cm distance from the tree base, T_2 = 40 cm distance from the tree base,
T_3 = 50 cm distance from the tree base, T_4 = Open field referred to as control

4.1.5.4 Fruit diameter (cm)

Significant influence was found on fruit diameter due to varied distance of Tomato plant from Moringa tree (Table 5). The highest fruit diameter (6.17 cm) was recorded in open field condition (T_4; control) whereas the lowest fruit diameter (4.42 cm) was recorded in plants under T_1 treatment which was 28.36% lower than control condition. Comparing the treatments of tree crop association, T_3 gave the highest the fruit diameter (5.79 cm) which was 23.66% higher than T_1 treatment which showed lowest fruit diameter among the treatment.

4.1.5.5 Number of fruits per plant

Due to different distance of Tomato plant from Moringa tree had significant influence on number of fruits per plant (Table 5). The highest number of fruits per plant (29.67) was recorded in open field condition (T_4; control) whereas the lowest number of fruits per plant (14.00) was recorded in plants under T_1 treatment which was 52.81% lower than control condition. Under the tree crop interaction, the treatment T_3 showed highest number of fruits per plant (26.33) and lowest was from T_1 treatment which was 46.82% lower than T_3 treatment.

4.1.5.6 Fruit yield per plant (g)

Significant variation was recorded on fruit yield per plant due to different distance of Tomato plant from Moringa tree (Table 5). The highest fruit yield per plant (2367.07 g) was recorded in control treatment T_4 and the 2^{nd} highest fruit yield per plant (2014.52 g) was recorded from T_3 treatment. The lowest fruit yield per plant (933.82 g) was recorded in T_1 which was 60.54% lower than control treatment and 53.64% lower than T_3 treatment.

4.1.5.7 Individual fruit weight (g)

Significant influence was found on individual fruit weight due to varied distance of Tomato plant from Moringa tree (Table 5). The highest individual fruit weight (81.91 g) was recorded in open field condition (T_4; control) whereas the lowest individual fruit weight (66.42 g) was recorded in plants under T_1 treatment. Under tree crop association,

T_3 gave the highest individual fruit weight (77.16 g) which was second highest among the treatments. Individual fruit weight from T_1 treatment was 18.91% lower than control treatment (T_4) and 13.92% lower than T_3 treatment.

4.1.5.8 Fruit yield per plot (kg)

Fruit yield mostly depend on vegetative growth and supply nutrient on fruiting time. There were significant variation among the different treatments due to different distance of Tomato plantation from Moringa tree (Table 5). The highest fruit yield per plot (9.09 kg) was recorded in T_4 treatment and the 2^{nd} highest fruit yield per plot (7.78 kg) was found in T_3 treatment. The lowest fruit yield per plot (3.61 kg) was recorded in plants under T_1 treatment which was 60.28% lower than control treatment and 53.59% lower than T_3 treatment.

4.1.5.9 Fruit yield per ha (t)

Due to different distance of Tomato plantation from Moringa tree fruit yield per ha among the different treatments was significantly varied (Table 5). The highest fruit yield (42.08 t per ha) was recorded in T_4 treatment and the 2^{nd} highest fruit yield (34.16 t per ha) was found in T_3 treatment which was 18.82% lower than T_4 treatment. Under the presents study, treatment T_4 is considered as without tree crop interaction but the treatments T_1, T_2 and T_3 are considered under tree crop interaction. The lowest fruit yield (16.05 t per ha) was recorded in T_1 treatment which was 61.85% lower than control treatment and 53.02% lower than T_3 treatment.

Table 5. Yield contributing parameters and yield of Tomato as influenced by planting distance from Moringa tree base

Treatments	Yield contributing parameters and yield					
	Fruit diameter (cm)	Number of fruits per plant	Fruit yield per plant (g)	Individual fruit weight (g)	Fruit yield per plot (kg)	Fruit yield per ha (t)
T_1	4.42 c	14.00 d	933.82 d	66.42 d	3.61 d	16.05 d
T_2	5.08 b	21.00 c	1389.83 c	72.48 c	5.87 c	26.06 c
T_3	5.79 a	26.33 b	2014.52 b	77.16 b	7.78 b	34.16 b
T_4	6.17 a	29.67 a	2367.07 a	81.91 a	9.09 a	42.08 a
$LSD_{0.05}$	0.44	1.37	254.82	1.95	0.68	4.05
CV (%)	4.13	3.02	7.61	1.31	5.19	6.85
Significance level	*	*	*	*	*	*

