TREE-CROP INTERACTIONS DURING THE EARLY ESTABLISHMENT PERIOD OF MORINGA PLANTATION

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CERTIFICATE

This is to certify that the thesis entitled, **“TREE-CROP INTERACTIONS DURING THE EARLY ESTABLISHMENT PERIOD OF MORINGA PLANTAION”** submitted to the faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka in partial fulfillment of the degree of **MASTER OF SCIENCE IN AGROFORESTRY AND ENVIRONMENTAL SCIENCE** embodies the result of a piece of bona fide research work carried out by **ARIF AHMED**, Registration No. 12-05081 under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma in any other institutes.

I further certify that any help or sources of information, as have been availed during the course of this investigation have duly been acknowledged.

Dated:
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DEDICATED TO MY BELOVED PARENTS
AND TEACHERS WHO LAID THE
FOUNDATION OF MY SUCCESS

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TREE-CROP INTERACTIONS DURING THE EARLY ESTABLISHMENT PERIOD OF MORINGA PLANTATION

ABSTRACT

An experiment was conducted in Agroforestry Field Laboratory at Sher-e-Bangla Agricultural University, Dhaka to find out the effect of planting distances on growth, yield and yield attributing characters of stem amaranth (*Amaranthus oleraceus*) during the early establishment period of Moringa (*Moringa oliaferae*) trees. The growth of Moringa as influenced by management practices was also determined. The study was conducted during the period from January to April, 2018 by following Randomized Complete Block Design (RCBD) comprising of four treatments with four replications. Four treatments were T_0 (open field condition as control), T_1 (6 inches distance from tree base), T_2 (12 inches distance from tree base), T_3 (18 inches distance from tree base). Significant variations were observed in respect of all characters at different days after sowing (DAS) with different planting distances. At harvest (50DAS), the maximum plant height of stem amaranth (59 cm), number of leaf per plant (25 cm) was recorded in control condition (T_0 treatment) and minimum plant height (49 cm), number of leaf per plant (20) was recorded in T_3 treatment. The highest leaf length (10 cm) and leaf breadth (5 cm), stem girth (6 cm), stem length (61 cm), root length(16 cm), shoot and root fresh weight (74 g and 16 g), shoot and root dry weight(4 g and root 1 g) and green yield (14 t/ha) were observed in open field condition (T_0 treatment). The yield was reduced by 15% in T_1 treatment (12 t/ha) compared to open field condition. The fresh yield of stem amaranth under T_2 (10 t/ha) and T_3 (10 t/ha) treatment with association of Moringa was recorded 26 % lower than the plants which were grown under control condition (T_0 treatment). The growth characters of *M. oliaferae* were also enhanced in association with stem amaranth. At harvest of stem amaranth, maximum bud length(8cm) and bud number (4) of Moringa sapling were also recorded in T_1 treatment thus showing its potential to be used in Moringa based agroforestry farming system in large-scale.

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ABBREVIATIONS

% = Percent

@ = At the rate

^{0}C = Degree centigrade

BARI = Bangladesh Agricultural Research Institute

BAU = Bangladesh Agricultural University

BBS = Bangladesh Bureau of Statistics

Var. = Variety

DAS = Days After Sowing

MAP = Months After Planting

e.g. = For example

et al. = And others

etc. = Etcetera

g = Gram

i.e. = That is

Kg = Kilogram

LSD = Least Significant Difference

SAU = Sher-e-Bangla Agricultural University

T = Treatment

FAO = Food and Agricultural Organization

CHAPTER I

INTRODUCTION

Bangladesh is one of the most densely populated countries in the world with its limited natural resources. The current population of Bangladesh is 165.8 million (BBS, 2018) that is equivalent to 2.18% of the total world population. The country has a land area of only 14.39 million hectares, but due to the ever increasing population, per capita land area is decreasing at an average rate of 0.005 ha/ year since 1989 (Hossain and Bari, 1996). The soil, crop and forestry are the most important natural resources which have diversified impact on all sectors of society. To maintain the environmental equilibrium and rate of socio-economic development at least 25% area of a country should be covered with forest. In Bangladesh the total forest area covers about 17% of the land area (BBS, 2010) but the actual tree covered area is estimated at around 9.4% which is decreasing at an alarming rate (Hossain and Bari, 1996).

The forest ecosystem has been modified by human interference, especially by the transformation into other land uses. Exponentially increasing use and dependence on forest goods and services by the fast growing population are the main problems. Again the demand of food crops in Bangladesh is increasing rapidly due to ever increasing population. Due to intensive cropping and use of high input technologies the fertility of lands is decreasing. So, the primary challenge for forest and natural resource management is finding ways to continue to produce ecological services.

It’s clear that the country has no scope to expand forest and crop areas. So, combined production system integrating trees and crops together has to be developed. In these circumstances, the practice of agroforestry is an authentic solution. Agroforestry, the integration of tree and crops or vegetables on the same area of land is a promising production system for maximizing yield and maintaining friendly environment (Nair, 1990). Bangladesh has a long tradition of agroforestry practice. But management has always been extremely poor. Selection of plants, planting techniques, and also their utilization in most cases is poorly done, although the country is mostly dependent on farming system grown in and around human habitats. Because of the increasing population, quick urbanization, and other forms of development efforts, the agroforestry practices are being emphasized.

It is assumed 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 is not sufficient. 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.

Amaranth is a common vegetable in Bangladesh. In early summer, the availability of vegetable is limited. In that period amaranth can partially overcome this limited condition. Amaranth leaves are high in protein, b-carotene, iron, calcium, vitamin C, and folic acid (Achigan-Dako *et al.*, 2014). Vegetable amaranth (*Amaranthus cruentus*) is a good source of minerals, vitamins, phenolics, and carotenoids; it also contains betalains, a nitrogen containing group of natural pigments, as well as proteins and fibers (Repo-Carrasco-Valencia; Hellstrom et al., 2010; Venskutonis and Kraujalis, 2013). Amaranths are often described as drought tolerant plants (Liu and Stutzel, 2002; Hura *et al.*, 2007).

In Bangladesh, Moringa is a common tree growing mainly in homestead areas (Padulosi *et al.*, 2013; Rudebjer *et al.*, 2013). Moringa is a multipurpose vegetable tree with a variety of potential uses, of which the nutritional and medicinal properties are initially considered the most interesting. In total there are 13 species in the genus Moringa, belonging to the family Moringaceae, of which *Moringa oleifera*, commonly referred to as the `drumstick tree' (describing the shape of its pods) or ‘horseradish tree’ (the roots can be used as a substitute for horseradish), is the most commonly cultivated species. *M. oleifera* is native to the sub-Himalayan tracts of north-west India, Pakistan, Bangladesh and Afghanistan (Foidl *et al.*, 2001). 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).

During the early establishment of Moringa (1-2 years) vegetables can easily grow in their surrounding areas. At the early establishment period of tree, the competition for growth resources (water, nutrients and light) between tree and associated crop is perhaps absent or minimum. Plantation of Moringa tree in association with vegetables and spices as agroforestry practice would be beneficial for socio economic development as well as for sound environmental condition. Hence, it would be wise to conduct experiments during the early period of the Moringa tree plantation in association with different vegetables at different spacing in terms of growth and yield performance for identifying best tree-crop combination. Therefore, the present study was undertaken with the following objectives:

1. To determine the growth and yield performance of stem amaranth in association of Moringa saplings at different distances from Moringa base, and
2. To determine the influence of stem amaranth on growth characters of Moringa at different distances from Moringa base.

CHPTER II

REVIEW OF LITERATURE

This chapter reviews the literature of other scholars and their past studies on agroforestry that is related to the current experiment collected through reviewing of journals, thesis, internet browsing, reports, newspapers, periodicals and other form of publications are presented.

2.1. Overview of Agroforestry

Agroforestry is an age old practice, indeed very old. It is an integral part of the traditional farming system in Bangladesh. The basic concept of agroforestry is the combination of Agriculture and Forestry on the same piece of land. It has been practiced by many groups of people in various ways under different conditions since ancient times. The idea of intercropping has been extended to Agroforestry system.

Agroforestry can be defined as a dynamic, ecologically balanced, natural resource management system that, through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels. In particular, agroforestry is crucial to smallholder farmers and other rural people because it can enhance their food supply, income and health. Agroforestry systems are multifunctional systems that can provide a wide range of economic, sociocultural, and environmental benefits (ICRAF, 1982).

Many authors have defined agroforestry in different ways. The most widely used definition have been given by Lundgren and Raintree (1982) that Agroforestry is a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land-management unit as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence. In agroforestry systems there are both ecological and economical interactions between the different components.

According to King and Chandler (1978) “Agroforestry is a sustainable land management system which increases the overall yield of the land, combines the production of crops (including tree crops) and forest plants and/or animals simultaneously or sequentially, on the same unit of land and applies management practices that are compatible with the cultural practices of the local population''.

Nair (1980) defined agroforestry as a land use system that integrates trees, crops and animals in a way that is scientifically sound, ecologically desirable, practically feasible and socially acceptable to the farmers.

