AGROFORESTRY PRACTICES WITH CHILLI DURING THE EARLY ESTABLISHMENT PERIOD OF *MORINGA* PLANTATION

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CERTIFICATE

This is to certify that the thesis entitled ***"AGROFORESTRY PRACTICES WITH CHILLI 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 (M.S.)*** *in* ***AGROFORESTRY AND ENVIRONMENTAL SCIENCE****, embodies the result of a piece of research work carried out by* ***MD. MAHEDI HASAN****, Registration No. 13-05562 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 duly been acknowledged.

June, 2020
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The Author

Dedicated to

My

Beloved Parents

AGROFORESTRY PRACTICES WITH CHILLI DURING THE EARLY ESTABLISHMENT PERIOD OF *MORINGA* PLANTATION

ABSTRACT

The experiment was conducted at the Agroforestry Farm of Sher-e-Bangla Agricultural University (SAU), Dhaka during the period from October 2018 to March 2019 to study the performance of chilli during the early establishment period of Moringa plantation. Four different treatments *viz*., (i) T_1 (20 cm distance from the tree base), (ii) T_2 (30 cm distance from the tree base), (iii) T_3 (40 cm distance from the tree base), and (iv)T_4 (open field plantation considered as control), were assessed by following Randomized Complete Block Design (RCBD) with four replications. The seedlings of chilli (*var*. BARI chilli-2) were used in this study. Recorded data on different growth, yield attributing parameters and yield were higher in control condition (T_4) compared to agroforestry treatments where chilli plants were grown at different distances from Moringa tree base. Results revealed that the highest plant height (44.13 cm), number of branches plant^{-1} (8), fruit length (6.65 cm), fruit diameter (0.96 cm), number of fruits plant^{-1} (307), fruit weight plant^{-1} (565.58 g), single fruit weight (1.84 g), fruit yield plot^{-1} (2.31 kg) and fruit yield ha^{-1} (10.29 t) were observed in T_4 (control) treatment. But under agroforestry practice, the highest plant height (37.54 cm), number of branches plant^{-1} (7), fruit length (6.48 cm), fruit diameter (0.92 cm), number of fruits plant^{-1} (268), fruit weight plant^{-1} (465.46 g), single fruit weight (1.74 g), fruit yield plot^{-1} (1.82 kg) and fruit yield ha^{-1} (8.15 t) were found in T_3 (40 cm distance from the tree base) treatment. Whereas the lowest plant height (22.8 cm), number of branches plant^{-1} (5), fruit length (5.18 cm), fruit diameter (0.82 cm), number of fruits plant^{-1} (183), fruit weight plant^{-1} (291.85 g), single fruit weight (1.59 g), fruit yield plot^{-1} (1.16 kg) and fruit yield ha^{-1} (5.15 t) were recorded in T_1 (20 cm distance from the tree base) treatment. The results of the experiment signified that there were negative tree-crop interactions in respect of different planting distances i.e., increased interaction of Moringa and chilli decreases growth and yield of chilli when Moringa tree were at their early stage of establishment. To obtain better result under tree crop interaction, measurement of optimum distances between tree and crop is very important which may be contributed to achieve best results on both tree and crop yield. According to regression analysis showed that 80 cm distance was optimum for minimizing these competitions and resulting approximately 10.44 ton/ha chilli yield.

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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
g	=	Gram (s)
i.e.	=	id est (L), that is
Kg	=	Kilogram (s)
LSD	=	Least Significant Difference
m^2	=	Meter squares
ml	=	MiliLitre
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
Ca	=	Calcium
L	=	Litre
µg	=	Microgram
USA	=	United States of America
WHO	=	World Health Organization

CHAPTER I

INTRODUCTION

Bangladesh is one of the most densely populated country in the world where 1015 persons are living per square kilometer (BBS, 2018). The per capita land area is decreasing at an alarming rate due to increasing population (Hossain and Bari, 1996). This availability of land has been declined from 0.19 ha in 1961 to 0.101 ha in 1992 and now the country is claimed to have the lowest per capita arable land of 0.02 ha (Iqbal *et al*., 2002).

To feed this over increasing population, agricultural land needs to be intensified. The productive capacity of our agricultural land is low due to poor soil health. In fact, rising population pressure and urbanization coupled with land degradation, soil salinization and global warming causing food and nutritional insecurity of Bangladesh (Chakraborty *et al*., 2015). Because of the increasing environmental hazards and demand for food, timber, fuel wood, fodder, fruits and poles etc. production of multiple products from the same land management unit is urgently needed. Multiple productions from homesteads and croplands are indispensable for a country like Bangladesh where the population growth rate is very high and faster than its agricultural growth rate (Hanif *et al*., 2010). Since there is neither scope for expanding forest area nor sole grain crop area, the country has to develop combined production system integrating trees and crops which is now being called agroforestry.

Agroforestry involves managing interactions between tree and non-tree components to produce diversified sustainable production system. Akinbile *et al.* (2007) described agroforestry as an aspect of farm forestry that encourages a deliberate integration of woody perennials with agricultural crops or animals on the same land management unit, with the aim of increasing income through the use of economic trees. By selecting tree and crop species with complementary patterns of light, water and nutrient acquisition, overall system productivity can be higher than for conventional agriculture or forestry and leaching losses can be reduced. Adding trees to agricultural fields provides wildlife habitat and so increases biodiversity, which in some circumstances may enhance biological control of crop pests through the encouragement of natural predators. As trees mature, they ameliorate soil and cast increasingly heavy shade creating a succession of different opportunities for intercropping. Thinning with above and below ground pruning allow the farmer considerable flexibility in controlling the speed and extent to which trees affect agricultural productivity (Hasan *et al.*, 2008).

According to Garrity (2004) agroforestry as alternative land management system addresses many of the global challenges, including deforestation, unsustainable cropping practices, loss of biodiversity, increased risk of climate change, as well as rising hunger, poverty and malnutrition. Agroforestry systems make maximum use of the land, every part of the land being suitable for useful plants. Well-designed systems of agroforestry maximize beneficial interactions of the crop plants while minimizing unfavorable interactions. Competition is the most common interaction which may be for light, water, or soil nutrients. Competition invariably reduces the growth and yield of any crop. Yet competition occurs in monoculture as well, and this need not be more deleterious in agroforestry than monoculture systems (Jahan and Rahman, 2012).

Fruit-crop-based agroforestry involves intentional, simultaneous association of annual or perennial crops with perennial fruit-producing trees on the same farm unit. Because of the relatively short juvenile (pre-production) phase of fruit trees, high market value of their products, and the contribution of fruits to household dietary needs, fruit-crop-based agroforestry enjoys high popularity among resource limited producers worldwide (Bellow, 2004).

Agroforestry is an integral part of the rural livelihood systems for centuries in Bangladesh and plays a key role in providing household food and energy security, income and employment generation, investment opportunities and environmental protection (Miah *et al.*, 2002). The integration of trees, agricultural crops, and/or animals into an agroforestry system has the potential to enhance soil fertility, reduce erosion, improve water quality, enhance biodiversity, increase aesthetics, and sequester carbon (Garrity et al., 1992). Moreover, tree plantations improve soil physical, chemical and biological properties through accretion and decomposition of organic matter through litter fall, and roots decay. Deep and extensive root systems of trees enable them to absorb substantial quantities of nutrients below the rooting zone of crops and transfer them to surface soil (Hartemink *et al.*, 1996; Allen *et al.*, 2004).

It is understood that total production of agroforestry is several times higher than that of annual crop system or forestry alone because of efficient use of growth resources *viz*. light, nutrient, water in this system. It is a sustainable and highly productive system that provides continuous production around the year. The vegetables that are grown in Bangladesh are not satisfactory. The demand of vegetables is increasing but unfortunately the area under vegetable production is decreasing due to increasing the area of rice and wheat cultivation.

Chilli is a common spice crop and very important for our daily dietary. It is an important spice as well as vegetable crop, where both ripe and unripe fruits are used for culinary, salad and processing purposes. Its extract is used in pharmaceutical industry for coloring the drugs. It is an excellent source of vitamin A and C. Being richest source of vitamin C, it is sometimes referred as capsule of vitamin C (Durust *et al*., 1997). It contains high nutritive value with 1.29 mg/100 g protein, 11 mg/100 g calcium, 870 I.U vitamins-A, 175 mg ascorbic acid, 0.06 mg thiamine, 0.03 mg riboflavin, 0.55 niacin per 100 g edible fruit and 321mg per 100 g of vitamin C (Agarwal *et al*., 2007). They have beta carotene which is as much as that found in spinach of 180 mg per 100 g (Olivier *et al*., 1981). It is cultivated in all over the country. In the country, chilli crops occupy 103.24 thousand hectares of land with a production of 137 thousand metric ton (BBS, 2017).

In Bangladesh, *Moringa* is a common tree growing mainly in homestead areas (Padulosi *et al*., 2013). *Moringa* is a multipurpose vegetable tree with potential uses of nutritional and medicinal properties. *Moringa* (*Moringa oleifera*) commonly known as 'drumstick tree' is the most commonly cultivated species. This multipurpose tree is characterized by high biomass yield and tolerance to unfavorable environmental conditions (Foidl *et al*., 2001). *Moringa* is said to provide 7 times more vitamin C than oranges, 10 times more vitamin A than carrots, 17 times more calcium than milk, 9 times more protein than yoghurt, 15 times more potassium than bananas and 25 times more iron than spinach (Rockwood *et al*., 2013).

Plantation of *Moringa* during establishment period of 1 to 2 years can easily grow in their surrounding areas. At this period, the competition for plant nutrients and water between tree and associated crop is probably absent or minimum. Plantation of *Moringa* tree in relation with vegetables and spices as agroforestry practice would be beneficial for socio economic development and also for better environment. Hence, the present study during the early period of the *Moringa* tree plantation in association with different vegetables at different spacing might be beneficial in terms tree-crop combination. Therefore, the present study was undertaken with the following objectives:

1. Feasibility of growing chilli with *Moringa* during the early establishment period of *Moringa* plantation.
2. To find out the optimum distance from *Moringa* root zone to minimize competition for obtaining better yield.

CHAPTER II

REVIEW OF LITERATURE

Different vegetables and spices such as chilli, tomato, carrot, onion, garlic, ginger, etc. are usually grown throughout the world; their performance is largely affected under multistoried agroforestry system because of inappropriate sunlight. Under the present study, chilli crop was grown with the interaction of *Moringa* tree. Limited review of literature of the past studies related to the present experiment is collected from journals, thesis, reports and from other scientific publications. And these findings are reviewed under the following headings.

2.1 Concepts of Agroforestry

Agroforestry is an age-old and ancient concept (Haque *et al*., 1996). Many definitions have been advanced for the term agroforestry. A widely used definition given by the International Centre for Research in Agroforestry (Nair, 1984) is that "Agroforestry is a collective name for all land-use systems and practices where woody perennials are deliberately grown on the same land management unit with agricultural crops or animals in some form of spatial arrangement or temporal sequence".

From a bio-economic point of view, agroforestry is a combined agriculture/tree crop or tree farming system which enables a farmer to make more effective use of his land and thereby receive a higher net economic return on a sustainable basis (Harou, 1983).

Agroforestry is a land use system, which contributes pragmatically in all these spheres to materialize the desired goals. The unmatchable advantages and implications of this land use system have precipitated the recent concerned interest in agroforestry all around including India. Agroforestry offers not only a sustained productivity, but also its sustainability over the longer period. It buffers against the vagaries of climate through its unique way of amelioration of microclimate and reshapes the agro-ecosystem with enhanced stability and resilience (Sanjeev *et al*., 2012 and Nair, 2007).

Agroforestry is receiving attention as an alternative land-use practice that is resource efficient and environmentally friendly in Ghana (Owusu, 2002). Multiple outputs and the flexibility of having several options for management make agroforestry an attractive alternative to conventional agriculture and forestry for landowners in many parts of both the Temperate and Tropical regions of the world (Jose and Gordon, 2008).