* = Significant at 5% levels of significance

T_1 = 30 cm distance from the tree base, T_2 = 40 cm distance from the tree base,

T_3 = 50 cm distance from the tree base, T_4 = Open field referred to as control

4.1.6 Relationship between different planting distances and the growth and yield parameters of Tomato

Correlation measures the degree by which two variables move in relation to each other. A perfect positive correlation means that as one variable moves, either up or down, the other variable also move in the same direction. Analyzed data showed very strong relationship (positive and negative) in between the different planting distances from Moringa tree base and the growth parameters of Tomato. Plant height had highly significant and strong positive correlation with fruit diameter (0.98442) and strong negative correlation with first flowering (-0.8419) date of Tomato. Number of branch had shown highly significant and strong positive correlation with fruit yield (0.999339) and strong negative correlation with first flowering (-0.97683) date. First flowering had highly significant and strongly negative correlation with number of fruit (-0.9402). First harvesting had shown highly significant negative correlation with first flowering (-0.6462). Complete harvesting gave highly significant and strong positive correlation with fruit diameter (0.99676) and strong negative correlation with first flowering (-0.9316). Fruit diameter had shown highly significant and positive correlation with complete harvesting (0.99676) and negative correlation with first flowering (-0.9316). Fruit yield had shown highly significant and strong positive correlation with fruit weight (0.99995) and negative correlation with first flowering (-0.917) (Table 6).

Table 6. Correlation between different planting distances from tree base and various growth and yield parameters of Tomato grown in association with Moringa

	Distance	**PH**	**NB**	**FF**	**FH**	**CH**	**FD**	**NF**	**FW**	**FY**
Distance	**1**									
PH	**0.83011**	1								
NB	**0.9135**	0.95756	1							
FF	**-0.6805**	-0.8419	-0.9039	1						
FH	**-0.1174**	0.30334	0.28284	-0.6462	1					
CH	**0.86568**	0.9688	0.994306	-0.9316	0.37296	1				
FD	**0.87389**	0.98442	0.992172	-0.9027	0.32953	0.99676	1			
NF	**0.87968**	0.94498	0.995471	-0.9402	0.36469	0.99626	0.98765	1		
FW	**0.90388**	0.94786	0.99892	-0.9203	0.31281	0.99465	0.98883	0.99846	1	
FY	**0.90593**	0.95026	0.99933	-0.917	0.30676	0.99482	0.9898	0.99802	0.99995	1

Note. PH, NB, CS, FF, FH, CH, FD, NF, FW and FY indicate plant height, number of branch, first flowering, first harvesting, complete harvesting, fruit diameter, number of fruit, fruit weight and fruit yield respectively.

4.1.7 Model to estimate Tomato yield as a function of distance from Moringa tree base

An equation of the following form (quadratic) was found to be most appropriate for predicting the approximate yield of Tomato in a Moringa based Agroforestry system.

$$Y = a + bX + cX^2$$

Where,

Y= Yield of Tomato in ton per hectare

X = Distance of Tomato plot from Moringa tree base in cm

a, b and c are constants

The ordinary least square (OLS) estimates of the regression coefficients (constants) together with their standard errors and t-values are presented in Table 7 and the analysis of variance of the model in Table 8. In explicit terms, the Tomato yield equation can be written as:

$$Y = -24.81 + 1.659\ X - 0.00994\ X^2$$

A model of the above form, i.e. the quadratic trend of Tomato yield with respect to the distance from the tree base depicts that Tomato yield gradually increases as the distance increases from tree base from an initial low to gradually optimum levels and decline or static thereafter with further increase in the distance from Moringa tree base.