Vergara (1982) defined agroforestry as a combination of trees and crops of various longevity ranging from annual to perennial plants), arranged either temporarily or spatially intercropping to maximize and sustain agricultural production.

According to Somariba (1992), "Agroforestry are diverse technical practices that have at least two different plants in biological interactions, one of these two plants is a perennial and another one is forage, a food crop or a tree crop".

Bhatia and Singh (1994) observed that agroforestry in India plays an important role in increasing biomass production, maintain soil fertility, conserving and improving soil and averting risk. Minj and Quli (2000) found improvement in all the socio- economic parameters except the size of the family due to the implementation of Agroforestry schemes.

According to Pandey (2007), "to promote well-being of the society, management of multifunctional agroforestry needs to be strengthened by innovations in domestication of useful species and crafting market regimes for the products derived from agroforestry."

In Bangladesh, the traditional agroforestry system exhibited the consideration of farmers, the tress as savings and insurance against risk of crops (Akhter *et al.*, 1989). Trees in the homesteads play an important role in the rural economy of Bangladesh. Often called homestead forests, such plantings are particularly important sources of fuel wood because fuel wood cannot be transported long distances from existing forest areas. In the absence of other wood sources, improved village forestry and homestead agroforestry are important to the development of Bangladesh (Nair, 1989). Agroforestry systems incorporate species and techniques that have been used traditionally in local areas for many generations, in some cases in thousands of years (Rahman *et al.*, 2011).

2.2. Characteristics of tree species in Agroforestry

In Agroforestry systems, people plants trees for fruit, fodder, fuel, shade, conservation purpose and various other purposes. Since large varieties of tree are available which could grow in different edaphic climatic condition, People can select trees of their choice very easily.

While selecting tree species for agroforestry systems, the following desirable characteristics should be taken into consideration. Though all desirable characters are not found in a single species, but their multiple uses are taken care of.

- Tree species selected should not interfere with soil moisture.
- Tree species selected for agroforestry have very less water requirement.
- Should not compete with main agricultural crops for water.
- Tree species must be deep tap rooted so that they can draw water from deep Strata of the soil.
- Tree species should not compete for plant nutrients.
- Tree species should not utilize more plant nutrients.
- They should help in building soil fertility.
- Leguminous tree species which fix atmospheric nitrogen in their roots should be preferred.
- Tree species should not compete for sunlight
- Tree species should be light branching in their habit.
- Trees permit the penetration of light into the ground and promote better crop, pasture growth and yield.
- Tree species can withstand pruning operation if it posses dense canopy.
- Tree species should have high survival rate and easy establishment.
- Trees species should have high survival percentage.
- They have less mortality percentage because they can tolerate transplanting shocks easily.
- Trees should have the ability to regenerate lateral roots within a short period of time after transplanting.
- Tree species should have fast growing habit and easy management.
- Tree species should have wider adaptability.
- Tree species should have high palatability as a fodder.
- Tree species should have shelter conferring and soil stabilization attributes.

- Tree species should have capability to withstand management practices.
- Many agroforestry systems demand extensive pruning and lopping of the trees in order to maximize production. In such cases, the trees must be able to withstand such treatment without drastically restricting growth rate.
- Tree species should have nutrient cycling and nitrogen fixation attributes.
- Within an agroforestry system, trees can play an important role in recycling nutrients, leached down through the soil profile and minerals released from weathering parent material such as rocks and sediments.
- Tree species should have thin bark.
- Tree species should be free from chemical exudations.
- The species selected for agroforestry combination must be free from allelochemicals as these allelochemicals affect the growth of under-ground crops.
- Tree species should have easily decomposable leaves.
- Tree species should have their multiple uses.
- The tree should yield more than one of the main produce like Fuel wood, leaf fodder, edible fruit, edible flower and fiber.
- Tree species should have high yield potential.

Hegde and MacDicken (1990) pointed out some criteria of suitable trees that should be planted under the agroforestry system:

- Non-interference with arable crops
- Easy establishment
- Fast growth and short gestation period
- No allelopathic effects on arable crops
- Atmospheric nitrogen fixation ability
- Easy decomposition of liter
- High returns and multiple uses
- Ability to withstand frequent lopping
- Employment generation ability

As it is not possible to select having all the above mentioned criteria, therefore researcher should select suitable species having most of the characters and adaptive to local environmental conditions.

2.3. Importance of Moringa in Agroforestry

Moringa is a multipurpose vegetable tree with a variety of potential uses, of which the nutritional and medicinal properties are initially considered the most interesting. In total there are 13 species in the genus Moringa, belonging to the family Moringaceae, of which *M. oleifera*, commonly referred to as the `drumstick tree' (describing the shape of its pods) or ‘horseradish tree’ (the roots can be used as a substitute for horseradish), is the most commonly cultivated species. *M. oleifera* is native to the sub-Himalayan tracts of north-west India, Pakistan, Bangladesh and Afghanistan (Foidl *et al.,* 2001). This multipurpose tree is characterized by high biomass yield and tolerance to unfavorable environmental conditions (Foidl *et al*., 2001).

The tree ranges in height from 5 to 10 m (Morton, 1991). It is found wild and cultivated throughout the plains, especially in hedges and in house yards, thrives best under the tropical insular climate, and is plentiful near the sandy beds of rivers and streams (Qaiser, 1973). Moringa trees do not need much water and can germinate and grow without irrigation if sown during the rainy season. The roots will develop in about twenty days and allows young plants to tolerate drought (Saint Sauveur and Broin, 2010; Fugli and Sreeja, 2011).

The Moringa tree has many potential uses, and as a result a great deal of research and development has been done. It provides different foods and other profitable uses with minimum growing and harvesting input. The tree can also be used to combat deforestation and to beautify streets and informal settlements. The leaves, fruit, flowers and immature pods are used as highly nutritive vegetable in many countries, particularly in India, Pakistan, Philippines, Hawaii and many parts of Africa (Anwar and Bhanger, 2003; Anwar *et al*., 2005).

Moringa leaves contain more beta-carotene than carrots, more protein than peas, more vitamin C than oranges, more calcium than milk, more potassium than bananas, and more iron than spinach. Crushed seed of *M. oleifera* has been shown to be an effective natural coagulant for the treatment of river waters exhibiting relatively high levels of suspended solids (Fuglie, 2001). Moringa responds well to pruning and the leaves intercept less light than other agroforestry species (Immanuel and Ganapathy, 2010). Regular pruning and leaf harvesting, therefore, would likely result in sufficient light below the canopy to allow for intercropping (Crosby and Craker, 2007). Palada *et al*. (2008) studied the competitive effects of Moringa intercropped with medicinal plants and culinary herbs and found that Moringa, with its rapid growth, was competitive against many herbaceous plants; however, lemon grass (*Cymbopogon citratus*) and basil (*Ocimum basilicum*) could be grown with Moringa during the early establishment phase.

Data gathered from the Bangladesh Bureau of Statistics (BBS, 2014) shows that *M. oleifera* is mainly cultivated in gardens and homesteads. Commercially cultivated Moringa trees account for an estimated annual harvest of 10 tons of pods, while another estimated 2860 metric tons of Moringa pods are being harvested in homestead gardens. The Bangladesh Bureau of Statistics (BBS) does not have estimations for the cumulative area of Moringa that is grown in homestead gardens. The data of the BBS confirm the main findings of the farmer survey. Commercial cultivation of *M. oleifera* is rare in Southern Bangladesh.

In the Barisal and Patuakhali Regions Moringa is not cultivated at all on agricultural lands. The average harvest per tree is higher in Jessore than in Khulna. However, the data are not exhaustive and conclusive, e.g. there were no data available for the estimated area under cultivation in Jessore, nor are there data available for homestead gardening (BBS, 2014).

2.4. Cultivation Technique of Moringa

2.4.1. Cultivation requirements

Moringa tolerates a wide range of environmental conditions. It grows best between 25 to 35^0C, but can tolerate up to 48^0C in the shade and survive a light frost (Palada and Change, 2003). It is a drought-tolerant tree that grows well in areas receiving annual rainfall amounts that range from 250 to 1500 mm, prefers a well-drained sandy loam or loam soil, also tolerates clay, but cannot survive under prolonged flooding and poor drainage (Palada and Change, 2003). Soil pH should range between 5.0−9.0. Altitudes below 600 m are best for Moringa, but this adaptable tree can grow in altitudes up to 1200 m in the tropics.

2.4.2. Cultivation Practices

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 (DAS) (Saint Sauveur and Broin, 2010). For intensive (commercial) leaf production the spacing of the plants should be 15×15 cm or 20×10 cm, with conveniently spaced alleys to facilitate plantation management and harvests (Saint Sauveur and Broin, 2010).This intensive system requires careful crop management. For semi-intensive leaf production plants are spaced 50 cm to 1 m apart. This is more appropriate for small-scale farmers and gives good results with less maintenance.

For fruit or seed production the spacing must be at least 2.5×2.5 meter in order to achieve good yields. For intensive production the land should be prepared by means of ploughing and harrowing to a maximum depth of 30 cm (Saint Sauveur and Broin, 2010). In case of semi-intensive production, it is better to dig planting pits (30 - 50 cm deep, 20 - 40 cm wide), which ensures good root system penetration and retains soil moisture, without causing too much land erosion (Fugli and Sreeja, 2011).