Agroforestry has been practiced by many groups of people in various way under different conditions over a long period of time such as bush following, taungya, alley cropping, green hedge and fences, afforestation blocks, protein banks, woody perennials for shelter, soil and water conservation, homestead agroforestry, cattle under woody perennials, dune fixing, aquaforestry Api-silviculture and many others (Torquaebian, 1990).

Among these, the taungya is a very ancient agroforestry system (Haque *et al*., 1996). The Burmese word "taungya" literally means hill (taung) cultivation (ya). It describes a method of raising forest trees in combination with agricultural crops on the same piece of land (Enabor, 1973). This is the most widely used term in Asia, Africa and Latin America.

Saxena (1984) pointed out that proper agroforestry utilizes the interspaces between tree rows for agricultural crops, and this does not impair the growth and development of the trees but enable farmers to derive extra income in addition to benefits accrued from the use of fuel and timber from trees.

Agroforestry systems improve and maintain soil fertility. It was hypothesized by Nair (1987) that an agroforestry system can play an important role in improving soil fertility by: (i) increasing organic matter content of soil through addition of leaf litter, pruning and other biomass, (ii) efficient nutrient recycling within the system, (iii) biological N_2 fixation in case of leguminous shrubs and trees; and (iv) possible complementary interactions among associated species due to differences in canopy structure, root system and active zone of water and nutrient absorption.

The physical, chemical and biological conditions of the soil are greatly influenced by the addition of organic matter through pruning of hedgerow (Nair, 1985; Young, 1984). Groot and Soumare (1995) observed that decomposition of tree roots and the substances of the root exudes greatly enhance soil organic matter and thereby soil fertility. Tree lateral roots may reduce loss of nutrients from the soil by recycling them that would have been otherwise leached from the system. Taproots may take up nutrients, which are released by weathering from deeper soil layers. A common hypothesis is strongly implied to the agroforestry system that integration of trees with annual crops improves the chemical properties of the soil (VonMaydell, 1987).

Shankarnaryan (1984) claimed that tree in agroforestry systems conserve soil moisture, increase atmospheric humidity and improve soil fertility. The process is enhanced by tree canopy cover which moderates the microclimate and enhances organic matter accumulation, microbial activity and mineralization (Verinumbe, 1987).

Bhatia and Singh (1994) observed that the agroforestry in India plays an important role in increasing biomass production, maintaining soil fertility, conserving and improving soil, and averting risk.

2.2 Agroforestry system and its structure

Morris *et al.* (2002) found that boundary vegetation is important resource for farmland wildlife, for biodiversity and as a landscape component. While commercial aspects generally dominated field boundary management, farmers and professionals and the wider public also appreciated hedgerows as landscape or countryside features. The study suggests it may be useful to build on or influence these attitudes to maintain or enhance the conservation value of field boundary vegetation.

Oiu *et al.* (2002) reported that the fields using curly willow in draws had substantially higher economic returns than thebaseline, which uses agricultural crops in alternative uses of two draws (i.e. switch grass and cottonwood) that had lower economic returns than the baseline for all three agricultural systems without Conservation Reserve Program payments. Three scenarios of crop price were evaluated, *viz.* 5, 10 and 15% simultaneous decreases in maize, soybean and wheat prices. Lower crop prices reduce the profitability of agricultural systems, thus encourage alternative uses of draws. Alternative uses of draws increase return flow and reduce surface runoff, sediment yield and nutrients, pesticide pollutants associated with runoff and sediment, such as N, P and pesticides.

Stirzakerm *et al.* (2002) predicted that the success of a tree/crop mixture becomes less likely with declining crop season rainfall and increasing seasonal variability and more likely when the tree products have a direct economic benefit.

Ahmed (2001) reported that Swiss Agency for Development and Cooperation (SDC) undertook a major cropland agroforestry initiative in the North Bengal in 1996 through its Village and Farm Forestry Project (VFFP). This was an action-oriented programme aimed at promoting production in non-forest areas (cropland and homegardens). The main objectives were to generate cash, fuel wood and fodder from privately owned farmland for the subsistence and sustenance of landless, marginal and poor farmers through planting trees on cropland and homegardens.

Koirala *et al.* (2001) found that landholding size, education level and forestry extension media play an important motivational factor in varying degrees in plantation programme in cropland agroforestry.

Neupane *et al.* (2001) observed that practices that 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.

Basavaraju *et al.* (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 density of trees, proper spatial arrangement and pruning and thinning of tree crowns and roots to reduce the negative effects of trees.

Francisco (1999) conducted the profitability analyses of the dominant agroforestry farming system I (agricultural crops with forest/fruit trees), agroforestry system II (mixed fruit/forest trees) and mono-perennial cropping systems) in Makiling Forest Reserve (MFR), in Philippines. He suggested that an average size of approximately two hectares can be an adequate farm size for farm households.

Kumar *et al.* (1998) conducted a research and found that there were 3 windbreaks situated on the North, West and East sides of the crop field. Crop infection was greater near the West and South windbreaks than the North windbreak or the open part of the field Microclimate investigations in the vicinity of the South windbreak showed lower air temperatures and light (i.e., greater shade), and greater relative humidity under the tree canopy than outside it during the day. *Alternaria* leaf blight was also recorded on *H. campestris*, but levels of this disease were not increased by the shelterbelts.

Solanki (1998) stated that agroforestry can significantly contribute in increasing demand of fuel wood, fodder, cash and infrastructure in many developing countries. He also stated that agroforestry has high potential to simultaneously satisfy 3 important objectives: (i) protecting and stabilizing the ecosystems (ii) producing a high-level output of economic goods (fuel, fodder, small timber, organic fertilizer etc.) and (iii) providing stable employment, improved income and basic material to rural populations.

Hocking and Islam (1997) observed that due to pruning of shoot and root the tree yield was reduced by 41% and crop (rice, wheat, jute and pulses) yield by 7%.

Shaikh (1996) conducted a study on the profitability of cropland agroforestry method of cultivation vis-a-vis non-agroforestry methods of crop cultivation. Cost benefit analysis of different cropping patterns on cropland agroforestry method (net area 2.2 ha.) showed that the net return was Tk 26686, as against a net return of Tk 44829 from the assumed area of the same 2.2 ha. under non-agroforestry method. Financial analysis of cropland agroforestry showed that benefit-cost ratio was 1.59, percent worth of net benefit was Tk. 291515, and internal rate of return was 19.15 percent. This study indicated that the cropland agroforestry method of cultivation is more profitable than non-agroforestry method.

Pavlovksy (1995) observed that agroforestry protected the ecology of farmlands by shelterbelt systems (including vertebrate fauna, agricultural productivity and ecology of afforested slopes, sands and grasslands; shelterbelts as a source of timber; the sanitary role of shelterbelts (in protecting against pollution); the aesthetic and recreational role of forest shelterbelts and design of agricultural lands; oasis type reclamation of arid steppe and semi-desert by afforestation; and organization of agroforestry.

Trees are grown in the cropland, homestead, orchard not only produce food, fruits, fodder, fuel wood or to generate cash for various purposes (Chowdhury and Satter, 1993) but also give better living environment (Haque, 1996).

Fernandes and Nair (1990) reported that the intimate mix of diversification agricultural crops and multipurpose trees fulfils most of the fundamental needs of the total populations and their multi-storied configuration and high species diversity avoid the environmental deterioration commonly associated with monocultural production systems. Moreover, they have produced sustained yields for centuries in a most resource efficient way. Thus, cropland is economically efficient, ecologically sound and biologically sustainable agroforestry systems.

Homestead gardens are common in Bangladesh where the fanners take up combination of 10-15 species of fruit, ornamental and multipurpose trees, along with vegetables to meet their own or aesthetic value (Rang *et al.,* 1990)

Zabala (1990) reported that the most level areas where there are no problems of soil erosion and runoff, protective trees are not required and thus there is no intercropping, instead trees are planted along the border of the area Fast growing, multipurpose trees are planted along properly borders; they are lopped off periodically for fuel wood and their leaves are also harvested and used as fodder or as green manure. In addition, normal litter-fall serves as added green fertilizer for the food crop.

Akter *et al.* (1989) mentioned that farmers also consider trees as savings and insurance against risk of crop failure and low yield, as well as assets for their children. Some farmers stated that tree would contribute toward expenses for marriage of their daughters.

Hosier (1989) observed that an agroforestry system, planners must pay attention to input and output mixes and attitudes toward risk as components of smallholder profitability. From the smallholder's perspective, local market conditions and existing practices may provide a greater indicator of project success or failure than environmental benefits, which may be nearly impossible to quantify. A positive on-farm economic analysis provides a necessary but not significant indication of the successful introduction of an agroforestry project

Akter *et al.* (1988) conducted a survey in the fanning system research site, Bagherpara, Jessore to understand the existing agroforestry situation. The investigation revealed that Date palm, Babla, Palmyra palm and Jackfruit were grown on the croplands for fruit, fuel, timber, juice, molasses, building materials etc. It was stated that manufacture of molasses, use of fuel and mat making are the primary reasons behind date palm cultivation. It was observed that among marginal and small fanner, income from date palm sustains the family maintenance for 5-6 months in a year.

Ong (1988) reported that intercorporating trees with arable crops could increase biomass production per unit area increased substantially when the roots of trees exploit water and nutrients below the shallow roots of crops and when a mixed canopy intercepts more solar energy.

Jackson (1987) stated that Agroforestry systems that incorporate a range of tree and crop species offer much more scope for useful management of light interception and distribution than do monoculture forests and agricultural crops. The potential benefits as a result of combining field crops with crops with trees are so obvious from consideration of the waste nutrient resources experienced in orchards and tree crop combination.

Lagemann (1987) opined that the cropland agroforestry system is very important in the economy of Bangladesh. In fact, agroforestry is a term that invariably brings up the homesteads to the forefront particularly in a country like Bangladesh.

Further, Asaduzzaman *et al.* (1986) conducted a study on existing agroforestry systems of crop field and the homestead area at the farming system research site, Bagherpara, Jessore district, Bangladesh. The study revealed that there exist 22 horticultural and 16 forestry species in the homestead and 7 horticultural and 8 forestry species in the crop field. Among the horticultural species in the crop field, the intensity of date palm was highest (17.45 trees per farm). It was shown that 5-15 percent yield of field crops reduced due to trees but this yield losses sub-situated by the fruits, juice and wood of the trees in the crop field on an average farmer earned yearly Tk. 5093.00 per farm from the crop field trees.

Rocheleau and Hock (1984) reported that in the densely settled farming community in the sub-humid mid-lands of Kenya, pathways, water courses, farm boundaries and internal borders were fully utilized for planting of appropriate trees and shrubs some 50 percent of the fuel wood and 40 percent of fodder requirements of the households in the area could be supplied by these hedgerows, with very little competition with existing agricultural land uses.

2.3 Features of *Moringa* and its benefits

The germination rate of *Moringa* seeds is high (Saint Sauveur and Broin, 2010). Furthermore, *Moringa* seeds have no dormancy period, so they can be planted as soon as they are mature. Seeds may be sown in seedbeds (for transplanting) or directly in the main field. *Moringa* seeds germinate 5 to 12 days after seeding (Saint Sauveur and Broin, 2010).

Moringa trees will at least flower and fruit annually. During its first year, a *Moringa* tree will grow up to five meters in height and produce flowers and fruits; when left alone, the tree can eventually reach 12 meters in height with a trunk 30 cm wide (Fugli and Sreeja, 2011). If the trees are left to grow naturally, yields will be low. Maintenance pruning is also required. This can be done at each harvest (i.e. if the leaves are removed). In fruit and seed producing farms, pruning helps induce more fruits, as well as larger fruits (Saint Sauveur and Broin, 2010). *Moringa* trees will generally grow well without adding very much fertilizer, but in order to achieve good yields the soil needs to provide enough nitrogen and minerals to the plant. Before seeding/planting, manure or compost need to mix with the soil used to fill the planting pits. Afterwards it is important to apply manure or compost at least once a year, for instance before the rainy season, when the trees are about to start an intense growth period (Saint Sauveur and Broin, 2010).