Table 7. OLS estimates of regression coefficients of the equation to estimate the yield of Tomato in Moringa based Agroforestry system with their standard error and t-values

Dependent variable = Y

Variable	Regression coefficient	Standard Error of estimate	t-value
Constant	-24.8137	0.956177429	-25.9509*
X	1.659317	0.034326477	48.33926*
X^2	-0.00994	0.000253034	-39.2845*

"Significant at 0.05 % level
R^2 = 0.99; standard error of regression = 0.204

Table 8. Analysis of variance for the equation to estimate the yield of Tomato in a Moringa based Agroforestry system

Source of variation	Degree of freedom	Sum of squares	Mean squares	F-value
Regression	1	359.7315033	179.8658	4305.9*
Error	2	0.041771723	0.041772	
Total	3	359.773275		

**Significant at 0.05 % level

4.1.8 Estimated yield of Tomato as a function of the distance from tree base in a Moringa based Agroforestry

The estimated yields of Tomato under Moringa based Agroforestry system as derived by using the developed model for this purpose are presented in figure 2.

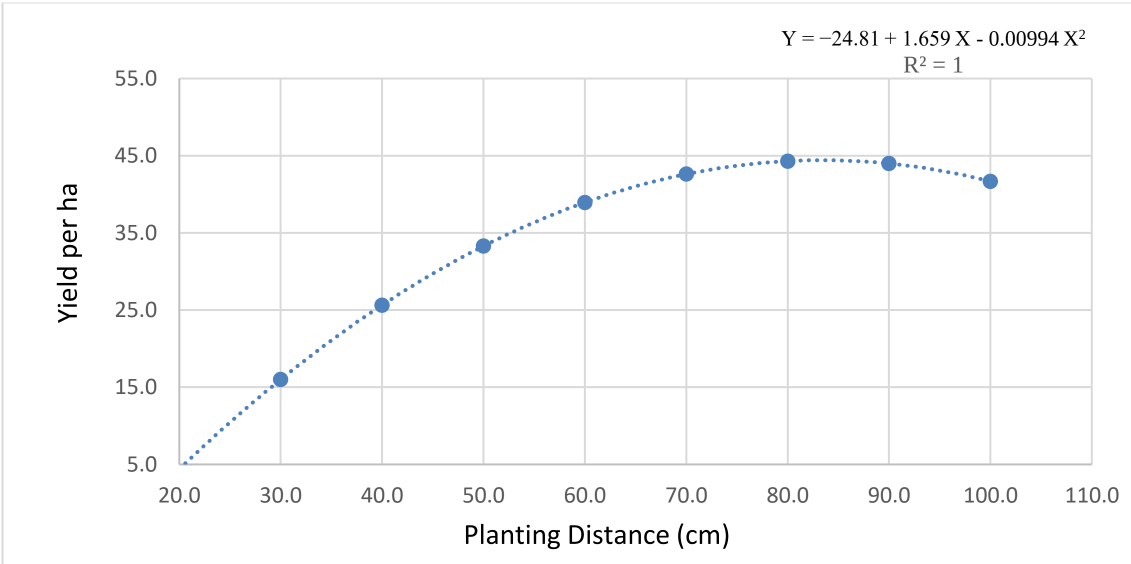

Figure 2. Estimated yield of Tomato as a function of the distance from tree base in a Moringa based Agroforestry

It was found that Tomato plant yield was increased with increasing planting distance from Moringa tree base. A quadratic relationship was observed of the Tomato in the Moringa based agroforestry farming system as a function of distance from tree base (Fig 2). The estimated equation of the quadratic relationship between planting distances from moringa tree base and Tomato plant yield was $y = - 24.81 + 1.659x - 0.0099x^2$. Above this regression line around minimum distance (10 cm) was found that zero yield but increasing distance yield increase gradually. Here it showed 16.01 t per ha in 30 cm distance from Moringa tree base and 33.29 t per ha in 50 cm distance. But maximum yield found in 80 cm distance (44.29 t per ha). But yield decrease when distance further increase and yield found in 100 cm distance 41.69 t per ha. Thus, it revealed that yield of Tomato was increased with the increase in planting distance at a certain point thereafter decline.

4.2 DISCUSSION

The treatment evaluated in this study varied not only in yield ability, but also in all the agronomic traits measured. Despite the wide variation in traits, none of the treatment gave satisfactory yield under agroforestry systems. Based on reports in earlier studies, the present study included a variety of commonly cited traits including plant height of Tomato, number of branch, fruit diameter, individual fruit weight, fruit yield, canopy spreading of Moringa. Significant variations among the treatment were recorded suggesting that selection based on those traits was practical. Among the agroforestry treatments, T_3 emerged as the most promising treatment compared to other treatments. T_3 performed very close to T_4 with regards to yield and yield attributing character.