Compost or manure can be mixed with the fresh topsoil around the pit and used to fill the pit. Moringa trees 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.

Pinching the terminal bud on the central stem is necessary when the tree attains a height of 50 cm to 1 m (Saint Sauveur and Broin, 2010). This will trigger the growth of lateral branches which need to be pinched too. Regular pinching will encourage the tree to become bushy and produce many leafs and pods within easy reach and helps the tree develop a strong production frame for maximizing the yield (Fugli and Sreeja, 2011). In fruit and seed producing farms, pruning induce more fruits, as well as larger fruits (Saint Sauveur and Broin, 2010).

The roots of Moringa develop in about twenty days and allows young plants to endure drought (Saint Sauveur and Broin, 2010; Fugli and Sreeja, 2011). It is however advisable to irrigate regularly to ensure optimal growth and continuous yield, especially in arid conditions. 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 can be mixed 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).

Weeding must be done regularly to avoid competition for nutrients, especially for nitrogen. Weeding must be more frequent when the plant is young and small. Mulching can be applied (covering the soil with crop or weed residues) in order to reduce the loss of soil moisture, minimize irrigation needs and also reducing weed growth. Moringa is fairly resistant to pests and diseases since its relatively fast vegetative growth allows it to regenerate quickly from any disturbance. The most common pests and diseases are grasshoppers, crickets, caterpillars, termites and fungal disease. Preventive measures and timely detection of pests and diseases are important in the pest and disease management strategy (Gongalez *et al*., 2015).

For human consumption, harvested pod should be young (about 1 cm in diameter) and snap easily. In seed producing farms (for planting or oil extraction), pods should be harvested when they reach maturity, i.e. when they turn brown and dry. Harvest the pods before they split open and seeds fall to the ground. Seeds should be extracted from the pods, bagged, and stored in a dry shady place. Harvesting of the leaves can be done by cutting shoots and leaves or by only removing the leaves, picking them directly off the tree. In this case it is advisable to apply pruning after the harvest of the leaves in order to ensure again a vigorous growth (Gongalez *et al*., 2015).

2.5. Response of crops in Agroforestry System

In agroforestry systems, the responses of different crops was different. Under shaded condition the size of the leaf increased in different vegetables such as tomato, brinjal and coriander (Miah, 2001). Martin and Rhodes (1983) studied variability of 95 associations of *Abelmuscus esculentus* and *Abelmuscus tetraphylous.* Significant differences were found among the association of all the characters studied viz. plant height, plant spread, number of primary braches, days to flowering, nodes when the first flower appeared, number of leaves per plant, leaf size, petiole length, number of pod per plant, pod weight and total yield.

The density of plant increases the yield of seed. It was recorded that the plants which were grown in high densities were taller, sparsely branched, less pruned to lodge, few seeds and pods (Weber *et al*., 1987). It was observed that maize yield was suppressed due to shading effect. While in the shorter second season, where rain ended abruptly, moisture competition was main factor causing drastically low yield. (Sing *et al.*, 1989).

Primak and Shelepora (1989) observed that tomato plants grown under low light intensity was recorded decrease in photosynthetic surface area of chloroplast and a reduction number of chloroplast numbers per unit area in the cotyledons of varieties with high light requirements compared with cotyledons from plant of the same varieties a high light intensity. This difference was marked less in shade tolerant varieties.

An experiment was conducted under eight levels of shading (0, 20, 37, 48, 50, 72, 87, 98 percent) in Radish, Cucumber and Tomato by Hanada (1990) where he observed that shading preserved soil moisture, decreased soil temperature and hindered insect attack.

Agrawal *et al*. (1992) observed that the rice which was incorporated yielded 59% to 99% sole to mungbean. They also reported that intercropping of upland rice with short duration grain legumes had shown promising productivity and resources used efficiently.

Singh *et al.* (1992-1993) observed in a field experiment during the rainy season of 1992-1993 at Hisar, Hariyana, in which 7 soybean cultivars were grown 200000, 400000 or 600000 plants/ha. Cultivar × plant density × year interactions were evident.

EI-Gizawy *et al.* (1993) observed the growth and development of tomato under shading (0, 35, 51 and 63%) effect provided by net where he recorded increased plant height and leaf area and reduced leaf number and dry weight. The days to flowering increased because of increased shading whereas the number of flowers/plant decreased under shading conditions compared to the rate at full sunlight.

A field experiment was conducted during the kharif season of 1991-1992 at Indore, Madhya Pradesh, India. Pigeon pea cv. ICPL 316 intercropped with soybean cv. JS 71-05 under paired rows (22.5/90cm) gave seed yield of 1.5 ton and 1.94 ton/ha, respectively, the highest gross monetary returned compared with other intercropping treatments. (Joshi *et al*., 1994).

The variability of 50 Okra genotypes was studied by Gondane and Bhatia (1995). They observed that all the genotypes responded differently to the environments. There were significant variations in the yield components, particularly plant height, plant spread, number of nodes per plant, number of leaf per plant, leaf length, leaf breadth, petiole length, pod per plant, nodes to first pod and yield.

Miah *et al.* (1995) recorded the reduced light availability on crop rows as they approached the tree rows across the alleys. The rate of decrease was greater in unpruned than in pruned alleys. The yield of Rice and Mungbean was decreased more in pruned (13kg/ha) than in unpruned (9kg/ha) condition. Hossain *et al.* (1996) stated that the different in primary branching in plant due to shading is important because it contributes towards the yield of grain legumes.

Ali (1998) reported that red amaranth and okra could be grown successfully under drumstick tree although 10-15 percent yield was reduced compared to open field condition. Ventimiglia *et al.* (1999) reported that soybean was sown at row spacing of 20 cm and 40 cm. Yield was higher in 20cm row spacing than 40 cm row spacing. Compensation points of photosynthesis were lower in shaded plants than in less shaded plants.

Miah (2000) observed that plant height at high light intensity has different leaf morphology from those grown at low light intensities, leaf size increased under shaded condition in different vegetables like radish, carrot, cabbage and tomato plants.

An experiment was conducted to study the effects of three levels of Irradiance (25, 60 and 100% of full sunlight) at early flowering, peak flowering and late flowering stages on the photosynthetic activity and yield of tomato (Liu *et al.*, 2002).

The three levels of Irradiance were imposed for 8 days using artificial shade net placed 2m above the pots. Increased shading increased the stomatal conductance and intercellular carbon concentrations and reduced mid-day photosynthetic rates at the early and peak flowering stages. Reddy *et al.* (2002) observed higher plant height under shaded condition, root length, dry weight, girth and total chlorophyll content were higher but yield were lower.

Senevirathna *et al*. (2003) studied the comparison of the growth photosynthetic performance and shade adaptation of nubbin plant growing in natural shade (33.55 and 70% reduction in incoming radiation) to control the plants growing in full sunlight, stem diameter and plants height were greatest in plants grown in full sunlight and both parameters decreased with increasing shade.

Total plants in 77% shade expansion of fruits leaf whorl monitored at 5-6 MAP, was slowest in plants in 77% shade and fasted in shade less plants which had more leaves and higher leaf areas and inter whole shoot lengths increasing shade, specific leaf area increased whereas leaf area ratio and relative growth rate decreased. Fertilizer trees including gliricidia (*Gliricidia sepium),* intercropped or in improved fallows, have been shown to increase maize (*Zea mays*) yield over current farmer practice across sub-Saharan Africa (Sileshi *et al.,* 2008), but with different performance across soil types, climates and fertilizer application (Sileshi *et al*., 2010).

2.6. Growth characteristics and importance of amaranth

Amaranth refers to plants of the genus *Amaranthus,* which contains 60-70 species of annual, mostly monoecious, plants with an upright, moderately branched growth habit. Amaranths are cultivated for ornamental, grain, or vegetable production, but most species are classified as weeds, including the well-known and troublesome pigweeds (Teutonico and Knorr, 1985).

Separation of these types is not entirely distinct, taxonomically or functionally, because all *Amaranthus* species have edible stems, leaves, and seeds. The young leaves of grain types are commonly eaten as greens, and, although the domestication of wild amaranths began over 2,000 years ago, many more species are eaten globally than would be considered truly domesticated. Amaranths have not been the subject of modern intensive breeding efforts, and frequent hybridization between cultivated and wild populations has led to the existence of many intermediate types (National Research Council, 2006).

Amaranths have a high capacity for osmotic adjustment (Liu and Stutzel, 2002) and a C4 photosynthetic pathway that allows efficient use of CO_2 in a large range of temperature and moisture stress environments, likely a major factor in their wide geographic distribution. This enables it to use light and water more efficiently in converting CO_2 to carbohydrate. This is particularly advantageous when sunlight is abundant (Stallknecht and Schulz-Schaeffer, 1993).