Moringa leaves are an exceptionally good source of vitamins A, B, and C, minerals (in particular iron and calcium), and the sulphur-containing amino acids methionine and cystine (Foidl *et al.*, 2001). *Moringa* leaves also acts as a good source of natural antioxidant due to the presence of various types of antioxidant compounds such as ascorbic acid, flavonoids, phenolics and carotenoids (Anwar *et al.*, 2007).

Biodiesel derived from *Moringa* oil is an acceptable substitute for petro-diesel when compared to biodiesel fuels derived from other vegetable oils. A survey conducted on 75 indigenous (India) plant derived non-traditional oils concluded that *M. oleifera* oil, among others, has good potential for. biodiesel production (Azam et al., 2005). A number of medicinal properties can be ascribed to the various parts of the *Moringa* tree. Almost all the parts of this plant: root, leaf, bark, gum, leaf, flowers, seed and fruit (pods) have been used for various ailments in the indigenous medicine of South Asia (Anwar *et al.*, 2007). Because of the nutritional characteristics of the *Moringa* tree, it is an excellent source of fresh forage material for livestock feed. The leaves are rich in protein, carotene, iron and ascorbic acid and the pod is rich in the amino acid lysine (Foidl *et al.*, 2001). Feeding animals *Moringa* has been linked to increased milk production, increased nutrient uptake, and faster weight gain than with other feeds (Reyes-Sánchez *et al.*, 2006; Foidl *et al.*, 2001). Another important advantageous characteristic of *Moringa* for livestock forage is its high productivity of fresh material per unit area compared with other forage crops (Foidl *et al.*, 2001).

2.4 Chilli cultivation

Chilli is an annual crop which grows at an altitude ranging from 1400m up to 2100m. Growing chilli requires soil that is well drained and rich in organic matter, as well as 600–650 mm annual rainfall. It grows well on well-prepared soil that is free from perennial weed. It is propagated by raising seedlings in a nursery. Depending on the area, harvesting starts from 4 to 5 months from transplanting. Planting is carried out in the beginning of rainy season (Abay, 2010).

Transplanting is used for more precise control of plant population and spacing, thinning, cost avoided and with efficient use of seed (0.8 to 0.9 kg seeds/ha) than direct planting (6.25 kg seeds/ha) (Sam-Aggrey, 1985; Leskkovar and Cantliffe, 1993).

Effective irrigation is essential to obtain the best yields of the fruit of the right size. The soil must be kept moist to a minimum depth of 45 cm. During the first 2 weeks after transplanting, the plants should be irrigated twice or thrice per week for the transplants to become established, thereafter once or twice per week depending on climatic conditions and soil type (Berke *et al.*, 2002).

Farmyard manures are responsible to nutrient availability for the crop in demand, improve soil physical properties (aggregation) and hence improve water retention capacity, particularly organic in nature, infiltration rate and biological activity of soil (Aliyu, 2000.). The advantage of farmyard manure application, however, greatly depends, among others, on proper application methods, which increase the value, reduce cost, and effectiveness (TekluEshetu and Tabor, 2004).

The most important traits for yield calculation of chilli include number of branches per plant (count), plant height, number of fruits per plant, days to maturity (count from days of transplanting), dry fruit yield per plant, fruit length, and single fruit weight (Lemma *et al.*, 2008).

About 103381.49 ha of land of Bangladesh is under chilli cultivation in both Rabi (winter season) and Kharif (spring and summer season), the production is about 136,872 metric ton (BBS, 2017).

2.5 Tree-crop interaction

Chauhan *et al*. (2013) evaluated an agri-horti-silvicultural model involving poplar (*Populus deltoides* Bartr. Ex Marsh.) as timber tree component, fruit trees and agronomic crops viz, turmeric (Curcuma longa L.) and mungbean (*Vigna radiata* L.) for yield. Net photosynthesis, stomatal conductance and transpiration in both crops were higher in open areas than in shaded ones. Agronomic crops showed initially better performance under partial shade in yield and yield contributing parameters, subsequently decreased as poplar canopy advanced in age. Changes in these parameters showed inverse relationship with canopy age and vice versa with more yield reduction under fifth year old canopy followed by preceding years and control. The results of studies on the micro-climatic interaction and resultant effect on physiology, yield and economics of agronomic crops under poplar tree canopy. There was gradual reduction in crop yield with advancement of age but the economic benefits of intercropping were two to three times higher than traditional crop rotation.

Shylla and Chauhan (2004) evaluated six orchard floor management practices, i.e., clean cultivation, glyphosate herbicide application, hay mulch, black polythene mulch, green manuring with cowpea and intercropping with soyabean for their influence on improving the cropping and quality of plum (*Prunus salicina*) cv. Santa Rosa grown on Myrobalan rootstock in a field trial conducted at Solan situated in the mid hill zone of Himachal Pradesh, India. According to their report, intercropping produced larger and heavier fruits compared with other management practices though it recorded a 15.95% less yield compared with herbicide treatment, which recorded the highest yield of 40.75 kg tree^{-1}.

Jha and Chhimwal (1995) studied the effect of *Eucalyptus camalduleuysis* on soil properties. Soil characters were changed under the trial area, which includes a reduction in soil pH and K and an increase in organic matter.

Hosur and Dasog (1996) investigated the influence of tree plantation *(Tectona grandis, Dalbergia sissoo* and *Acacia catechu)* on the properties of red soil (Inceptisol) in Karnataka, India. Tree plantation decreased bulk density and pH whereas soil aggregation, organic matter and exchangeable calcium of the soils were increased. The nutrient status of the soil was little changed by tree plantations. The nutrient return through litter fall followed the order Ca>K>N in *D. sissoo* and *A. catechu* and Ca>N>K in Teak.

Sreemannarayana *et al*. (1996) evaluated some multipurpose tree species and their influence on a red loamy soil in southern Andhra Pradesh. Best growth was shown by *Eucalyptus camcldulensis* and *Leucaena leucocephala,* while fertility (as measured by soil organic matter and available P_2O_5 and K_2O) was best under *Albizia lebbek*, followed by *L. leucocephala.*

There are numerous examples of self-propagated trees that are allowed to persist in rice fields. In Bangladesh, trees of *Acacia nilotica, A. catechu* and *Acacia albida* are found growing in paddy fields in Meherpur. Kushtia, Pabna. Sirajgonj, Rajshahi and Natore district. A similar system is reported from Madhya pradesh (India), where *Acacia nilotica* is intercropped with rice (Vismananath and Kaushik, 1993).

In a small ancillary study, the crop impact of these existing trees was measured by standard crop cut method, comparing yield under the tree canopy and outside (well away from tree influence). Rice yield under the various tree species were depressed by 20% - 50% depending on the tree species (canopy density) and size, and on season and availability of irrigation (Hocking, 1997).

To maintain sustainable production, the diversification of agriculture by changing the crops in the present crop rotation itself, and by including fast growing tree species in the present agriculture system were suggested by Johi *et al*. (1986) and Bhalla (1989).

Khan and Aslam (1974) studied the effect of single shishoo *(Dalbergia sissoo)* tree on the yield of wheat crop. Yield was measured from plots within a quadrat of lm^2. The quadrats were taken at a distance of 3m, 4.5m and 6m from the base of tree. One quadrat was taken from the center of the field, that is, well away from the influence of trees involved. The grain yield showed a decrease of 30.88%, 23.6% and 12.7% at the distance of 3, 4.5 and 6m respectively as compared to of the field. Both the trees and the crop were raised under irrigated condition.

Khattak *et al*. (1980) found that the yield of wheat in association with *Dalbergia sissoo* was significantly higher than that with *Eucalyptus camaldulensis*, *Populus deltoides* and *Bombax ceiba*. Sheikh and Cheema (1976) conducted a study to find out the effects of 3 row belts of *Eucalyptus camaldulensis* on the yield of wheat and cotton. It was observed that the yield was not depressed when wheat was sown at the time the trees were 5 to 6m's in height. However, in case of cotton when the height of tree belts was up to 7 m the yield was comparatively poor within a distance of 15-30 m on either side of the belt. The experiment was maintained under irrigated conditions and the observations were recorded for two years.

Sheikh and Haq (1986) summarized the important finding of tree-crop interaction in agroforestry as under:

1. tree in close proximity depress the crop yield.
2. this effect varies with the crop and tree species
3. farmers are prepared to raise the tree species if they are fast growing and have good market value.

For tree planting in crop fields to be acceptable by farmers, the interaction of the trees with the arable crop should be positive or neutral, or, if negative, the value of the tree crop should be more than that of the arable crop. Selected species of trees, either without additional management (tree with a thin, light canopy or that are leafless in the cropping season) or with appropriate thinning of the leafy canopy, can be grown in crop fields with minimal or no impairment of yields of the undercrops. Well-documented examples include *Paulownia* spp and wheat in china (Zhu *et al*. 1986), and poplars and wheat in India (Chaturvedi, 1982). Such trees are commonly tolerated and even encouraged by farmers for the sake of their valuable products, but their overall contributions to the farming system are more subtle and complex. For example, in situations of low fertility and low levels of management intensity, yield of under crops may be enhanced through contribution of nutrients recycled in the dropped leaves (Charreau and Niccou, 1971), although other factors also to partially explain enhanced crop yields under such trees (Geiger *et al.*, 1992; VandenBeldt and Williams, 1992).

Agroforestry systems offer a great scope for efficient nutrient use because of their distinct root systems. Tree is known to be deep rooted and are described as "Nutrient pump" which use nutrients from below the crop rooting zone (Beer, 1987) and recycle them to the crop in litter fall and in the green pruning (Beer, 1988).

When trees and crops are grown close together, they inevitably compete each other for growth resources (Ong *et al.*, 1992). The competition becomes critical when trees remain unpruned or when pruning are removed for use as fuelwood and fodder. Above and belowground interactions in alley cropping were critically examined by Singh *et al*. (1989) who found out that growth and yield of crops declined from 15% to 30% than that of sole crops as the distance from the tree rows decreased from 5m to 0.3m. Thicker roots, close to the tree stem, help anchor the plant while fine roots take up water and nutrients depends on the relative distribution of fine roots of both trees and crops. Competition is usually more severe if trees are shallow rooted and occupy the same soil layers as food crops occupy (Noordwijk *et al.*, 1995).

Lai (1989) evaluated the growth and yield of maize and cowpea grown in association with single row hedges of *Gliricidia sepium* and *Leucaena leucocephala* in a tropical Alfisol. He observed that maize growth and yield were suppressed only in the vicinity of hedgerows. Maize grain yield was about 10% lower than that of the control. In contrast, the agroforestry system drastically suppressed cowpea grain yield. The mean cowpea yield was 30-50% of the control. He concluded that shading was responsible for suppression of yield while in the shorter second season, where rains ended abruptly, moisture competition was the main factor causing the reduction of yield. Hoekstra (1982) and Singh *et al*., (1989) also reported similar competitive effects of hedges and crops.

Szott (1987) investigated the *edulis* rows were reduced by 50% compared with those in rows farthest away. A follow-up research was designed to observe the effect of *edulis* on upland rice yield. It was shown that Inga *edulis* has a pronounced effect, reducing rice yields by 50% up to 2.5 m away; beyond that, yield was similar to those in rows 6m away (Palm *et al*. 1992).

Basri *et al*. (1990) observed that hedgerow trees competed for nutrients and light with upland rice crop to a significant extent. Competition was most severe in the 2-3 rice rows closest to the hedgerows where yields were reduced by 50- 70% compared with those in the center of the alley.

Garrity *et al*. (1992) observed that in an alley cropping system, yield depression of upland rice was obtained in the zone near the hedgerows, although plant height was not affected much. Results of three years trial indicated that *Gelirici dasepium* exhibited the lowest yield depression on upland rice in rows near the hedges.

Itnal *et al*. (1993) observed influence of various economic tree species on growth and yield of rabi sorghum. Sorghum was grown in strips on the upstream side of *Dalbergia sissoo, Tectona grandis, Casuarina equisetifolia, Acacia auriculiformis, A. nilotica, Albizia lebbek., Eucalyphtus tereticornis, Acacia catechu, and Leacaena leucocephala*. Reductions in stover yields compared with controls were 75.7-97.1% at 0-1.35 m and 0-58.1% at 9.45- 10.8m from the trees.