From the early stages of growth, plants belong to control treatment (T_4) was the fastest growing and performed consistently better in height compared to other plants belong to other treatments. This might be due to the fact that water with soluble nutrients provided the efficient growth condition of Tomato as irrigation was done intensively at control conditions (Ahmed, 2017). Tomato plant height in this study indicated that distance between tree and crop showed significant influence and higher distance resulted higher plant height and lower distance showed lower plant height. Similar observation were also documented by Sumona (2017) who found growth and yield of red amaranth were influenced by the distance of Moringa tree base.

Photosynthetically active radiation (PAR) is considered as the most important limiting factor for yield loss of Tomato. Hanif *et al.* (2010) observed that prolonged shading used to impede photosynthetic capacity of plants due to changing the stomata and mesophyll cell properties and resulting in reducing accumulation of photosynthesis. Besides partial shade during the early establish period of Moringa perhaps created optimum growth condition for Tomato by conserving moisture, microbial activities and protecting the plants from scorching heat. Al -Mamun (2009) conducted a study with turnip in association of Boilam tree and found the similar result in respect of yield. Closer spacing between tree and crop indicate nutrient competition between them and as a result lower Tomato fruit diameter in the plants of treatment T_1 compared to other treatments. Our research results were corroborated by the findings of Uddin *et al.* (2010) in a Litchi-Indian spinach based agroforestry system.

Sunlight intercepted by Moringa canopy resulting less warming the soil underline the shade compared to the non-shaded open space which was responsible for reduced yield of Tomato. Our findings were consistent with the studies of past research experiences Mukherjee *et al.* (2008); Tanga *et al.* (2014). Light availability was higher in open field compared to agroforestry system, which effect on Tomato fruit weight. Individual weight of fruit was the highest in T_4 Treatment compared to other treatment. This findings were also in line with the work conducted by Miah *et al.* (2008) on Tomato under *Azadirachta indica* and *Dalbergia sissoo* based agroforestry systems.

Intercropping legumes crops with fruit trees in different agroforestry systems have shown significant yield increment of fruit trees. In our study, intercropping of Tomato with Moringa trees have shown competitive interactions in case of most of the studied parameters compared to control whereas the outcomes of the study conducted by Arora and Mohan (1986) on Cowpea and Soybean in association with Peach tree had shown positive effect on fruit yield as 36 kg/tree with cowpea and 43 kg/tree with soybean as compared to 33 kg/tree in the control.

CHAPTER V

SUMMARY AND CONCLUSION

5.1 SUMMARY

The experiment was conducted at the Agroforestry farm of Sher-e-Bangla Agricultural University, Dhaka during the period from October 2018 to January 2019 to study the performance of Tomato during the early establishment period of Moringa plantation. The results was presented on growth, yield and yield attributing characters of Tomato as influenced by Moringa plantation regarding different planting distance of Moringa and Tomato. The experiment consisted of four treatments *viz.*T_1, T_2, T_3 and T_4. The experiment was laid out in Randomized Complete Block Design (RCBD) comprising four replications. The seedling of Tomato (var. Minto Super F_1 Hybrid) were collected from Agriculture Training Institute (ATI) and transplanted in the main field with 30 days old seedling of Tomato. Data were collected on Tomato plant height, number of branches per plant, days to 1st flowering, days to 1st harvest, days to complete harvest, fruit diameter, number of fruits per plant, fruit yield per plant, individual fruit weight, fruit yield per plot and fruit yield per ha. The collected data were analyzed statistically and the differences between the means were evaluated by least significant test (LSD).

Growth and yield attributing parameters were higher in control condition compared with other agroforestry treatments where plants were grown at different distances from tree base. The results of the experiment showed that the different treatments had significant effect on all the parameters tested.

The highest plant height (71.83 cm) was observed in the control condition and the lowest plant height of Tomato (49.59 cm) was recorded in T_1 treatment. Among the agroforestry treatments, the highest plant height (69.49 cm) was found in T_3 treatment. As expectation, the maximum number of branches per plant at harvest (8.34) was observed in the T_4 (control) treatment, which was significantly higher from agroforestry treatments. Among the agroforestry treatments, the highest number branches per plant (7.00) was recorded in the plants belong to T_3 treatment however the lowest number branches per plant (4.33) was recorded in T_1 treatment.