Amaranth is grown and eaten as a vegetable in over 50 countries worldwide, in such geographically diverse locations as South America, Nepal, China, Greece, India, and South Pacific Islands (National Research Council, 2006). Nutritional assessments of common vegetable species (*A. blitum, A. cruentus, A. dubius, A. tricolor, and A. viridis*) show high protein content and significant levels of essential micronutrients, including beta-carotene, iron, calcium, vitamin C, vitamin A, and folic acid (Teutonico and Knorr, 1985; Mziray *et al*., 2001; Achigan- Dako *et al.*, 2014).

High nutritional value and tolerance of many biotic and abiotic stresses have made amaranth an especially important vegetable crop in Africa, where some societies derive as much as 25% of their protein intake from amaranth leaves during the production season, and its sale by the thousands of tons annually has significant economic impact (National Research Council, 2006; Mandu *et al*., 2012).

The Creole word Callao, which refers to both amaranth plants and a traditional stew made with amaranth, is also used with great pride colloquially to indicate the unique blend that constitutes Creole culture (National Research Council, 2006). Though cultural views of amaranth vary by location and socioeconomic class, its pervasiveness and significance globally are without dispute. *Amaranthus* species are mainly eaten as a vegetable e.g. *A. tricolor, A. cruentus, A. dubius, A. caudatus, A. hybridus, and A. viridis*. Amaranth leaves and stems are steamed, used in soups, boiled in several changes of water, or young leaves are eaten raw (Achigan-Dako et al., 2014). While amaranth seed production in the U.S. is around 6,000 acres, centered in the Great Plains region, commercial vegetable amaranth production is effectively nonexistent and requires increased research (Green, 2003).

2.7. Tree-crop interaction in agroforestry

The influence of Grewia on the wheat produce varied according to the distance of the tree. Competition for growth and yield was more pronounced in close vicinity of the tree at 1 and 2 m. The more negative effect in close vicinity of trees can be ascribed to more competition for moisture, nutrients and light, which is also evident from the present study. Reductions in yield of wheat below the tree crown due to resource competition were also reported by Puri and Bangarwa (1992) and Dhillon *et al*., (1998). An agrisilviculture system (Wheat + Grewia) was established and it was reported that integration of *Grewia optiva* (tree density 666 trees/ha) with wheat pollarded at 1m height reduces the wheat grain yield by 24 per cent only as compared to 50 per cent in natural agroforestry system in this paper. This indicates that reduction in the wheat yield due to natural growing Grewia trees on farmland can be reduced by about 50 percent of the yield obtained in present studies by adopting tree management practices of pollarding (Verma *et al.*, 2002).

At the time of sowing of wheat less soil moisture competition can be attributed to dormant period of Grewia at this stage. The significant lower moisture at 1 m and 2 m distance at all other growth stages of wheat can be attributed to the competition for moisture by the superficial root systems of the tree; as most of the lateral root spread of Grewia is confined within two meter distance from the trees base (Zegye, 1999).

Competition for moisture in agroforestry systems is common occurring phenomenon, which can affect the system adversely (Ong *et al*., 1991; Rao *et al.,* 1991). Higher moisture in subsurface layer as compared to surface layer may be attributed to more sorption of moisture by crop and tree roots from upper layer since both the species are having shallow root system in general. Further, majority of roots of Grewia remains confined to 60 cm soil depth (Zegye, 1999). Below canopy, lower soil temperature was maintained at 1m and 2m distances at the time of milking and harvesting. A similar effect of tree canopy on soil temperature was observed by Vandenbelt and Williams (1992).

Beneath canopy temperature also showed more reduction at 1 and 2m, which again can be ascribed to direct shading effect of Grewia on wheat. Reduced temperature below trees has also been reported by Monteith *et al*. (1991), Hazra and Patil (1996), and Thakur and Kaur (2001).

In recent decades, integrating trees with crops for food and wood production has received considerable attention in both tropical (Garrity *et al*., 2010) and temperate regions (Palma *et al*., 2007). Agroforestry has shown potential to increase and sustain food production per unit area in systems like the parklands of the Sahel (Bayala *et al*. 2012), through the use of ‘fertilizer trees’ intercropped or in fallow rotations with crops throughout sub-Saharan Africa (Sileshi *et al.,* 2008) and through integrating trees with crops on sloping land (Tiwari *et al*., 2009).

Agroforestry is increasingly seen as a promising approach to improving food security (Glover *et al.,* 2012), largely because the trees are associated with enhancing and sustaining soil health and hence crop yield (Barrios *et al*., 2012). Trees also produce fodder, fuel and construction materials, which are in high demand in many rural areas and if produced on farm may reduce the costs of obtaining them off-farm. Through production of high value timber, farmers can often generate substantial additional revenue in both temperate (Dupraz *et al*., 1997) and tropical contexts (Dupraz *et al*., 1997; Bertomeu, 2006; Santos-Martin and van Noordwijk, 2009). Fruits obtained from trees can enhance both income (Mithöfer and Waibel, 2003; Luedeling and Buerkert, 2008) and human nutrition (Goenster *et al.,* 2009; Kehlenbeck *et al.,* 2013).

Agroforestry practices are often part of strategies to improve natural resource management (Ong and Kho, 2015), and they are often more effective than other land uses in providing regulating, supporting and cultural ecosystem services (Pagella and Sinclair, 2014), such as microclimatic buffering, amelioration of soil structure and water infiltration, reduction of overland flow, regulation of the water cycle and provision of habitat for wild species (Bayala *et al.,* 2014).

The potential of agroforestry practices to sequester carbon in wood and soil has been widely demonstrated (Luedeling *et al.,* 2011; Kuyah *et al*., 2013).Agroforestry may also affect emissions of other greenhouse gases either positively or negatively (Verchot *et al*., 2008; Rosenstock *et al.,* 2014) and is expected to help farmers adapt to climate change through the risk-mitigating effects of additional farm products derived from trees, positive microclimatic effects through shading and enhanced farm productivity through tighter nutrient and water cycles (Garrity *et al*., 2010).

The magnitude of all documented or assumed benefits of agroforestry depends on site-specific responses by trees, crops or other components of the system, with strong variation between locations and farming contexts (Coe *et al*., 2014). Benefits also vary over time, because many effects of trees on soils are slow to materialize (Barrios *et al*., 2012).

Trees can also compete with crops for water and nutrients and reduce the land area available for crops, so that the net effect of agroforestry on crop yields over time will depend on attributes and interactions of the trees, crops, soil, climate, and management (Bayala *et al.*, 2012). For instance, the beneficial effects of *Faidherbia albida* on crop yields have been reported to start only after the trees reach 20 to 40 years of age (Ong and Kho, 2015).

CHAPTER III

MATERIALS AND METHOD

The experiment was conducted to evaluate the responses of early summer vegetable amaranth in association with drumstick (*M. oleifera*) as well as to find out the best tree crop interactions in Agroforestry system. The materials, followed methodologies and other relevant activities during the experimental period are elaborately presented in this chapter. A brief description on the experimental site, season, soil, weather and climate, land preparation, fertilizer application, experimental design and treatment combination, planting materials, intercultural operations, data collection, statistical analysis etc. are included here.

3.1. Location and Time

The experiment was carried out at the Agroforestry Field Laboratory under the Department of Agroforestry and Environmental Science, Sher-e-Bangla Agricultural University, Dhaka during the period from January 2018 to April 2018. The location of the site is 23^{o}074/N latitude and 90^{o}035/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 from January to April. The rate of annual rainfall, maximum and minimum temperature, relative humidity and other relevant information were collected from Bangladesh Meteorological Department.

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 cuttings of *M. oliaferae* were collected from Manikganj. From each site, three mother tree were selected and tagged properly. Four equal sizes of branches were collected from each tree. The seeds of Amaranth, variety dhrutoraj was purchased from United seed company, Siddique Bazar, Gulisthan, Dhaka.