Puri and Bangarwa (1993) studied wheat yield in agroforestry system. They collected data on crop yield for each tree species at different distances (1,3,5 and 7m) and in 4 directions (east, west, north and south) from the tree bases and control (no trees). The results indicated that *Azadirachta indica* and *Prosopis cineraria* did not make any significant difference to wheat yield. While *Acacia* *nilotica* reduced yield by 4-30%, but reduction was only up to a distance of 3 m. In general, the effect of trees on wheat yield was observed up to 3m distance and there was little effect from 3 to 5 m distances, and almost no effect at 7 m distance. In all the tree species, the wheat yield was reduced to a maximum on the north side of the trees and had almost no effect in the southern direction.

Khan and Ehrenreich (1994) determined the influence of boundary trees of *Acacia nilotica* on the growth and yield of associated wheat *(Triticum aestivum)* crops under irrigated conditions. The results indicated that close proximity to trees adversely affected tillers/m^2 weight/1000 grain and the grain yield of wheat planted up to distance of 8.5 m from the trees. Tree size did not affect wheat height, tillers/ m^2 grains/spike or weight/1000 grains, but grain yields were slightly lower near the largest trees (diameter at breast height 50- 54.9 cm).

For most trees, the depressing effect on the yield of rice crop was extended up to 4 m distance from the tree. There was no adverse effect on crop beyond 4m distance from the trees. Of the total 73 farmers managed trees, the impact on yield was limited up to 2-3m distance for 63 trees and 3-4 m for 33 trees. This impact was rather positive for 22 trees beginning at 2-3m and 13 trees at 3-4m distance from trees. All naturally- growing trees in crop fields had yield depressing effect up to 4m away from the trees (Indrajit, 1997).

Hocking (1997) reported that traditional management of trees in crop fields resulted in 20-50% loss in yield, mainly through competition for light. In Bangladesh, competition for water is important only in the post monsoon season and only in areas where there is no irrigation. Farmers know that tree cause losses of under crops, but they nevertheless raise valuable trees in their fields for compensating tree products.

2.6 Tree crop competition in agroforestry system

Growing of woody perennials with annual crops is an old practice to facilitate easy availability of various products. The continuous removal of nutrients from soil by crops creates deficiency of certain nutrients such as N, P K, Sulphur, Zinc and even Boron. The deficiency of organic matter decreases the soil fertility which causes ultimately low yield of crop (Misra, 2011).

Essentially the underlying processes involved in the partitioning of resources (e.g. light, water and nutrients) are not well understood. A better mechanistic understanding of resource capture and utilization in agroforestry system is required to facilitate the development of improved systems in terms of species combinations, planting arrangement and management (Howard *et al.,* 1995).

Thicker roots, close to the tree stem, help to anchor the plant and they contain transport tissue, while line roots take up water and nutrients. Competition for water and nutrients depends on the relative distribution of fine roots of both trees and crops. Competition is usually more severe if trees are shallow rooted and occupy the same soil layers as food and crops (Nasiruddin *et al.,* 1995). When trees and crops are grown close together, they inevitably compete each other of growth resources (Ong *et al.,* 1992).

2.7 Light and shade on plant growth, development as well as production

The effect of shade is not always a decrease in the yield of the associated crop. Some forage plants (e.g., tall fescue) can, under partial shade (i.e. 50%), produce a total biomass and protein content greater than those observed in full light (Lin *et al.*, 1999). In Ontario, Clinch *et al*. (2009) also observed improved performance of a willow crop under moderate shade compared with the same crop grown in monoculture.

Jayachandran *et al* (1998) conducted studies in Kerala, India and indicated that the coconut (*Cocos nucifera*)-ginger (*Zingiber officinale*) system under rainfed condition gives good returns, because ginger performs well under shade where few other crops do. The yield of ginger under 0, 25, 50 and 75% artificial shade was tested.

Light is an essential factor on plant growth and development. The major light factors affecting plant growth are light quality, light intensity, photoperiod and day/night cycle (Goto, 2003).

Harinder *et al.* (2001) observed that the effect of three species namely eucalyptus *(Eucalyptus tereticomis)*, acacia *(Acacia nitotica*) and poplar *(Populus deltonics)* on the performance of turmeric *(Curcuma longa)* was investigated in Kamal, Haryana, India. The mean germination count of turmeric was maximum when grown in association with acacia and minimum in the control i.e., in open. The mean height attained by turmeric after 90 days was highest under eucalyptus and lowest under poplar. The yield of turmeric was in the order: eucalyptus> control> poplar> acacia.

Ali (1999) conducted that red amaranth and lady's finger could be grown successfully under drumstick tree although 10-15 percent yield was reduced compared to the open field.

Battistelli *et al.* (1998) stated that at low light levels, plant growth rate, leaf area and specific leaf dry weight were reduced and shoot: root ratio was increased compared with plants grown at high levels. CO_2 assimilation rate was higher for plants grown under high light levels. Low light affected photosynthetic light driven reactions, the capacity of Calvin cycle and starch and sucrose synthesis pathways, enabling acclimatization to shade condition and thus promoting survival under shade condition.

Contntto *et al.* (1998) studied the effect of shade (0 or 30%) on growth and photosynthetic parameters of capsicum in Italy and reported that shaded plants exhibited better growth and higher yields than control plants. Fruits from shaded treatments showed better quality than those of control treatments.

Solanki (1998) stated that fruit trees and crops are grown together in various ways. Depending on the pattern and configuration, these companion crops are known as intercrops, under planting, hedgerow planting or alley cropping. In agroforestry systems where agricultural crops are normally grown between rows of fruit trees, the agricultural crops provide seasonal revenue, whereas fruit trees managed for 30-35 years giving regular returns of fruit and in some cases fuel wood from pruned wood and fodder. Several kinds of crops are also under planted to take the advantage of shade provided by the canopy of fruit trees.

Wang and Zhang (1998) conducted an experiment under reduced light by 0, 20, 60 and 80% and reported that stem height was greatest with 80% shading. Stomatal density was greatest without shading.

Miah *et al.* (1995) reported that the mean light availability on crop rows decreased as they approached the tree rows across the alleys. The rate of decrease was greater in unpruned than in pruned alleys. Rice and mungbean yield decreased more in pruned conditions (13 kg/ha) than in unpruned condition (9 kg/ha).

Michon and Mary (1994) said that multistoried village gardens in the vicinity of Bogor, West Java, Indonesia have long been essential multipurpose production system for low-income households. However, they are being subjected to important conversion processes linked to socioeconomic changes presently found in over cowed semi urban zones.

Nair (1993) stated that multispecies tree gardens characterized by a large variety of multipurpose plants in various vegetation layers, which provides for effective utilization of environmental factors like water nutrients and sunlight. He also stated that shade lowers ground surface temperature which may reduce the rate of soil organic matter by oxidation.

According to Ong *et al.* (1991) shading by trees is responsible for poor yields of associated crops. Limiting light is obviously the most important factor that causes poor performance of under storied crops.

Singh (1988) reported that low light (25% of normal sunlight) produced by shading, significantly decreased tuber yields due to reduction in tuber size apparently caused by uses partitioning (harvest index) of the lower biomass production.

Zhong and Kato (1988) observed that decreasing the light intensity decreased dry weight and low light intensity decreased the rate of exudation Shading also decreased the starch and soluble sugar contents of roots.

Reifanyder (1987) reviewed that solar radiation in one of the major constraints' mono-climate and growth agroforestry practice is. Interaction among the trees and sole geometry produce the particular solar climate of a tree/crop system These interaction and effects include interception of radiation by tree stands of various densities, effect of canopy structure, effect of spacing, effect of latitude and time of year on solar paths, shade from single crowns and spectral quality of sunlight under partial shade.

CHAPTER III

MATERIALS AND METHOD

The experiment was carried out to evaluate the responses of chilli in association with drumstick (*Moringa oleifera*) as well as to find out the best tree crop interactions in Agroforestry system. The materials, followed by methodologies and other relevant activities during the experimental period are elaborately presented in this chapter. A brief description on experimental details are presented in this chapter under the following headings.

3.1 Location and time

The experiment was carried out at the Agroforestry Field under the Department of Agroforestry and Environmental Science, Sher-e-Bangla Agricultural University, Dhaka during the period from October 2018 to April 2019. The location of the site is 23°74′N latitude and 90°35′E longitude with an elevation of 8.2 meter from sea level.

3.2 Weather and climate

The experimental site is situated under monsoon climate that is characterized by scanty rainfall during the months of October to April. The rate of annual rainfall, maximum and minimum temperature, relative humidity and other relevant information were collected from Bangladesh Meteorological Department (Dhaka).

3.3 Soil characteristics

The research work was conducted in a high land belonging to the AEZ 28, Madhupur tract (Tejgaon soil series). The structure of the soil was fine with an organic carbon content of 0.45%. The texture was silty clay with a pH of 5.6. The general soil type was non-calcareous dark grey. The experimental area was on medium to high land above the flood level (FAO, 1988).

3.4 Planting materials

In this experiment, a total of 12 established *Moringa oleifera* trees (1 year old) were selected for conducting the research. From each plot, four mother trees were selected and tagged properly. Another plot was selected for control treatment. The seedlings of chilli cv. BARI chilli-2 (30 days old seedlings) were collected from Agriculture Training Institute (ATI), Dhaka-1207.

3.5 Land Preparation

The experimental field preparation was started on 5th October 2018 and all operations were done by spades. Then the land was left fellow for one month. During this time all crop residues and weeds were removed from the land, broken stones and bricks were sorted out and finally 20 cm raised bed was leveled properly for transplanting chilli seedlings.

3.6 Experimental design and treatment combination

Chilli in association of one year old *Moringa* plants were planted following the Randomized Complete Block Design (RCBD). The unit plot size was 1.5 m × 1.5 m. Each of the four treatments was replicated four times. Four treatments which were used in this study are as follows: -

T_1 = 20 cm distance from the tree base

T_2 = 30 cm distance from the tree base

T_3 = 40 cm distance from the tree base

T_4= Open field as control

BLOCK-I		BLOCK-II		BLOCK-III		BLOCK-IV
T_3		T_2		T_4		T_1
T_4		T_1		T_2		T_3
T_2		T_3		T_1		T_4
T_1		T_4		T_3		T_2

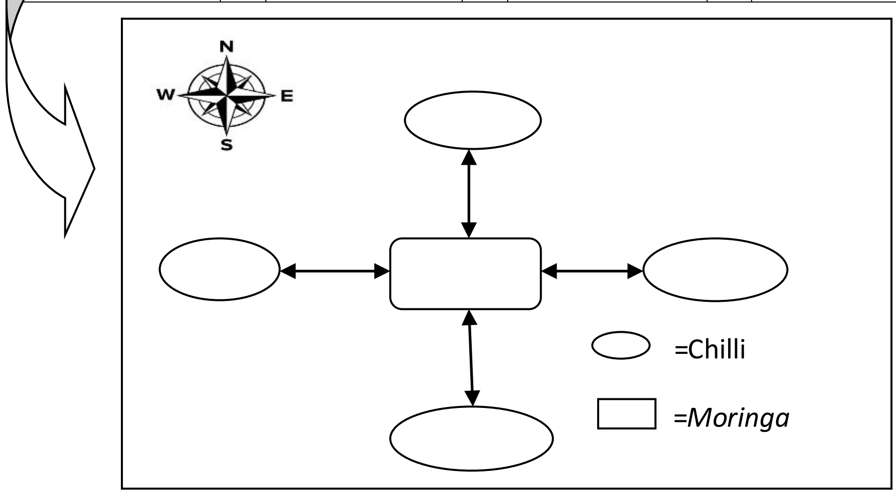

Figure 1: Layout of the Experiment Field

3.7 Chilli transplanting

Thirty (30) days old chilli seedlings were transplanted in the experimental plot on 10 November 2018 according to the treatment assigned.

3.8 Management practices

3.8.1 Fertilizer application

No chemical fertilizers were used for this experiment but only cow dung (20 t ha^{-1}) was applied into the experimental field during final land preparation.