In agroforestry practice, T_3 showed better canopy spreading (N/S = 225.00 cm and E/W = 240.00 cm) but the lowest canopy spreading (N/S = 180.00 cm and E/W = 173.30 cm) was found from T_1 treatment.

In terms of yield contributing parameters and yield, with tree-crop interaction T_3 showed the lowest days to 1st flowering and T_4 showed the lowest days (64.33 days) to 1st harvest whereas the highest days to flowering and days to 1st harvest was achieved from T_1 treatment (35.67 and 70.33 days, respectively).

Again, the highest result in respect of fruit diameter, the highest (6.17 cm) was found in open field condition (T_4 treatment). Similarly, the highest number of fruits per plant (29.67), fruit yield per plant (2367.07 g), individual fruit weight (81.91 g), fruit yield per plot (9.09 kg) and fruit yield per ha (42.08 t) was also found in open field condition (T_4 treatment). But among the agroforestry practice (under tree crop interaction), the higher fruit diameter (5.79 cm), number of fruits per plant (26.33), fruit yield per plant (2014.52 g), individual fruit weight (77.16 g), fruit yield per plot (7.78 kg) and fruit yield per ha (34.16 t) were obtained from T_3 treatment. On the other hand, the lowest fruit diameter (4.42 cm), number of fruits per plant(14.00), fruit yield per plant (933.82 g), individual fruit weight (66.42 g), fruit yield per plot (3.61 kg) and fruit yield per ha (16.05 t) were obtained from T_1 treatment. Fruit yield from T_1 treatment was 61.86% lower than control treatment and 53.02% lower than T_3 treatment. So T_4 treatment gave better yield than T_3, T_2 and T_1 for higher distance of crop to tree, which ensure lesser competition for nutrition pool. Distance between tree and crop had strong positive correlation with all maximum parameters and first flowering had strong negative correlation except first harvesting. Estimated regression line, based on observed data points, predicted optimum distance of Tomato plot from one year old Moringa tree would be approximately 80 cm for maximum Tomato yield (44.29 t/ha) in Moringa based Agroforestry system.

5.2 CONCLUSION

The yield performance of Tomato influenced significantly due to different distance from Moringa tree base. The findings of the experiment concluded that open field condition exhibited the highest results in respect of growth and yield of Tomato. Apart from control, the second highest yield was observed in T_3 treatment compared to T_1 and T_2 which was 18.82% less than that of control condition. The yield decline continued up to 38.07% for treatment T_2 and 61.86% for treatment T_1 compared to that of control condition. Therefore, this study had showed best yield (34.16 t) performance of Tomato at treatment T_3 which was 50 cm distance from tree base in association with Moringa tree. Distance between tree and crop had strong positive correlation with all maximum parameters and first flowering had strong negative correlation except first harvesting. Estimated regression line, based on observed data points, predicted optimum distance of Tomato plot from one year old Moringa tree would be approximately 80 cm for maximum Tomato yield (44.29 t/ha) in Moringa based Agroforestry system. Thus farmer can cultivate Tomato in association with Moringa tree maintaining 80 cm distance from tree base without much loss.

5.3 RECOMMENDATIONS

All the data generated in this study were based on one trail which conducted from 0 to 4 months Tomato seedling. Therefore, to make a final conclusion, repeated trail of tomato should be conducted in association with Moringa. Moringa should be intercropped with others Rabi and Kharif vegetables to know the Moringa−vegetables interactions more precisely.

CHAPTER VI

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APPENDICES

Appendix I. Monthly records of air temperature, relative humidity and rainfall during the period from September 2018 to January 2019.

Year	**Month**	**Air temperature (°C)**			**Relative humidity (%)**	**Rainfall (mm)**
		Max	***Min***	***Mean***		
2018	September	30.8	21.80	26.30	71.50	78.52
2018	October	30.42	16.24	23.33	68.48	52.60
2018	November	28.60	8.52	18.56	56.75	14.40
2018	December	25.50	6.70	16.10	54.80	0.00
2019	January	24.02	11.03	17.53	54.10	0.00

Source: Bangladesh Meteorological Department (Climate division), Agargaon, Dhaka-1212.

Appendix II. Characteristics of experimental soil analyzed at Soil Resources Development Institute (SRDI), Farmgate, Dhaka.