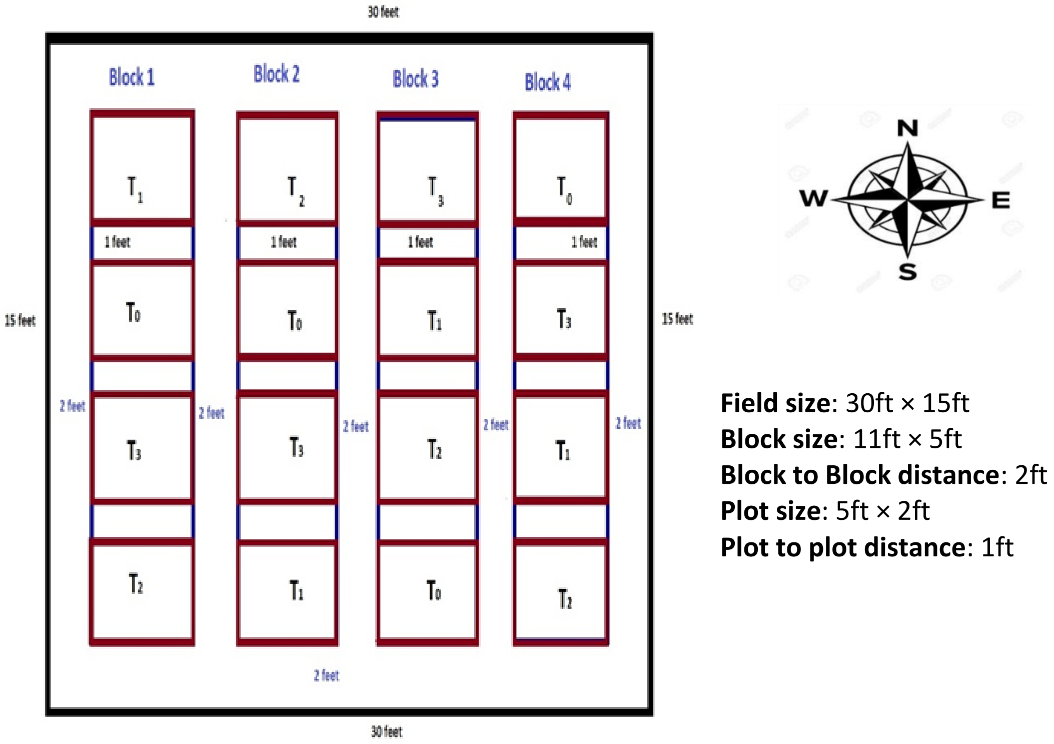
3.5. Tree Establishment

A 40 cm deep square size pit was dug at 5 feet distance in the experimental field. Then each pit was filled with surrounding soils. All the cuttings were 3.8 feet in length which was placed separately at the center of each pit. After planting, the above ground length of each sapling was 2.6 feet which was similar for all used as tree planting materials. Irrigation was done as necessary by using watering cane.

3.6. Experimental Design and Treatment Combination

The vegetable Amaranth in association of 15 days old Moringa saplings were sown and/or planted following the Randomized Complete Block Design (RCBD). The total plot size was 30 feet x 15 feet. Individual block size was 11 feet × 5 feet. Each of the four treatments was replicated four times. Four treatments which were used in this study are as follows:-

T_0= Open field referred to as control
T_1= 6 inch distance from the tree base
T_2= 12 inch distance from the tree base
T_3= 18 inch distance from the tree base



Field size: 30ft × 15ft
Block size: 11ft × 5ft
Block to Block distance: 2ft
Plot size: 5ft × 2ft
Plot to plot distance: 1ft

Figure 1: Layout of the Experiment Field

3.7. Land Preparation

The experimental field preparation was started on 1 January 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 Moringa plantation.

3.8. Crop Establishment and Management

Amaranth seeds (Dhrutoraj) were sown in the experimental plot on 11 February 2018 by line sowing method at a depth of 10 cm furrow line maintaining a spacing of 9 cm from row to row.

3.9. Management Practices

3.9.1. Fertilizer application

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

3.9.2. Weeding and Irrigation

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

3.9.3. Thinning out

First emergence of Amaranth was observed at day seven after sowing. Thinning was carried out two times. For Amaranth first and second thinning was done at 10 days and 20 days after sowing, respectively.

3.9.4. Pest and Disease Management

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

3.10. Data Collection

3.10.1 Amaranth

Amaranth was harvested at 50 days after sowing (DAS) when the crop reached at edible size. Plant samples of amaranth were collected randomly from each rows of the respective plots. A total of 20 (5 from each replication) plants of amaranth were selected from each plot for data collection.

Samples were collected for measuring following parameters:-

- Plant height (cm)
- Number of leaf per plant
- Leaf length and leaf breadth
- Stem girth (cm),
- Shoot length (cm)
- Root length (cm)
- Fresh weight per plant(g)
- Dry weight per plant(g)
- Fresh yield (t/ha)

3.10.1.1. Plant Height (cm): Plant height was measured in centimeter (cm) by using a scale at 10, 20, 30, 40 and 50 DAS from the ground level to the tip of the plant leaf.

3.10.1.2. Number of leaf per plant: Five plants from each plot were selected randomly and tagged properly. The leaf number was counted precisely for each plant.

3.10.1.3. Leaf length and leaf breadth (cm): Five plants from each plot were randomly selected and then the length and breadth of the leaves were measured against a centimeter scale.

3.10.1.4. Stem girth (cm): Randomly 5 plants were selected and measured each stem of the plant with a roller scale, then the sum of stem diameter was divided by 5 to record average stem diameter of plant.

3.10.1.5. Shoot length (cm): Randomly selected five plants from each plot were measured for shoot length by a centimeter scale at harvest.

3.10.1.6. Root length (cm): After harvest, the length of the root was measured by a centimeter scale for randomly selected five plants from each plot. Then the sum of the root length was divided by five to record root length of plant.

3.10.1.7. Fresh weight (g): Randomly 5 plants were selected from the each plot. Then shoot and root weight were weighted separately by balance. The sum of the fresh weight of five plants was divided by five then it was recorded as fresh weight of single plant (g).

3.10.1.8. Dry weight (g): After taking fresh weight, the sample plants were oven dried. Then shoot and root weight were weighted separately by electronic balance. The sum of the dry weight of five plants was divided by five then it was recorded as dry weight of single plant (g).

3.10.1.9. Fresh yield (t/ha): The yield of stem amaranth per hectare was calculated by converting the total yield (kg) of stem amaranth per plot.

3.10.2. Moringa Sapling:

Data as collected during the establishment period of Moringa trees concerning followings:

- Number of bud per tree
- Bud length per tree

3.10.2.1. Number of bud per tree: After sowing of amaranth seeds with association of Moringa, the number of bud for each Moringa sapling was counted at 10, 20, 30, 40 and 50 days after sowing (DAS).

3.10.2.2 Bud length per tree (cm): The length of each bud of a single tree was measured by a centimeter scale at harvesting time of stem amaranth. The sum of the bud length was divided by the number of bud and recorded as bud length (cm).

3.11. Analysis of data

All the data were subjected to analysis of variance (ANOVA) and tested for significance using Least Significant Difference (LSD) using R-3.5.1 software (R Core Team).

CHAPTER IV

RESULTS AND DISCUSSION

In this chapter the presentation and discussion of results from the current experiment is carried out to study and analyze the effect of *M. oleifera* on the growth, yield and yield attributing parameters of stem amaranth. The results of the experiment are presented and interpreted with the following headings and sub-headings.

4.1. Results

4.1.1. Influence of Moringa (*M. oleifera)* on growth and yield of stem amaranth (*A. cruentus*)

Table 1. Effect of Tree-crop interactions on plant height (cm) of Stem amaranth at different measurement dates

	Plant Height(cm)				
Treatments	10DAS	20DAS	30DAS	40DAS	50DAS
T_0	3.75a	13.75a	27.75a	50.87a	58.75a
T_1	3.62a	12.75b	26.75b	49.5b	56.37b
T_2	3.37a	11.75c	26.75b	47.12c	53.25c
T_3	2.75b	11.25c	25.37c	45.78d	49.00d
LSD	0.421	0.53	0.682	1.16	1.06
CV (%)	7.8	2.6	1.6	1.5	1.2
Significance level	**	**	**	**	**

T0 = Control; T1= 6 inch distance from the tree base; T2= 12 inch distance from the tree base; T3= 18 inch distance from the tree base. Different alphabetical letters within the same column indicate significant differences among various treatments according to a least significant difference test (LSD) ($P < 0.01$).

Plant height of stem amaranth was found significantly different due to different spacing from tree base at different sampling dates (Table 1). The plant height was increased gradually with the advancement of crop growth up to harvest.

At 10 DAS, the plants belong to open field condition (T_0 treatment) exhibited the highest plant height that was statistically similar with the plant height recorded in T_1 and T_2 treatments.

At 30 DAS, significantly highest plant height (27.75 cm) was observed in control condition (plants without Moringa) which was significantly higher than other treatment combination followed by T_1 and T_2. The lowest plant height (25.37 cm) was recorded in plants grown at 18cm distance from the tree base (T_3 treatment).

At harvest (50DAS), plant height ranges from 58.75cm to 49cm where plants belong to control treatment appeared as tallest followed by T_1 and T_2 treatments and plants belong to T_3 treatment was the shortest in height.

Table 2: Effect of Tree-crop interactions on number of leaves of Stem amaranth at different measurement dates

	Number of Leaves				
Treatments	10DAS	20DAS	30DAS	40DAS	At Harvest
T_0	4.25a	9.75a	12.25a	16a	24.75a
T_1	3.25b	8.75b	10.62a	14.75b	21.62b
T_2	2.87b	7.37b	10.5b	14b	21.37b
T_3	3.25b	8.5c	11.5b	14.75b	19.75c
LSD	0.628	0.88	0.824	1.17	0.94
CV (%)	11.53	6.45	4.59	4.94	2.69
Level of significance	**	**	**	*	**

T0 = Control; T1= 6 inch distance from the tree base; T2= 12 inch distance from the tree base; T3= 18 inch distance from the tree base. Different alphabetical letters within the same column indicate significant differences among various treatments according to a least significant difference test (LSD) ($P < 0.01$).

Number of leaves per plant exhibited different results under different treatments (Table 2).The highest number of leaves per plant at harvest was found where amaranth was grown under control conditions i.e., without association with Moringa which was significantly higher than other treatments where stem amaranth was grown under discrete distances from the tree base.