3.8.2 Weeding and irrigation

Weeding was done as and when necessary to keep the field free from weed during the experimental period. To maintain optimum soil moisture all plots were irrigated as and when necessary.

3.8.3 Pest and Disease Management

No pesticide and insecticide were applied as the crops were not infected by any major pest and disease.

3.9 Data collection

Growth and yield data of chilli were collected at different days after transplanting (DAT). Harvesting of chilli was completed at 139 DAT.

The following parameters were collected from chilli during data collection

1. Plant height (cm)
2. Number of branches per plant
3. Days to 1st flowering
4. Days to 1st harvest
5. Days to complete harvest
6. Fruit length (cm)
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)

3.10 Procedure of recording data

3.10.1 Plant Height (cm)

Plant height at different days after transplanting (DAT) was measured from the selected plants in centimeter from the ground level to the tip of the uppermost leaf and the mean value for each treatment was calculated. Plant height was recorded at 30, 60, 75, 100 DAT and at harvest of fruits.

3.10.2 Number of branches per plant

At different days after transplanting (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 plant^{-1} was recorded at 60, 100 DAT and at harvest of fruits.

3.10.3 Days to 1st flowering

The interval between transplanting to first flowering from each replication was calculated and expressed in days.

3.10.4 Days to 1st harvest

The interval between transplanting to first harvest from each replication was calculated and expressed in days.

3.10.5 Days to complete harvest

The interval between transplanting to final harvest of each replication was calculated and expressed in days.

3.10.6 Fruit length (cm)

By using a digital slide calipers fruit length was measured from the neck of the fruit to the tip from ten randomly selected fruits and their average value was taken as the length of the fruit.

3.10.7 Fruit diameter (cm)

By using a digital slide calipers fruit diameter was measured randomly from ten fruits and their average was taken as the diameter of the fruit.

3.10.8 Number of fruits per plant

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

3.10.9 Fruit yield per plant (g)

Total weight of fruits (g) from four selected plants was recorded and yield per plant was calculated.

3.10.10 Individual fruit weight (g)

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

3.10.11 Fruit yield per plot (kg)

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

3.10.12 Fruit yield per ha

It was measured by the following formula:

$$\text{Fruit yield}\left({}^{\text{t}}/_{\text{ha}}\right) = \frac{\text{Fruit yield per plot (kg)} \times 10000}{\text{Area of plot (m}^2\text{)} \times 1000}$$

3.11 Analysis of data

The correlation and relationship in between distance from tree base, growth and yield parameters were regressed by using Microsoft Excell version-2013.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, 2013).

3.12 Modelling of Chilli yield as a function of distance from tree base

The observed yield of chilli in the study were regressed on distance from tree base of the respective plots 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-2013).

3.13 Estimation of chilli yield in the *Moringa* based agroforestry system of different distances from tree base

The expected yield of chilli in the *Moringa* based agroforestry system with different distances from tree base ranging from 10-100cm were computed by using the equations developed for this purpose through regression analysis described above. Then, the expected yield of chilli in the *Moringa* based agroforestry system were computed by using the equation developed for estimating chilli yield as a function of distances from tree base, described earlier.

CHAPTER IV

RESULTS AND DISCUSSION

This chapter deals with tree-crop interactions under *Moringa* based agroforestry system maintaining different chilli plantation distances from *Moringa* tree base during cropping period of chilli. The analytical result of the study was presented and discussed and possible interpretation was given through different Tables and Graphs. The experiment was carried out to study *Moringa* and chilli interactions on the growth, yield and yield contributing characters of chilli. Under the following headings, the results of the experiment are presented and discussed:

4.1 Growth parameters

4.1.1 Plant height (cm)

All the treatments under study showed significant variations in terms of chili plant height at different sampling dates (Figure 2 and Appendix Ill). The plant height in all treatments increased gradually up to final harvest where the initial growth increments were higher than that of the advanced growth stages. The highest plant height was recorded in the plants under T_4 treatment at all sampling dates (12.76, 26.26, 29.1, 36.47 and 44.13 cm at 30, 60, 75, 100 DAT and at harvest, respectively) which was closely followed by the plants under T_3 treatment (40 cm distance from tree base). The least plant height was recorded in T_1 treatment (8.63, 13.72, 14.71, 17.23 and 22.8 cm at 30, 60, 75, 100 DAT and at harvest, respectively) which was only 20 cm away from *Moringa* tree base.

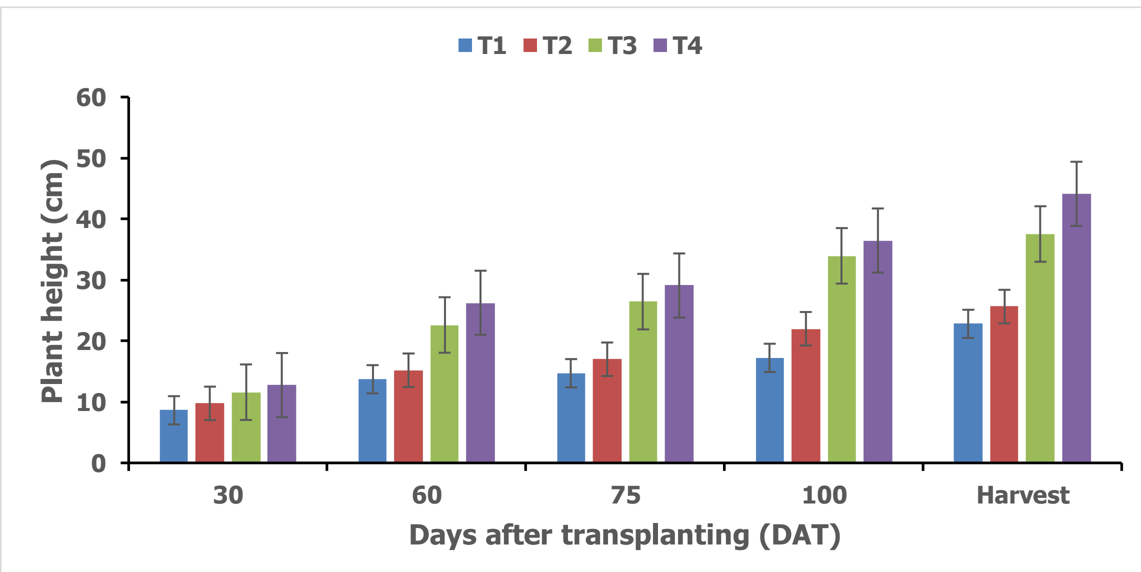

Figure 2: Plant height of chilli as affected by planting distance from *Moringa* plant under agroforestry system

Note: T_1 = 20 cm distance from the tree base, T_2 = 30 cm distance from the tree base, T_3 = 40 cm distance from the tree base, T_4 = Open field plantation considered as control

4.1.2 Number of branches per plant

All the treatments were significantly differed in their branching ability (Figure 3 and Appendix IV). Chilli plants under study started branching very early even before 60 DAT. Chilli belongs to the treatment T_4 and T_3 emerged as the most prolific branch producing plants (5 branch/plant) at 60 DAT. At 100 DAT, the trend was almost similar for all treatments where T_4 produced the highest number of branches/plants. As expectation, at harvest the significantly highest branching (8 branch/plant) was found in plants belong to treatment T_4 followed by T_3 (7 branch/plant). During harvest, only 5 branch/plant were recorded in the plants of treatment T_1 which were 20 cm away from the *Moringa* tree base.

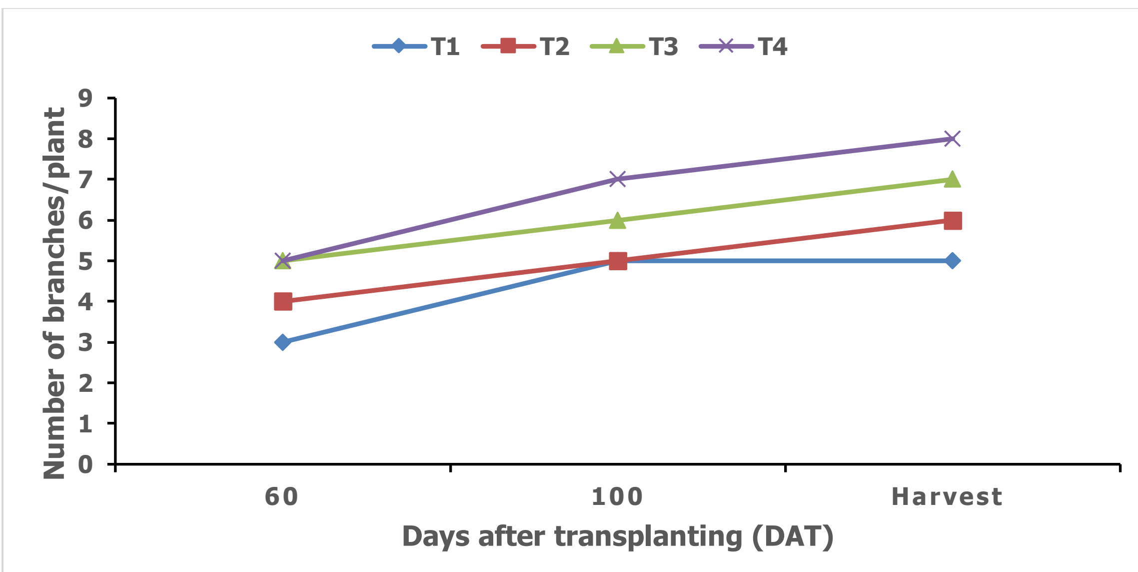

Figure 3: Number of branches per plant of chilli as affected by planting distance from *Moringa* plant under agroforestry system

Note: T_1 = 20 cm distance from the tree base, T_2 = 30 cm distance from the tree base, T_3 = 40 cm distance from the tree base, T_4 = Open field plantation considered as control

4.2 Yield contributing parameters and yield

4.2.1 Days to 1st flowering

Chilli plants studied under different treatments demonstrated a broad range in days required for 1st flowering of chilli (Table 1 and Appendix V). First flowering duration of the plants in this study ranged from 45 to 56 days. The minimum days to 1st flowering (45 days) was recorded in T_4 (open field plantation considered as control) treatment which was statistically identical with T_3 (40 cm distance from the tree base). Chilli plants grown in control condition took less than 11 days for 1st flowering of the plants grown under T_1 treatment.

4.2.2 Days to 1st harvest

Plants belongs to different treatments revealed a broad range in days required for 1st harvest (Table 1 and Appendix V). It was observed that the highest days to 1st harvest (85 days) was required for plants under T_1 treatment (20 cm away from the tree base) which was significantly different from other treatments whereas the lowest days to 1st harvest (74 days) was needed for T_4 (open field referred to as control) treatment which was significantly lower from other treatments. Under tree crop association, the lowest days to 1st harvest (77 days) was required for T_3 (40 cm distance from the tree base) treatment.

4.2.3 Days to complete harvest

Different treatments under *Moringa* based agroforestry system demonstrated significant variation on days to complete harvest of chilli (Table 1 and Appendix V). In this study growth duration of chilli plants under different treatments ranged from 117 to 139 days. Plants under treatment T_1 took less than 22 days to complete chilli harvesting. The highest duration (139 days) to complete chilli harvesting was recorded in plants under control treatment (T_4) whereas the least days to complete harvesting (117 days) was observed in T_1 (20 cm distance from the tree base) treatment which was significantly different from other treatments. Regarding the treatment under chilli and *Moringa* interaction, the highest duration to complete harvest was recorded in T_3 (40 cm distance from the tree base) treatment followed by T_2 (20 cm distance from the tree base) and T_1 (30 cm distance from the tree base) treatments, respectively.