A. Morphological characteristics of the experimental field

Morphological features	**Characteristics**
Location	Agroforestry Farm, SAU, Dhaka
AEZ	Modhupur Tract (28)
General Soil Type	Shallow red brown terrace soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly leveled
Flood level	Above flood level
Drainage	Well drained
Cropping pattern	Not Applicable

Source: Soil Resource Development Institute (SRDI)

B. Physical and chemical properties of the initial soil

Characteristics	Value
Partical size analysis % Sand	27
%Silt	43
% Clay	30
Textural class	Silty Clay Loam (ISSS)
Ph	5.6
Organic carbon (%)	0.45
Organic matter (%)	0.78
Total N (%)	0.03
Available P (ppm)	20
Exchangeable K (me/100 g soil)	0.1
Available S (ppm)	45

Source: Department of Soil Science, SAU.

Appendix III. Analysis of variance of the data on plant height of Tomato as influenced by distance from Moringa tree base

Response PH30DAT:

```
            Df  Sum Sq Mean Sq F value    Pr(>F)
Replication  2   1.189   0.595  1.3959    0.3178
Treatment    3 102.563  34.188 80.2465 3.117e-05 ***
Residuals    6   2.556   0.426
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

> lsd=with(X,LSD.test(PH30DAT,Treatment,DFerror=6,MSerror=0.426))
> lsd
$`statistics`
  MSerror Df    Mean       CV  t.value   LSD
    0.426  6 25.1625 2.593887 2.446912 1.304


$groups
  PH30DAT groups
4 28.94667      a
3 26.48667      b
2 24.20000      c
1 21.01667      d
```

Response PH60DAT:

```
           Df Sum Sq Mean Sq F value   Pr(>F)
Replication  2  37.58  18.791  5.0422  0.05191 .
Treatment    3 873.45 291.150 78.1249 3.37e-05 ***
Residuals    6  22.36   3.727
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

> lsd=with(X,LSD.test(PH60DAT,Treatment,DFerror=6,MSerror=3.727))
> lsd
$`statistics`
  MSerror Df    Mean       CV  t.value      LSD
    3.727  6 47.9625 4.025111 2.446912 3.857024

$groups
  PH60DAT groups
4 56.50333      a
3 55.27000      a
2 44.46667      b
1 35.61000      c
```

Response PH75DAT:

```
           Df  Sum Sq Mean Sq   F value    Pr(>F)
Replication  2    1.39    0.69    3.2044     0.113
Treatment    3 1227.54  409.18 1889.9467 2.583e-09 ***
Residuals    6    1.30    0.22
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

> lsd=with(X,LSD.test(PH75DAT,Treatment,DFerror=6,MSerror=0.22))
> lsd
$`statistics`
  MSerror Df     Mean       CV  t.value       LSD
     0.22  6 53.92417 0.869817 2.446912 0.9370959

$groups
  PH75DAT groups
4 66.02333      a
3 61.13000      b
2 47.77333      c
1 40.77000      d
```

Response PH90DAT :

```
           Df  Sum Sq Mean Sq   F value    Pr(>F)
Replication  2    1.55    0.77    1.8767    0.2328
Treatment    3 1353.81  451.27 1094.9624 1.325e-08 ***
Residuals    6    2.47    0.41
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

> lsd=with(X,LSD.test(PH90DAT,Treatment,DFerror=6,MSerror=0.41))
> lsd
$`statistics`
  MSerror Df     Mean       CV  t.value      LSD
     0.41  6 58.31833 1.097961 2.446912 1.279277

$groups
   PH90DAT groups
4 70.93667      a
3 66.29667      b
2 50.87333      c
1 45.16667      d
```

Response PHHARV :

```
           Df  Sum Sq Mean Sq  F value    Pr(>F)
Replication  2    1.91    0.95   1.7362    0.2541
Treatment    3 1011.48  337.16 613.1800 7.508e-08 ***
Residuals    6    3.30    0.55
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

> lsd=with(X,LSD.test(PHHARV,Treatment,DFerror=6,MSerror= 0.55))
> lsd
$`statistics`
  MSerror Df     Mean       CV  t.value      LSD
     0.55  6 61.85083 1.199046 2.446912 1.481679

$groups
    PHHARV groups
4 71.83333      a
3 69.49333      b
2 56.48667      c
1 49.59000      d
```

Appendix IV. Analysis of variance of the data on the number of branches per plant of Tomato as influenced by distance from Moringa tree base