At early stage of growth that is 10DAS, open field condition (T_0 treatment) resulted the highest number (4.25) of leaves compared to other combination of treatments followed by T_1, T_3 and T_2. During the middle stages of growth (30 DAS), amaranth grew at both 6 and 12 inches away from tree showed least no. of leaves.

At harvest, under T_0 treatment, the number of leaves per plant was 24.75 which was highest and the lowest no. of leaves were found for T_3 treatment that was 19.75 where amaranth was grown at 18 inches distance from tree base.

Table 3: Effect of Tree-crop interactions on leaf length and leaf breadth of stem amaranth

Treatments	Leaf Length (cm)	Leaf Breadth (cm)
T_0	9.6a	5.37a
T_1	8.77b	4.75ab
T_2	8.42b	4.33b
T_3	7.29c	4.28b
LSD	0.55	0.65
CV (%)	4.1	8.75
Level of significance	**	*

T0 = Control; T1= 6 inch distance from the tree base; T2= 12 inch distance from the tree base; T3= 18 inch distance from the tree base. Different alphabetical letters within the same column indicate significant differences among various treatments according to a least significant difference test (LSD) ($P < 0.01$).

Leaf length and leaf breadth differ significantly among the treatments (Table 3). The highest leaf length was recorded in T_1 treatment (9.6cm) which was closely followed by the plants belong to T_2 treatment (8.87cm) that is statistically similar with T_3 treatment (8.42cm). The lowest leaf length was recorded in plants under T_3 treatment which was 24.06% lower than control condition.

Again in case of leaf breadth, the highest leaf breadth (5.37cm) was found in control conditions (T_0) where amaranth was grown in open field which was statistically similar with the leaf breadth (4.75cm) recorded in T_1 treatment(6inch away from tree base) and the lowest results (4.28cm) were recorded in plants 18 inches distance from tree base (T_3 treatment).

Table 4: Effect of Tree-crop interactions on stem girth, Stem length and Root length of stem amaranth

Treatments	Stem girth (cm)	Stem length (cm)	Root length (cm)
T_0	5.71a	60.66a	15.88a
T_1	4.68b	57.9b	14.68b
T_2	4.43bc	55.42c	12.89c
T_3	4.12c	51.85d	11.72d
LSD	0.46	1.2	0.7
CV (%)	6.15	1.33	3.21
Level of significance	**	**	**

T0 = Control; T1= 6 inch distance from the tree base; T2= 12 inch distance from the tree base; T3= 18 inch distance from the tree base. Different alphabetical letters within the same column indicate significant differences among various treatments according to a least significant difference test (LSD) ($P < 0.01$).

Significant variation was observed among the different treatments in respect of stem girth at harvest of stem amaranth (Table 4). Maximum Stem girth was recorded (5.7cm) in open field condition followed by T_1 treatment (4.68cm). Stem girth (4.43cm) observed in plants 12 inches away from tree base was statistically similar with the result found in T_1 treatment. The minimum stem girth (4.12cm) was found under 18 inches distance from tree (T_3 treatment). It was noteworthy that stem girth of the plants belonging to the treatments T_2 and T_3 were statistically similar.

The length of stem differ significantly among different treatments (Table 4). The length of stem was observed maximum (60.66cm) where plants were in control conditions (T_0) followed by T_1 and T_2 treatment. The lowest stem length (51.85cm) was results in plants that were grown at 18 inches (T_3) distance from tree base.\

Root length significant variation was observed in respect of root length for different treatment combinations (Table 4). Highest root length (15.88cm) was found in plants that were grown in open field condition followed by plants grown in 6inches and 12 inches distance from tree base. The minimum root length (11.72cm) was resulted for T_3 treatment.

Table 5: Effect of Tree-crop interactions on fresh Weight (g) of stem Amaranth

Treatments	Shoot FW (g)	Root FW (g)
T_0	74.1a	15.62a
T_1	72.05ab	14.05b
T_2	71.o7bc	13.7b
T_3	68.7c	11.97c
LSD	2.45	0.59
CV (%)	2.14	2.7
Level of significance	**	**

T0 = Control; T1= 6 inch distance from the tree base; T2= 12 inch distance from the tree base; T3= 18 inch distance from the tree base. Different alphabetical letters within the same column indicate significant differences among various treatments according to a least significant difference test (LSD) ($P < 0.01$).

Shoot fresh weight per plant of stem amaranth was observed significantly different among treatments (Table 5). The best result (74.1gm) for fresh weight was found for T_0 treatment (control condition). The second highest result (72.05gm) was recorded in T_1 treatment which was statistically similar with T_0 treatment. The minimum result (68.7gm) was recorded in plants at 18inches distance from tree base (T_3 treatment).

Significant variation was observed among treatments in respect of root fresh weight. The highest weight (15.62gm) of root per plant was recorded in open field condition (T_0) followed by T_1 and T_2 treatment. The results found for T_1 (14.05gm) and T_2 (13.7gm) had no significant different. The lowest root weight was recorded in T_3 (11.97gm) treatment which was significantly different from other treatment combinations.

Table 6: Effect of Tree-crop interactions on dry Weight (g) of stem Amaranth

Treatments	Shoot DW (g)	Root DW (g)
T_0	4.33a	1.05a
T_1	3.81b	0.96b
T_2	3.68b	0.93b
T_3	3.54b	0.87c
LSD	0.3	0.052
CV (%)	4.97	3.41
Level of significance	**	**

T0 = Control; T1= 6 inch distance from the tree base; T2= 12 inch distance from the tree base; T3= 18 inch distance from the tree base. Different alphabetical letters within the same column indicate significant differences among various treatments according to a least significant difference test (LSD) ($P < 0.01$).

Dry weight of amaranth shoot exhibited different results in terms of different treatments (Table 6). Shoot dry weight was observed highest (4.33gm) on open field conditions (T_0 treatment), where T_2 treatment (plant at 6 inches distance from tree cuttings base) comprises second highest dry weight. The plants under T_3 treatment was found minimum in shoot dry weight (3.545gm) results in distance of 18 inches from tree base.

The root dry weight of stem amaranth varied significantly in different treatments. Maximum root dry weight was recorded in T_0 treatment (1.05gm) followed by T_1 and T_2 treatment. The results found for T_1 (0.96gm) and T_2 (0.93gm) had no significant difference. The lowest root dry weight (0.87gm) was observed in T_3 treatment (18 inches away from tree base).

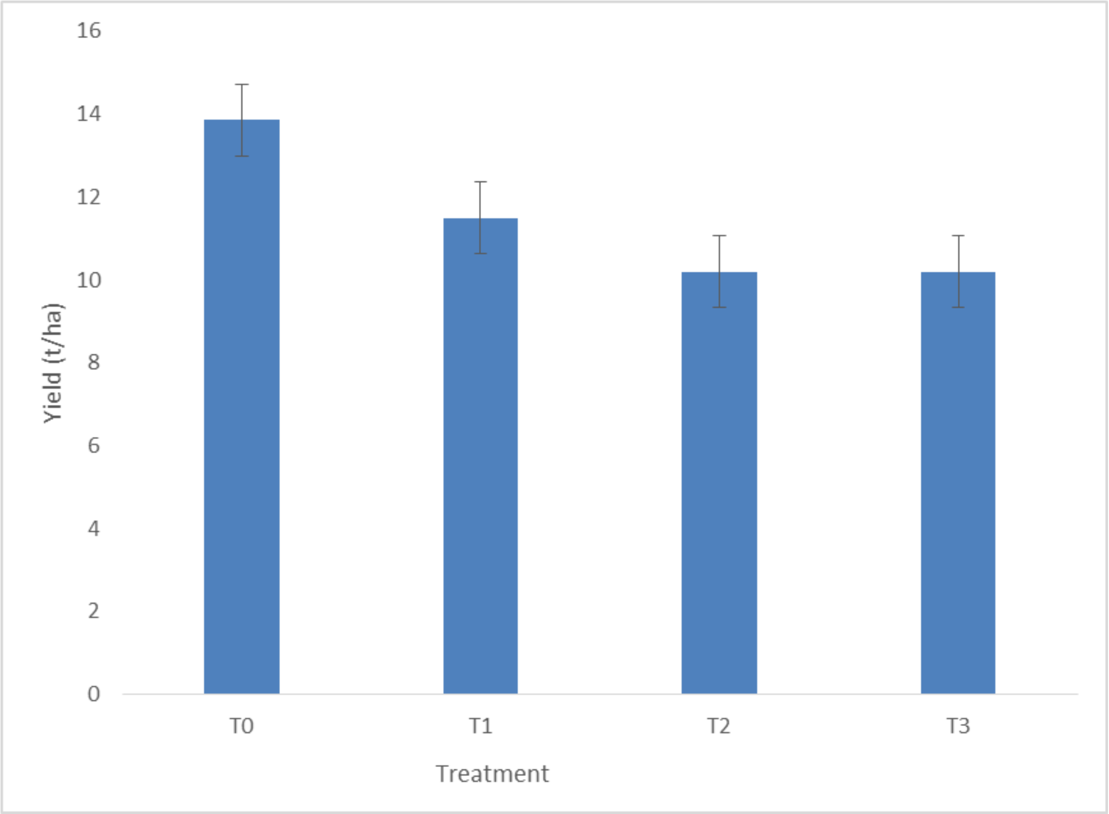


Figure 2: Effect of tree-crop interactions on Yield (t/ha) of stem Amaranth.