Table 1: Days to 1st flowering, days to 1st harvest and days to complete harvest of chilli as affected by planting distance from *Moringa* plant under agroforestry system

Treatments	**Yield contributing parameters of chilli**		
	Days to 1st flowering	**Days to 1st harvest**	**Days to complete harvest**
T_1	56 a	85 a	117 d
T_2	51 b	81 b	126 c
T_3	48 c	77 c	135 b
T_4	45 d	74 d	139 a
$LSD_{0.01}$	3.30	2.21	2.99
CV (%)	3.34	1.40	1.16
Significance level	**	**	**

Note: T_1 = 20 cm distance from the tree base, T_2 = 30 cm distance from the tree base, T_3 = 40 cm distance from the tree base, T_4 = Open field plantation considered as control

4.2.4 Fruit length (cm)

Chilli fruit length significantly differed in between different treatments in *Moringa* based Agroforestry system (Table 2 and Appendix VI). Among the different treatments, the highest fruit length (6.65 cm) was recorded in open field condition (T_4) which (6.48 cm) was statistically at par with the plants grown under T_3 (40 cm distance from the tree base) treatment. Comparing the treatments of tree crop association, T_3 (40 cm distance from the tree base) produced the longest fruit (6.48 cm) and the least fruit length (5.18 cm) was found in T_1 (20 cm distance from the tree base) treatment.

4.2.5 Fruit diameter (cm)

Statistically significant differences were not found on fruit diameter due to varied distance of chilli plot from *Moringa* tree base (Table 2 and Appendix VI). However, the highest fruit diameter (0.96 cm) was recorded in T_4 (open field plantation considered as control) treatment, closely followed by fruits in T_3 treatment whereas the least fruit diameter (0.82 cm) was recorded in T_1 (20 cm distance from the tree base) treatment.

4.2.6 Number of fruits per plant

Chilli plantation with or without interaction of *Moringa* tree showed significant influence on number of fruits per plant of chilli (Table 2 and Appendix VI). The highest number of fruits per plant (307) was recorded in T_4 (open field plantation considered as control) treatment but under agroforestry practice (*Moringa*-chilli interaction), the treatment T_3 (40 cm distance from the tree base) showed highest number of fruits per plant (268) compared to T_1 (20 cm distance from the tree base) and T_2 (30 cm distance from the tree base). The lowest number of fruits per plant (183) was recorded in T_1 (20 cm distance from the tree base) treatment which was (40.40%) lower than T_4 (open field plantation considered as control) and 31.72% lower than T_3 (40 cm distance from the tree base) treatment.

4.2.7 Fruit weight per plant (g)

Different plantation distances of chilli from tree base of *Moringa* showed significant variation on fruit weight per plant of chilli (Table 2 and Appendix VI). Results indicated that the highest fruit weight per plant (565.58 g) was recorded from without tree crop interaction i.e., control treatment T_4 (open field condition). But under tree crop interaction, the highest fruit weight per plant (465.46 g) was recorded from T_3 (40 cm distance from the tree base) treatment which was 2nd highest among the treatments. The lowest fruit weight per plant (291.85 g) was recorded in T_1 (20 cm distance from the tree base) treatment which was 49.18% lower than control treatment and 37.30% lower than T_3 (40 cm distance from the tree base) treatment.

4.2.8 Single fruit weight (g)

Significant variation was observed on single fruit weight due to varied distance of chilli plant from the base of *Moringa* tree (Table 2 and Appendix VI). The highest single fruit weight (1.84 g) was recorded in T_4 (open field plantation considered as control) treatment whereas the lowest single fruit weight (1.65 g) was recorded in T_1 (20 cm distance from the tree base) which was statistically same with T_2 (30 cm distance from the tree base) treatment.

4.2.9 Fruit yield per plot (kg)

Fruit yield plot^{-1} among the different treatments was statistically significant due to different distance of chilli plantation from *Moringa* tree (Table 2 and Appendix VI). The highest fruit yield plot^{-1} (2.31 kg) was recorded in T_4 (open field plantation considered as control) treatment. Under agroforestry practice (tree crop interaction), the best fruit yield plot^{-1} was found in T_3 (40 cm distance from the tree base) treatment and it was 2nd highest among the treatments. The lowest fruit yield plot^{-1} (1.16 kg) was recorded in plants under T_1 (20 cm distance from the tree base) treatment which was 49.78% lower than control treatment and 36.26% lower than T_3 (40 cm distance from the tree base) treatment.

4.2.10 Fruit yield per ha (t)

Fruit yield per ha was significantly varied among the different treatments due to different distance of chilli plantation from *Moringa* tree (Table 2 and Appendix VI). The highest fruit yield (10.29 t/ha) was recorded in T_4 (open field plantation considered as control) treatment i.e., non agroforestry practice. But under agroforestry practice (tree crop interaction), the best fruit yield (8.15 t/ha) was found in T_3 (40 cm distance from the tree base) treatment which was the 2nd highest among the treatments and 20.80% lower than control treatment. The lowest fruit yield (5.15 t per ha) was recorded in T_1 (20 cm distance from the tree base) treatment which was 49.95% lower than control treatment and 36.81% lower than T_3 (40 cm distance from the tree base) treatment.

Table 2: Yield contributing parameters and yield of chilli as affected by planting distance from *Moringa* plant under agroforestry system

Treatments	Yield contributing parameters and yield						
	Fruit length (cm)	**Fruit diameter (cm)**	**Number of fruits plant^{-1}**	**Fruit weight per plant (g)**	**Single fruit weight (g)**	**Fruit yield plot^{-1} (kg)**	**Fruit yield per ha (t)**
T_1	5.18 c	0.82	183 d	291.85 d	1.59 c	1.16 d	5.15 d
T_2	6.05 b	0.86	239 c	391.21 c	1.64 c	1.57 c	6.95 c
T_3	6.48 a	0.92	268 b	465.46 b	1.74 b	1.82 b	8.15 b
T_4	6.65 a	0.96	307 a	565.58 a	1.84 a	2.31 a	10.29 a
$LSD_{0.01}$	0.43	0.16	10.23	19.27	0.09	0.11	0.43
CV (%)	3.51	0.80	2.05	2.25	2.70	3.19	2.85
Significance level	**	NS	**	**	**	**	**

Note: T_1 = 20 cm distance from the tree base, T_2 = 30 cm distance from the tree base, T_3 = 40 cm distance from the tree base, T_4 = Open field plantation considered as control

4.3 Relationship between different planting distances and the growth and yield parameters of chilli

Analyzed data showed strong positive correlation in between different planting distances from *Moringa* tree base with the growth parameters and yield of chilli. Plant height had highly significant and strong positive correlation with number of branch (0.977) of chilli. Number of branch had shown highly significant and strong positive correlation with fruit yield (0.995). Fruit yield had shown highly significant and strong positive correlation with single fruit weight (0.985) (Table 3).

Table 3: Correlation between different planting distances from tree base and various growth and yield parameters of chilli grown in association with *Moringa*

	Distance	**PLH**	**NB**	**FWP**	**SFW**	**FY**
Distance	1					
PLH	0.887**	1				
NB	0.898**	0.977**	1			
FWP	0.908**	0.965**	0.998**	1		
SFW	0.931**	0.992**	0.990**	0.985**	1	
FY	0.928**	0.959**	0.995**	0.998**	0.985**	1

Note: PLH: Plant height; NB: Number of branches; FWP: Fruit weight per plant; SFW: Single fruit weight and FY: Fruit yield per ha.

4.3.1 Relationship between planting distances and plant height of chilli

Significant relationship was found in between planting distances from *Moringa* tree base and plant height of chilli (Figure 4). Results showed that plant height increased gradually with increasing planting distance from *Moringa* tree base. A positive polynomial relationship was observed between them. The equation under the correlation between planting distances and plant height were

$$Y = -0.0071X^2 + 1.1369X + 1.3789$$

Where, the coefficient of determination, $R^2 = 0.9389$ which indicates a good fit around the observed data points.

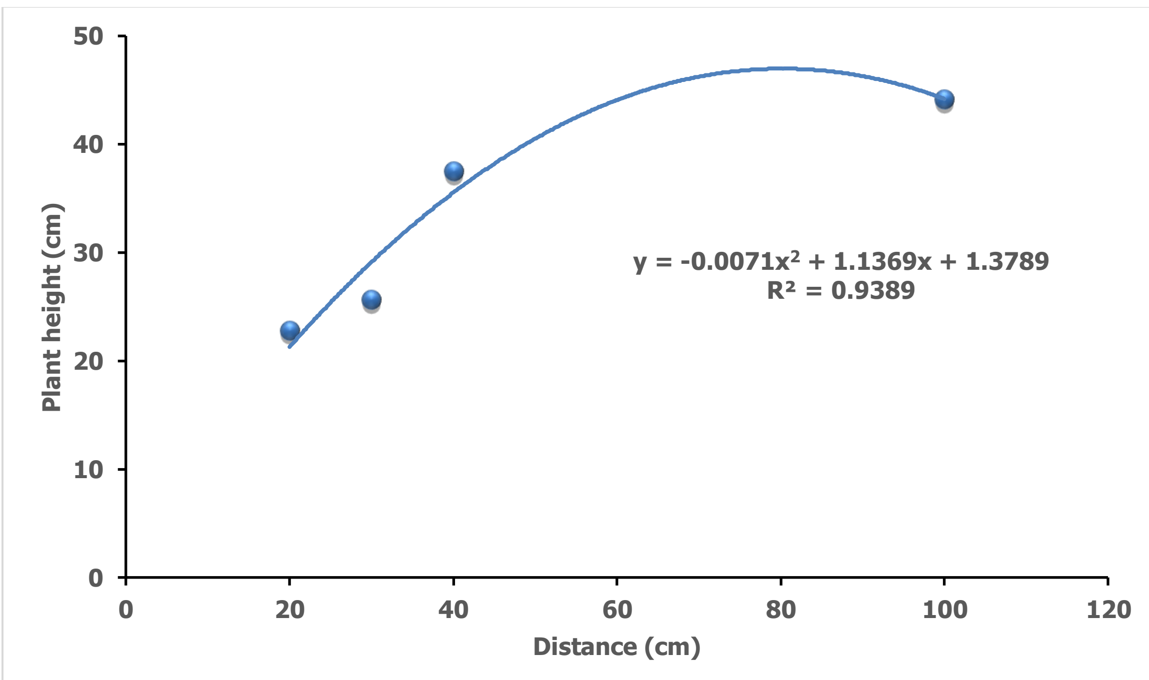

Figure 4: Relationship between different planting distances and plant height of chilli

4.3.2 Relationship between planting distances and number of branches per plant of chilli

Results showed that number of branches in chilli plant increased with increasing planting distance of chilli plot from *Moringa* tree base. A quadratic relationship was observed between them (Figure 5). The equation under the regression analysis in between planting distances and number of branches per plant were

$$Y= -0.001X^2 + 0.1611X + 2.1586$$

Where, the value of the coefficient of determination, $R^2 = 0.9986$ which indicates 99.86% of the total variations could be explained by using the regression equation to predict the number of branches in chilli plants due to distance from *Moringa* tree base.