Response NB60DAT :

```
            Df  Sum Sq Mean Sq F value    Pr(>F)
Replication  2  1.1667  0.5833     4.2   0.07234 .
Treatment    3 29.6667  9.8889    71.2 4.416e-05 ***
Residuals    6  0.8333  0.1389
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

> lsd=with(X,LSD.test(NB60DAT,Treatment,DFerror=6,MSerror=0.1389))
> lsd
$`statistics`
  MSerror Df     Mean       CV  t.value       LSD
   0.1389  6 5.166667 7.213411 2.446912 0.7446013

$groups
   NB60DAT groups
4 7.333333      a
3 5.666667      b
2 4.666667      c
1 3.000000      d
```

Response NB90DAT :

```
            Df Sum Sq Mean Sq F value    Pr(>F)
Replication  2  0.500  0.2500     1.8    0.2441
Treatment    3 32.667 10.8889    78.4 3.336e-05 ***
Residuals    6  0.833  0.1389
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

> lsd=with(X,LSD.test(NB90DAT,Treatment,DFerror=6,MSerror=0.1389))
> lsd
$`statistics`
  MSerror Df Mean       CV  t.value       LSD
   0.1389  6    6 6.211548 2.446912 0.7446013

$groups
   NB90DAT groups
4 8.333333      a
3 6.666667      b
2 5.000000      c
1 4.000000      d
```

Response NBHARV :

```
           Df  Sum Sq Mean Sq F value    Pr(>F)
Replication  2  0.1667  0.0833  0.4286 0.6699219
Treatment    3 25.5833  8.5278 43.8571 0.0001785 ***
Residuals    6  1.1667  0.1944
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
> lsd=with(X,LSD.test(NBHARV,Treatment,DFerror=6,MSerror=0.1944))
> lsd

$`statistics`
  MSerror Df     Mean       CV  t.value       LSD
   0.1944  6 6.416667 6.871296 2.446912 0.8808883

$groups
   NBHARV groups
4 8.333333      a
3 7.000000      b
2 6.000000      c
1 4.333333      d
```

Appendix V. Analysis of variance of the data on days to 1st flowering, 1st harvest and complete harvest of Tomato as influenced by planting distance from Moringa tree base

Response FLOW :

```
           Df Sum Sq Mean Sq F value    Pr(>F)
Replication  2  0.500  0.2500    0.36 0.7117802
Treatment    3 81.583 27.1944   39.16 0.0002463 ***
Residuals    6  4.167  0.6944
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

> lsd=with(X,LSD.test(FLOW,Treatment,DFerror=6,MSerror= 0.6944))
> lsd
$`statistics`
  MSerror Df  Mean       CV  t.value      LSD
   0.6944  6 31.75 2.624588 2.446912 1.664859

$groups
     FLOW groups
1 35.66667      a
2 32.33333      b
```

```
4 30.33333      c
3 28.66667      d
```

Response HARV:

```
           Df Sum Sq Mean Sq F value   Pr(>F)
Replication  2   2.00   1.000   1.000 0.421875
Treatment    3  58.25  19.417  19.417 0.001718 **
Residuals    6   6.00   1.000
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1


> lsd=with(X,LSD.test(HARV,Treatment,DFerror=6,MSerror= 1.000))
> lsd
$`statistics`
  MSerror Df  Mean       CV  t.value      LSD
        1  6 67.25 1.486989 2.446912 1.997895

$groups
      HARV groups
1 70.33333      a
2 68.00000      b
3 66.33333      b
4 64.33333      c
```

Response COMHARV:

```
           Df Sum Sq Mean Sq  F value    Pr(>F)
Replication  2   0.50   0.250   0.2195    0.8091
Treatment    3 704.92 234.972 206.3171 1.929e-06 ***
Residuals    6   6.83   1.139
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1


lsd=with(X,LSD.test(COMHARV,Treatment,DFerror=6,MSerror=1.139))
> lsd
$`statistics`
  MSerror Df   Mean        CV  t.value      LSD
    1.139  6 108.75 0.9813696 2.446912 2.132232

$groups
   COMHARV groups
4 119.0000      a
3 112.6667      b
2 104.3333      c
```

1 99.0000 d

Appendix VI. Analysis of variance of the data on the yield contributing parameters of Tomato as influenced by planting distance from Moringa tree base