T0 = Control; T1= 6 inch distance from the tree base; T2= 12 inch distance from the tree base; T3= 18 inch distance from the tree base. Different alphabetical letters within the same column indicate significant differences among various treatments according to a least significant difference test (LSD) ($P < 0.01$).

Significant variation was found among different treatment combination in respect of fresh yield (Figure 2). Among different treatments, yield was recorded highest (13.85 t/ha) in open field condition where stem amaranth was grown intensively without association with Moringa tree. The yield found for different planting distances had no significant difference though second highest yield (11.5 t/ha) was found for T_1 treatment followed by T_2 and T_3 treatment.

4.1.2. Effect of stem amaranth on growth of Moringa saplings

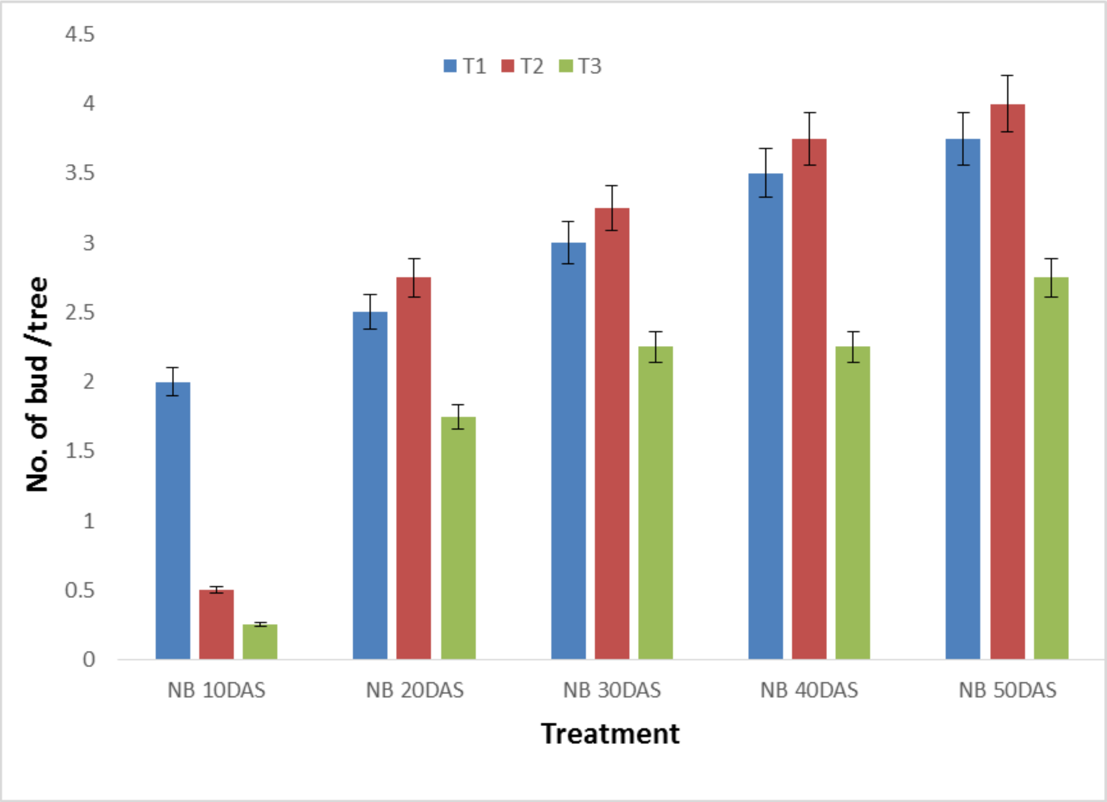


Figure 3: Effect of stem amaranth on Number of bud of Moringa sapling.

T1= 6 inch distance from the tree base; T2= 12 inch distance from the tree base; T3= 18 inch distance from the tree base.

Different alphabetical letters within the same column indicate significant differences among various treatments according to a least significant difference test (LSD) ($P < 0.01$).

At early stage of growth (10 DAS), the number of bud tree^{-1} was found maximum (2) in T_1 treatment followed by T_2 and T_3 treatment. At 30 DAS of stem amaranth, the no. of bud tree^{-1} was observed the highest in T_2 treatment (3) while the lowest no. of bud tree^{-1} was recorded in T_3 treatment (2). At harvesting period of stem amaranth, number of bud tree^{-1} was recorded the highest in T_2 treatment (4) followed by T_1 (3.75) and T_3 treatment (3).

Table 7: Effect of tree-crop interactions on bud Length of Moringa Sapling

Treatments	**Bud length at harvest (cm)**
T_1	8.07a
T_2	6.75a
T_3	4.38a
LSD	9.41
CV (%)	85.01
Level of significance	NS

T1= 6 inch distance from the tree base; T2= 12 inch distance from the tree base; T3= 18 inch distance from the tree base.

Different alphabetical letters within the same column indicate significant differences among various treatments according to a least significant difference test (LSD) ($P < 0.01$).

There was no significant variation was observed in respect of bud length of Moringa tree cuttings among different treatments during the harvesting period of stem amaranth. However, the highest bud length (8.07cm) was found in trees which were 6 inch away from amaranth plants (T_1 treatment) followed by T_2 treatment (6.75cm) and the lowest bud length (4.38cm) was recorded in T_3 treatment though they were statistically similar.

4.1.3. Relationship between different planting distances and the growth and yield parameters of stem amaranth

When data were plotted in the analysis including control condition, negative relationships were found between the different planting distances and the growth parameters of stem amaranth. A strong negative correlation was found between planting distances and plant height (cm) of amaranth (r= -0.9916). On the other hand, planting distances was found to have the strongest negative correlation with shoot length (cm) of stem amaranth (r= -0.9968).Under Moringa-stem amaranth association, negative relationship was also found between different planting distances and growth parameters. However the strongest negative correlation was found in case of root dry weight (g) of stem amaranth (r= -0.9998). On the other hand the least negative correlation was found between planting distances and number of leaves/plant (r= -0.125).

Table 8: Correlation between different planting distances from tree base and Various growths and yield parameters of stem amaranth grown in association with Moringa

Relationship between	**Correlation coefficient (r)**	
	Including open field	**Excluding open field**
Different planting distances (cm) and		
Plant height (cm)	-0.9916	-0.996
No. of leaves/plant	-0.7419	-0.125
Leaf length	-0.5672	-0.9877
Leaf breadth	-0.9458	-0.9122
Stem girth (cm)	-0.9397	-0.997
Shoot Length (cm)	-0.9968	-0.9946
Root Length (cm)	-0.9964	-0.9926
Shoot fresh weight(g)	-0.989	-0.9723
Root fresh weight(g)	-0.9742	-0.9341
Shoot dry weight (g)	-0.9356	-0.9998
Root dry weight (g)	-0.9812	-0.982
Yield (t/ha)	-0.9684	-0.9214

4.1.4. Regression Relationship between different planting distances and plant height (cm) of stem amaranth

When the plant height of stem amaranth was regressed against the different planting distances from Moringa tree base, a negative linear relationship was observed between them (Fig 4). The equation under the variable plant height was $y = -3.2375x + 62.438$ and the value of the coefficient of determination $R^2 = 0.9834$ was not a good fit and the regression line had a significant regression coefficient. So, plant height (cm) of stem amaranth was decreased with the increase in planting distances.