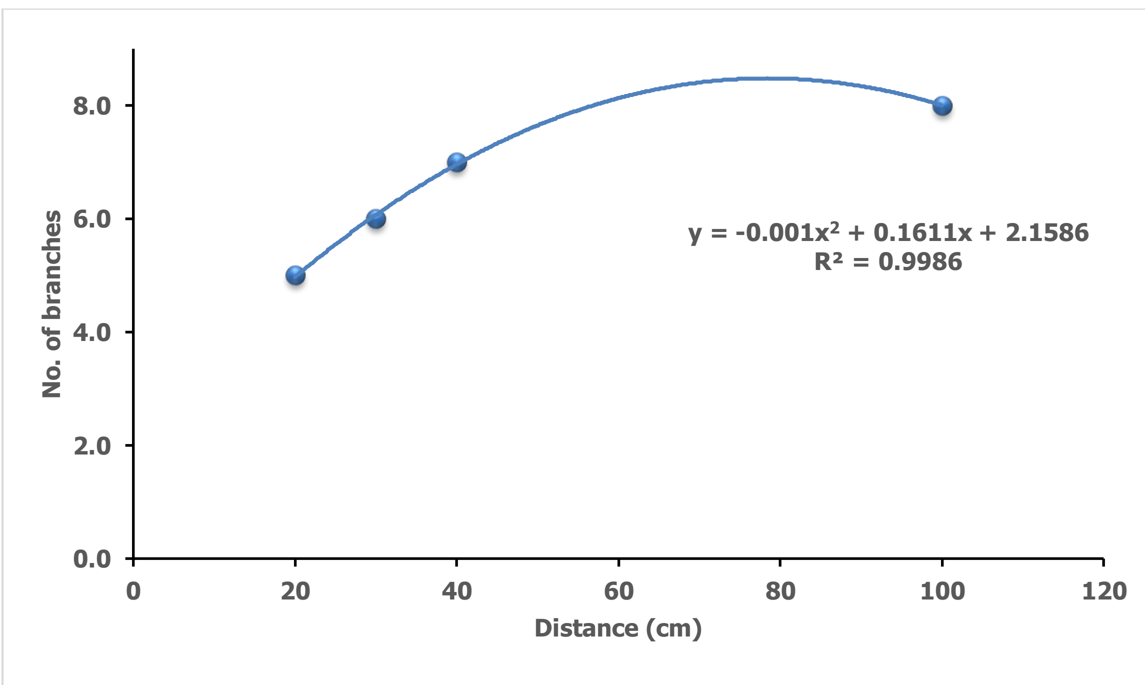

Figure 5: Relationship between different planting distances and number of branches per plant of chilli

4.3.3 Relationship between planting distances and fruit weight per plant of chilli

Significant relationship between planting distances of *Moringa*-chilli and fruit weight per plant of chilli was found (Figure 6). Results revealed that fruit weight per plant increased initially with increasing planting distance of chilli plot from *Moringa* tree base up to certain distance and thereafter decline. The equation of the regression analysis in between planting distances and fruit weight per plant were

$$Y = 48.414 + 13.99X - 0.0882X^2$$

Where, the value of the coefficient of determination, $R^2 = 0.9998$ which indicated a good fit of the estimated regression line around observed data points.

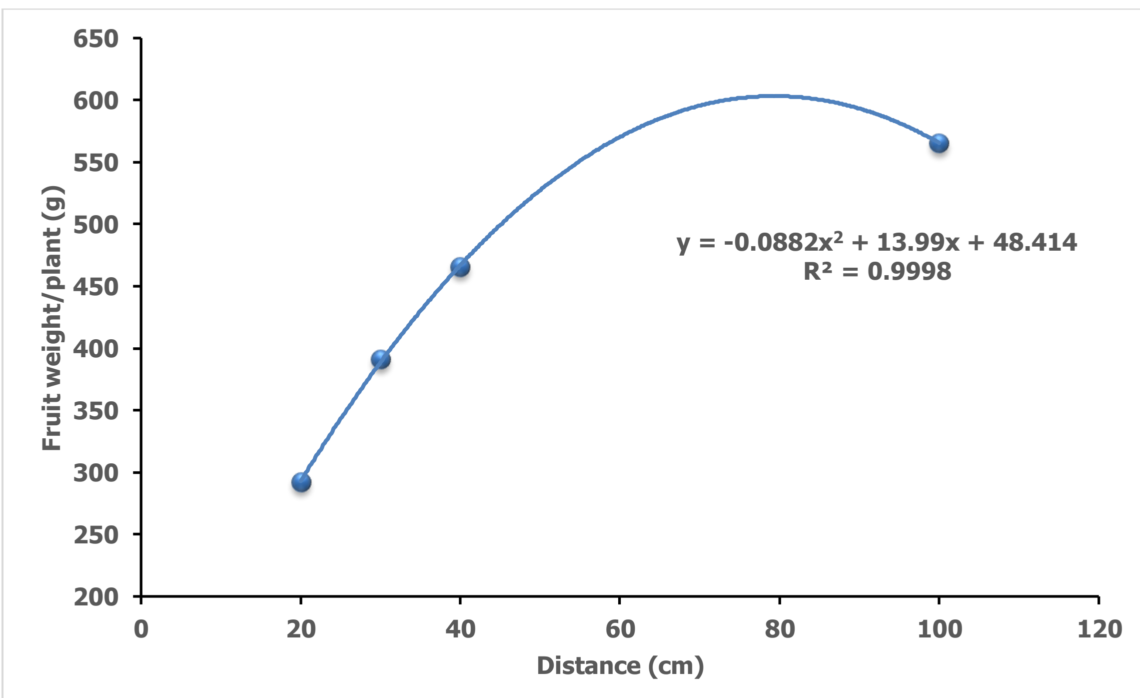

Figure 6: Relationship between different planting distances and fruit weight per plant of chilli

4.3.4 Relationship between planting distances and single fruit weight (g) of chilli

Significant relationship was found between planting distances of *Moringa*-chilli and single fruit weight of chilli (Figure 7). As expectation, results revealed that single fruit weight increased with increasing planting distance of chilli plot from *Moringa* tree base up to a certain point thereafter declined. The equation of the relationship between planting distances and single fruit weight were

$$Y = 1.3792 + 0.0114X - 7E\text{-}05X^2$$

Where, the value of the coefficient of determination, $R^2 = 0.9815$ which indicated a good fit regression line around the observed values.

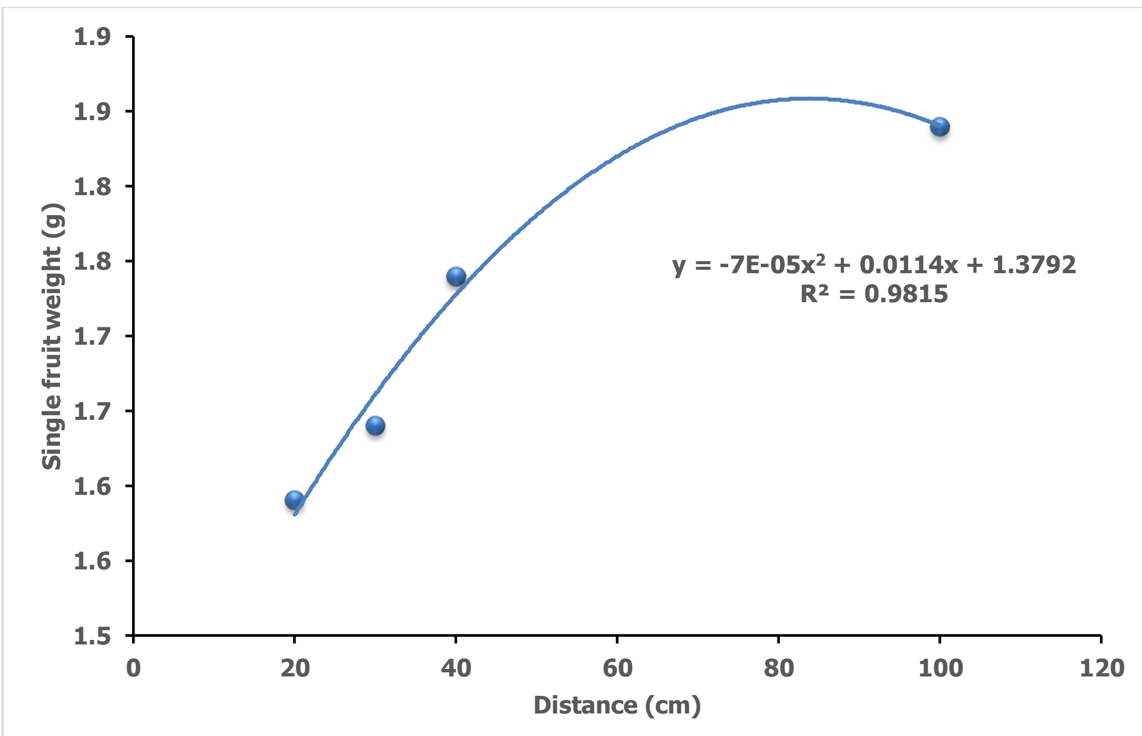

Figure 7: Relationship between different planting distances and single fruit weight (g) of chilli

4.3.5 Relationship between planting distances and fruit yield of chilli (t/ha)

Figure 8 depicted that fruit of chilli increased with increasing planting distance of chilli plot from *Moringa* tree base. A polynomial relationship was observed between them (Figure 8). The equation of the regression analysis between planting distances and chilli yield were

$$Y = 1.0188 + 0.2378X - 0.0015X^2$$

Where, the value of the coefficient of determination, $R^2 = 0.9988$ which was a good fit line around the observed chilli yield.

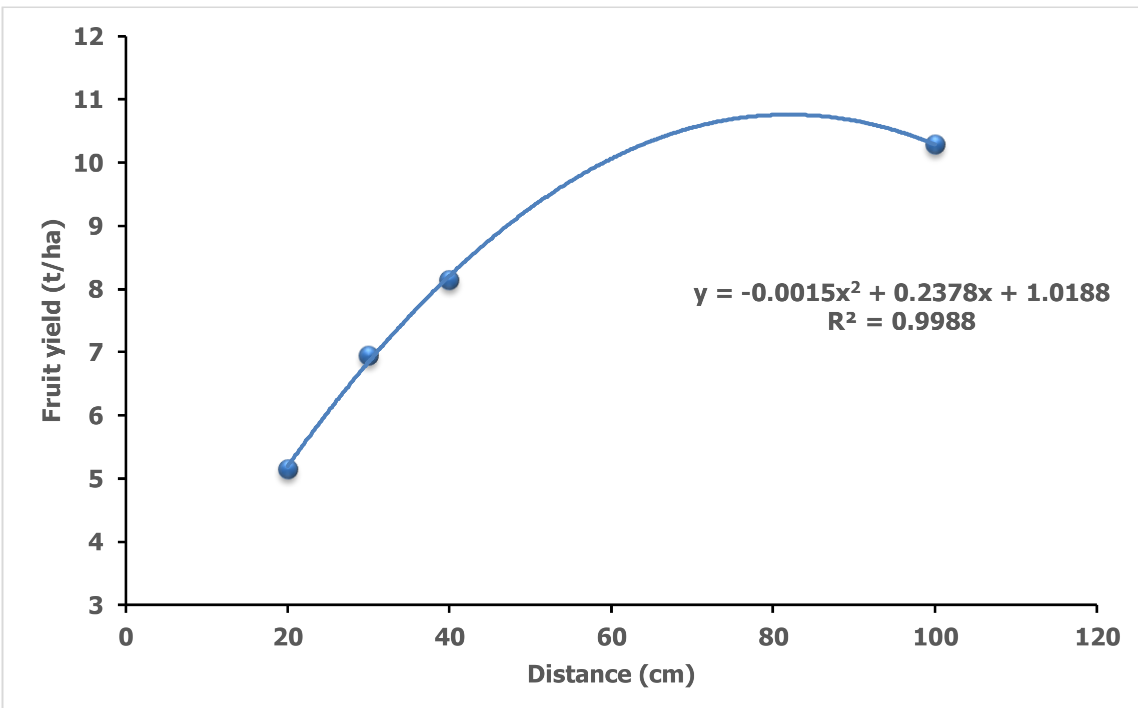

Figure 8: Relationship between different planting distances and fruit yield (t/ha) of chilli

4.3.6 Estimated chilli yield as a function of the distance from *Moringa* tree base

The estimated yields of chilli in *Moringa* based Agroforestry system derived by using the developed model are presented in Figure 9. The Figure 9 showed that estimated chilli yield increased with increasing planting distance from *Moringa* tree base and thereafter declined with further increase in planting distance. The estimated equation of the quadratic relationship between planting distances from *Moringa* tree base and chilli yield was

$$Y = 1.0188 + 0.2378X - 0.0015X^2$$

The estimated model depicted that optimum distance in between *Moringa* tree base and chilli plot would be 80 cm where predicted chilli yield was approximately 10.44 ton/ha.