Response FD:

```
           Df Sum Sq Mean Sq F value    Pr(>F)
Replication  2 0.1074 0.05372  1.0936 0.3935820
Treatment    3 5.4144 1.80481 36.7391 0.0002951 ***
Residuals    6 0.2947 0.04912
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

> lsd=with(X,LSD.test(FD,Treatment,DFerror=6,MSerror= 0.04912))
> lsd
$`statistics`
  MSerror Df   Mean       CV  t.value       LSD
  0.04912  6 5.3675 4.129116 2.446912 0.4427941

$groups
        FD groups
4 6.173333      a
3 5.793333      a
2 5.080000      b
1 4.423333      c
```

Response NFP:

```
           Df Sum Sq Mean Sq  F value    Pr(>F)
Replication  2   0.50   0.250   0.5294    0.6141
Treatment    3 420.92 140.306 297.1176 6.523e-07 ***
Residuals    6   2.83   0.472
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1


> lsd=with(X,LSD.test(NFP,Treatment,DFerror=6,MSerror=0.472))
> lsd
$`statistics`
  MSerror Df  Mean       CV  t.value      LSD
    0.472  6 22.75 3.019879 2.446912 1.372599


$groups
       NFP groups
```

```
4 29.66667      a
3 26.33333      b
2 21.00000      c
1 14.00000      d
```

Response FYP:

```
           Df  Sum Sq Mean Sq F value    Pr(>F)
Replication  2    9837    4918  0.3024    0.7497
Treatment    3 3674677 1224892 75.2992 3.752e-05 ***
Residuals    6   97602   16267
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

> lsd=with(X,LSD.test(FYP,Treatment,DFerror=6,MSerror= 16267))
> lsd
$`statistics`
  MSerror Df    Mean       CV  t.value      LSD
    16267  6 1676.31 7.608506 2.446912 254.8158

$groups
        FYP groups
4 2367.0667      a
3 2014.5233      b
2 1389.8267      c
1  933.8233      d
```

Response IFW:

```
           Df Sum Sq Mean Sq F value    Pr(>F)
Replication  2   3.38   1.689   1.773    0.2483
Treatment    3 393.94 131.314 137.813 6.369e-06 ***
Residuals    6   5.72   0.953
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

> lsd=with(X,LSD.test(IFW,Treatment,DFerror=6,MSerror= 0.953))
> lsd
$`statistics`
  MSerror Df     Mean       CV  t.value     LSD
    0.953  6 74.49417 1.310461 2.446912 1.95038

$groups
       IFW groups
4 81.91000      a
3 77.16333      b
2 72.48000      c
```

```
1 66.42333      d
```

Response FYP:

```
           Df Sum Sq Mean Sq  F value    Pr(>F)
Replication  2  0.709  0.3543   3.0243    0.1235
Treatment    3 51.159 17.0530 145.5827 5.416e-06 ***
Residuals    6  0.703  0.1171
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
> lsd=with(X,LSD.test(FYP,Treatment,DFerror=6,MSerror= 0.1171))
> lsd
$`statistics`
  MSerror Df     Mean       CV  t.value       LSD
   0.1171  6 6.585833 5.195983 2.446912 0.6836773

$groups
       FYP groups
4 9.086667      a
3 7.780000      b
2 5.866667      c
1 3.610000      d
```

Response FY:

```
           Df  Sum Sq Mean Sq F value    Pr(>F)
Replication  2   30.50   15.25  3.7091   0.08941 .
Treatment    3 1117.78  372.59 90.6157 2.185e-05 ***
Residuals    6   24.67    4.11
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
> lsd=with(X,LSD.test(FY,Treatment,DFerror=6,MSerror= 4.11))
> lsd
$`statistics`
  MSerror Df  Mean       CV  t.value     LSD
     4.11  6 29.59 6.851347 2.446912 4.05036


$groups
        FY groups
4 42.08000      a
3 34.16333      b
2 26.06333      c
1 16.05333      d
```

PLATES

Plate 1. Plot preparation

Plate 2. Cow dung application

Plate 3. Tomato seedling Collection

Plate 4. Seedling transplanting

Plate 5. Watering

Plate 6. Flowering

Plate 7. Fruiting

Plate 8. Fruit Ripening

Plate 9. Weighting of fruit