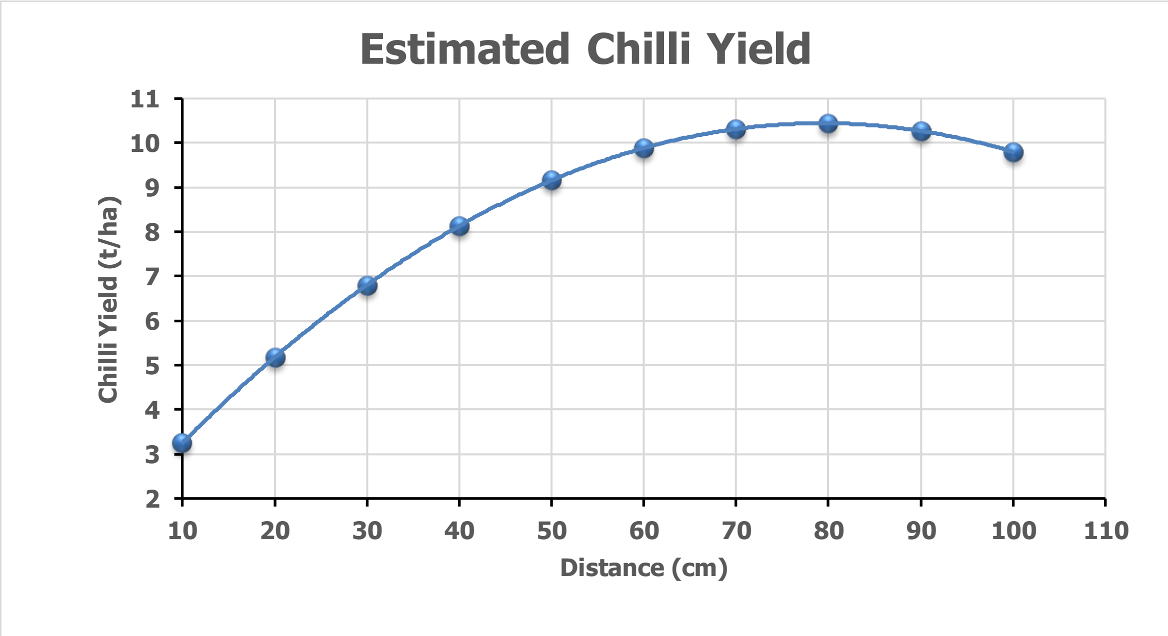

Figure 9. Estimated chilli yield as a function of the distance from tree base in a *Moringa* based Agroforestry system

DISCUSSION

The result obtained from the treatments evaluated in this study showed dissimilarities in yield contributing characters of Chilli. None of the treatments in association with *Moringa* performed better than T_4 treatment which was cultivated in open field without any interaction of *Moringa* tree. Chilli under T_3 treatment (40 cm away from *Moringa*) showed better result than the other agroforestry treatments. Association of *Moringa* with Chilli was responsible for yield loss of Chilli. Such low yield could be due to declining soil fertility (Batino, 2007).

Competition among *Moringa* and Chilli for resources (light, water and nutrients) was also reflected in the result. Closer spacing between *Moringa* and Chilli caused higher competition for resources resulting least yield. Similar observation was found by Bayala (2002). Trenbath (1974) also found greater yield in monoculture than agroforestry systems.

Belowground competition for nutrients and water was a major determinant of the performance of Chilli growing under *Moringa* tree. This competition can be minimized at a significant level by applying fertilizer and irrigation and crop performance can potentially be improved (Bayala, 2004).

Sunlight intercepted by *Moringa* canopy was seem to be responsible for reduced yield of Chilli. Other studies have also found that shading by trees can reduce crop yields by 50 to 70% (Bayala, 2002).

Photosynthetically active radiation (PAR) is considered as another important limiting factor for yield loss of Chilli. Shading used to impede photosynthetic capacity of plants resulting reduced accumulation of photosynthates. Our findings also corrobated by Miah (2008).

In this study the degree of competition was varied by maintaining different distances between *Moringa* and Chilli. The regression analysis showed that 80 cm distance was optimum for minimizing these competitions and resulting approximately 10.44 ton/ha Chilli yield.

CHAPTER V

SUMMARY AND CONCLUSION

The experiment was carried out at the Agroforestry Farm of Sher-e-Bangla Agricultural University (SAU), Dhaka-1207 during the period from October 2018 to March 2019 to evaluate the performance of chilli during the early establishment period of *Moringa* plantation. Chilli was grown under two different levels with four treatments *viz*. (i) T_1 (20 cm distance from the tree base), (ii) T_2 (30cm distance from the tree base), (iii) T_3 (40 cm distance from the tree base), and (iv) T_4 (open field considered as control), by following the Randomized Complete Block Design (RCBD). Each treatment was replicated four times, and thus as a total of 16 unit of plots having 1.5 m × 1.5 m sized were in the experimental plot. The seedlings of chilli (var. BARI chilli-2) were transplanted at 15 October 2018. Data on the selected parameters were collected from randomly selected plants of each plot and analyzed and means were compared by LSD test at 0.05 and 0.01 levels of significance. Data were collected on plant height, number of branches plant^{-1}, days to 1st flowering, days to 1st harvest, days to complete harvest, fruit length, fruit diameter, number of fruits plant^{-1}, fruit weight plant^{-1}, single fruit weight, fruit yield plot^{-1} and fruit yield ha^{-1}.

Recorded data on different growth, yield attributing characters and yield were higher in control treatment (T_4) compared to agroforestry treatments where plants were grown at different distances from tree base. The significant variations were found on all the parameters tested except fruit diameter. Results revealed that the highest plant height (44.13 cm) was observed in T_4 (open field considered as control) treatment but under agroforestry practice, the 2nd highest plant height (37.54 cm) was found in T_3 (40 cm distance from the tree base) treatment whereas the lowest plant height (22.8 cm) was recorded in T_1 (20 cm distance from the tree base) treatment.

Again, the maximum number of branches plant^{-1} (8) was observed in the T_4 (open field plantation considered as control), Among the agroforestry treatments, the highest number branches plant^{-1}, (7) was recorded in T_3 (40 cm distance from the tree base) treatment whereas the lowest number of branches plant^{-1} (5) was recorded in T_1 treatment.

Regarding days to 1st flowering and days to 1st harvest, the lowest (45 and 74 days, respectively) was recorded from control treatment T_4 but under tree crop interaction (agroforestry practice), the lower days to 1st flowering and days to 1st harvest, (48 and 77 days, respectively) was found from T_3 (40 cm distance from the tree base) whereas the highest days to 1st flowering and days to 1st harvest (56 and 85 days, respectively) was found from T_1 (20 cm distance from the tree base) treatment. In terms of days to complete harvest, the highest result (139 days) was found in T_4 (open field considered as control) treatment followed by T_3 treatment (135 days) whereas the lowest days to complete harvest (117 days) was found from T_1 (20 cm distance from the tree base) treatment.

Considering, the highest result in respect of fruit length, fruit diameter, number of fruits plant^{-1}, fruit weight plant^{-1}, single fruit weight, fruit yield plot^{-1} and fruit yield ha^{-1}; (6.65 cm, 0.96 cm, 307, 565.58 g, 1.84 g, 2.31 kg and 10.29 t, respectively) were found in open field condition (T_4 treatment). But under agroforestry practice, the highest fruit length, fruit diameter, number of fruits plant^{-1}, fruit weight plant^{-1}, single fruit weight, fruit yield plot^{-1} and fruit yield ha^{-1} (6.48 cm, 0.92 cm, 268, 465.46 g, 1.74 g, 1.82 kg and 8.15 t, respectively) were found in T_3 (40 cm distance from the tree base) treatment whereas the lowest (5.18 cm, 0.82 cm, 183, 291.85 g, 1.59 g, 1.16 kg and 5.15 t, respectively) were found in T_1 (20 cm distance from the tree base) treatment. Here it can also be mentioned that fruit yield ha^{-1} from T_3 treatment was 20.80% lower than T_4 (control) treatment and yield from T_1 (20 cm distance from the tree base) was 49.95% lower than control treatment and 36.81% lower than T_3 treatment. According to regression analysis 80 cm distance was optimum for minimizing competition and resulting approximately 10.44 ton/ha Chilli yield.

Conclusion:

So, from the above findings, it can be concluded that there were significant variations among different treatments in terms of growth, yield parameters and yield of chilli. The treatment under open field condition (without tree crop interaction, T_4) exhibited the highest results in respect of growth, yield parameters and yield of chilli but under tree crop interaction, the best results were found from T_3 (40 cm distance from the tree base) treatment compared to T_1 (20 cm distance from the tree base) and T_2 (30 cm distance from the tree base) treatments. So, it can be acknowledged that chilli is a suitable crop in association of *Moringa* tree as an agroforestry practice. Correlation and regression analysis revealed that 80 cm was optimum for Chilli-*Moringa* intercropping and resulting approximately 10.44 ton/ha Chilli yield. The aim of the study was to evaluate the tree-crop interactions between *Moringa* and chilli. The results of the experiment signified that there were negative tree-crop interactions in respect of different planting distances i.e., increased interaction of *Moringa* and chilli decreases growth and yield of chilli when *Moringa* tree were at their early stage of establishment.

Recommendations:

To construct a final ending, repeated trails of chilli should be conducted in association with *Moringa* with different ages and planting densities. These interactions should also be in consideration of different environmental factors (air temperature, rainfall, relative humidity, sunshine hour etc.), soil, plant nutrient status and water availability, hence study should be repeated in different Agro-ecological zones. Some other vegetable crops should also be intercropped with *Moringa* to justify the present findings.

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APPENDICES

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

Year	Month	Air temperature (°C)			Relative humidity (%)	Rainfall (mm)
		Max	*Min*	*Mean*		
2018	October	30.10	27.10	28.6	53.55	15.3
2018	November	29.5	22.4	25.95	49.01	4.9
2018	December	26.7	18.05	22.38	42.25	0.0
2019	January	23.80	11.70	17.75	46.20	0.0
2019	February	22.75	14.26	18.51	37.90	0.0
2019	March	35.20	21.00	28.10	52.44	20.4

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	Agronomy Farm, SAU, Dhaka
AEZ	Madhupur 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: Soil Resource Development Institute (SRDI)

Appendix III. Mean square of plant height of chilli at different days after transplanting (DAT)

Sources of variation	Degrees of freedom	Mean square of plant height				
		30 DAT	60 DAT	75 DAT	100 DAT	Harvest
Replication	2	0.10	0.25	0.10	0.35	1.03
Factor A	3	10.24**	107.23**	148.14**	258.06**	301.92**
Error	6	0.16	0.40	0.82	1.31	1.28

NS = Non-significant * = Significant at 5% level ** = Significant at 1% level

Appendix IV. Mean square of Number of branches plant^{-1} of chilli at different days after transplanting (DAT)

Sources of variation	Degrees of freedom	Mean square of number of branches plant^{-1}		
		60 DAT	100 DAT	Harvest
Replication	2	0.08	0.08	0.25
Factor A	3	2.08**	2.75**	4.08**
Error	6	0.08	0.08	0.25

NS = Non-significant * = Significant at 5% level ** = Significant at 1% level

Appendix V. Mean square of Days to 1st flowering, days to 1st harvest and days to complete harvest of chilli

Sources of variation	Degrees of freedom	Mean square of yield contributing parameters of chilli		
		Days to 1st flowering	Days to 1st harvest	Days to complete harvest
Replication	2	0.33	2.33	0.58
Factor A	3	63.44**	64.97**	296.75**
Error	6	2.78	1.22	2.25

NS = Non-significant * = Significant at 5% level   ** = Significant at 1% level

Appendix VI. Mean square of Yield contributing parameters and yield of chilli

Sources of variation	Degrees of freedom	Mean square of yield contributing parameters and yield						
		Fruit length	Fruit diameter	Number of fruits plant^{-1}	Fruit weight plant^{-1}	Single fruit weight	Fruit yield plot^{-1}	Fruit yield ha^{-1}
Replication	2	0.08	0.0004	10.3	73	0.0004	0.002	0.03
Factor A	3	1.3**	0.01**	8085.9**	40223**	0.04**	0.70**	13.93**
Error	6	0.05	0.0006	26.2	93	0.002	0.003	0.05

NS = Non-significant * = Significant at 5% level   ** = Significant at 1% level

Appendix VII. Some pictorial presentation of the experiment

Plate 1. Field preparation

Plate 2. Seedling transplanting and irrigation

Plate 3. Reproductive stages of chilli