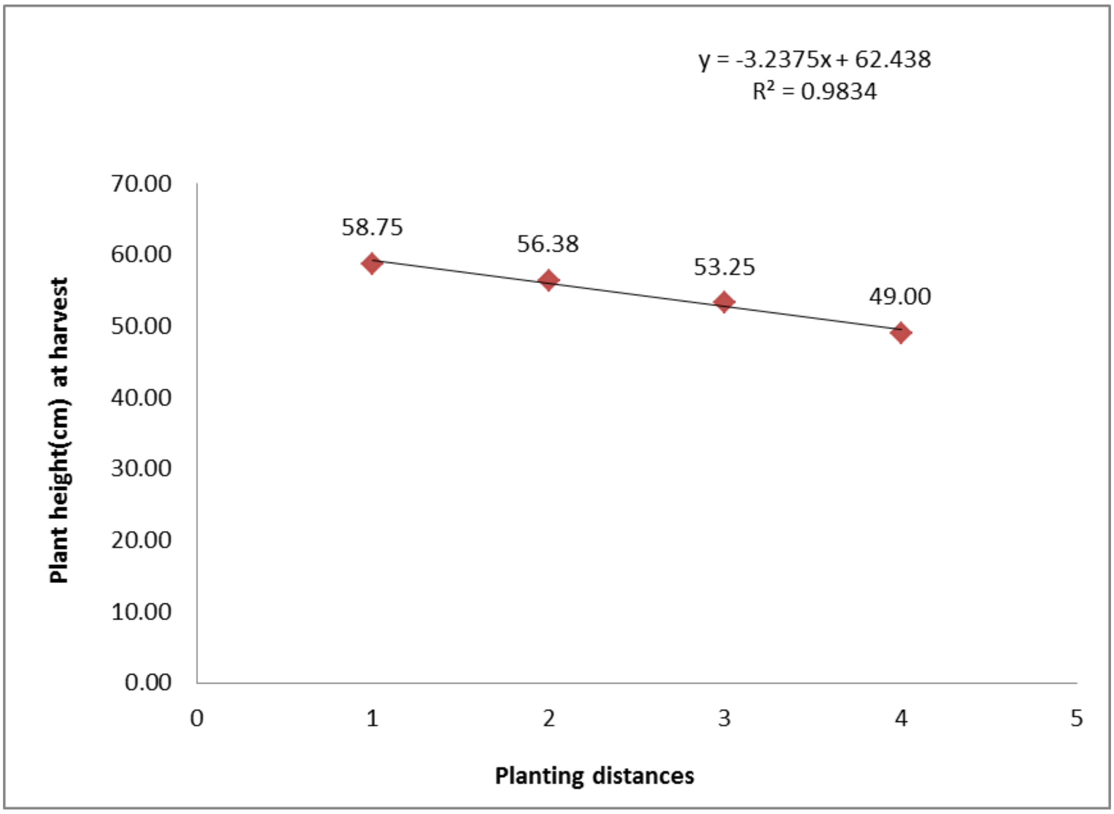


Figure 4: Relationship between different planting distances and plant height of stem Amaranth.

4.1.5. Regression Relationship between different planting distances and yield (t/ha) of stem amaranth

When the yield of stem amaranth was regressed against the different planting distances from Moringa tree base, a negative linear relationship was observed between them (Fig 5.). The equation under the variable yield was $y = -1.225x + 14.5$ and the value of the coefficient of determination $R^2 = 0.8443$ was not a good fit and the regression line had a significant regression coefficient. So, the yield (t/ha) of stem amaranth was decreased with the increase in planting distances.

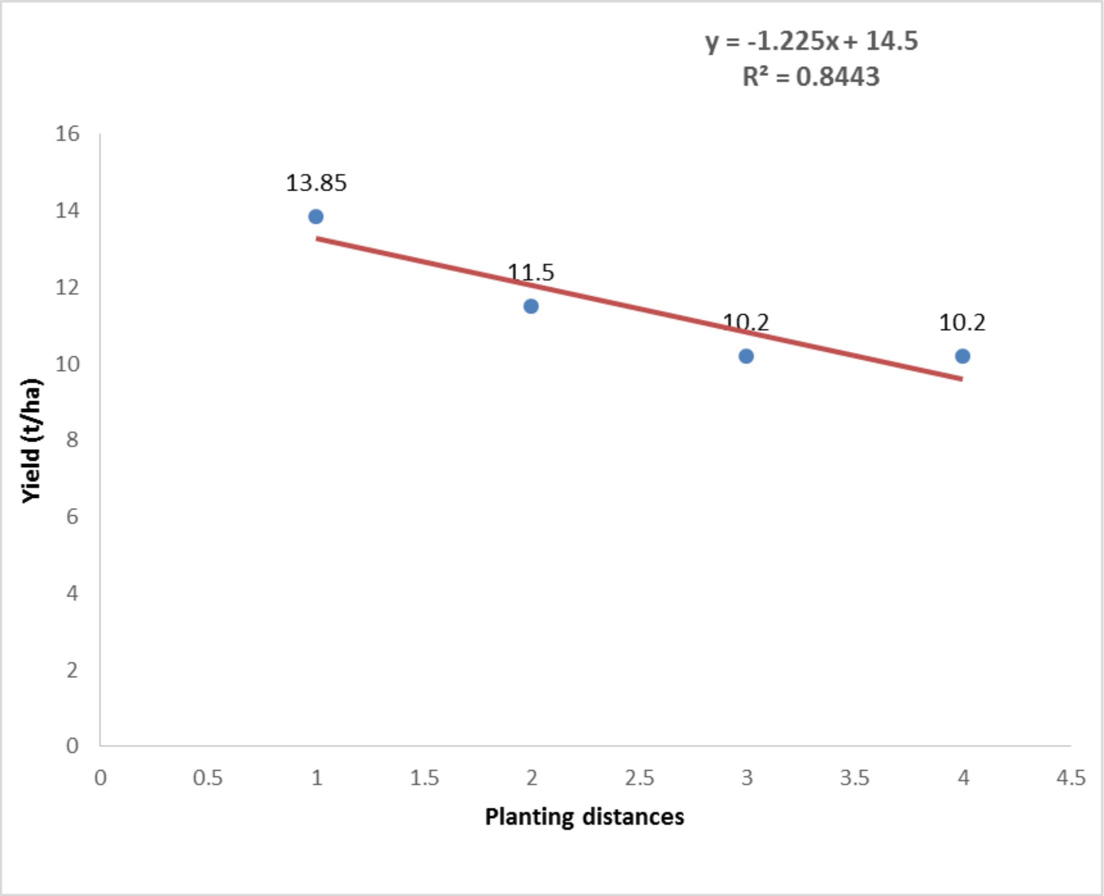


Figure 5: Relationship between different planting distances and yield (t/ha) of stem Amaranth.

4.2. Discussions

From the early stages of growth, plants belong to control treatment (T_0) was the fastest growing and performed consistently better in height compared to other plants belong to other treatments. This might be due to the fact that water with soluble nutrients provided the efficient growth condition of stem amaranth as irrigation was done intensively at control conditions (White *et al*., 1988). Plant height is influenced by genetic as well as environmental conditions. The increase in plant height also could be due to better availability of soil nutrients in the growing areas, especially nitrogen and phosphorus which have enhancing effect on the vegetative growth of plants by increasing cell division and elongation and the varietal variability to absorb the nutrients from the soil (El-Tohamy *et al*., 2006). Another reason for increased plant height at different levels might be due to the availability of nutrients came from manuring which helped in vegetative growth of stem amaranth. This result is similar with the results of Sharma *et al*. (1999).

The number of leaves under T_3 treatment was 20.2% lower than control condition at harvest. The highest no. of leaves among agroforestry treatments were found for T_1 and T_2 treatments respectively. The results indicated that availability of water at open field condition increased the number of leaves per plant because irrigation was sparsely done for plants close to the Moringa tree cutting as they cannot tolerate heavy watering during their establishment. Water soluble nutrients and nitrogen provided by cow dung enhanced the growth and development of amaranth at different levels.

As higher doses of nitrogen in cow dung increased the length of stem amaranth plant resulted in increasing the number of leaves per plant. Research results obtained by Devi *et al*. (2003) is relevant to this character. As Moringa trees were at their early stage of establishment, there was no shading effect on stem amaranth. So there was no competition for light which enhanced the number of leaves per plant. Decreased light can become a limiting factor to plant growth when shading occurs; one major effect of shade is to slow the rate of photosynthesis relative to respiration (Harper, 1977).

Leaf length and leaf breadth in control condition (T_0 treatment) were maximum followed by T_1, T_2 and T_3 treatment. These results indicated that leaf length and leaf breadth i.e., total leaf area increased because of increased growth of plant. As there was no competition for lights between tree and amaranth plants, maximum light interception by plants was the most promising factor that enhanced the size of the leaf. Maintenance of a high leaf length and breadth is very important for sustaining growth rate. Solar radiation capture by individual plants is a function of several factors including leaf size, angle of display, pubescence, age and physiological condition (Risper 1985). Our research findings were in line with the results of Broughman (1956) who suggested that maximum growth occur in plants when leaves are sufficient to intercept 95% of the incoming solar radiation.

Stem girth was recorded different for different treatments that might be due to the accumulation of nutrient which enhanced the overall plant growth of amaranth as increased plant diameter. Nitrogen has been reported to be a major nutrient that increased basal area per plant, size of stems and leaves (Vallentine 1980). Our results are in accordance with the findings of Sundstrom (1984), who reported that increased available nutrients increased the stem diameter. The results also showed that the manure cow dung progressively and significantly increased the cell number and/or size in stem amaranth. Shaktawat and Bansal (1999), Devi (2003) and Uddin *et al.* (2004) also reported same results.

The variation in shoot and root length among different treatments might resulted due to the variation of moisture. In the relation of water to long term growth and yield, the cell growth is generally more sensitive to water stress than is stomatal opening and carbon dioxide assimilation. Similar results were recorded by Hsiao (1973). Slatyer (1974) reported that the most obvious effects of prolonged water stress on shoot development were reduced internode length and reduced leaf size.

Control condition exhibited highest fresh weight compared to plants grown under agroforestry practice. This is might be due to the availability of water and soil nutrients accumulated by plants. Available soluble nutrients enhanced the overall growth as increased the shoot length, weight of stem and root. These observations were revealed in previous research (Wight and Black, 1979; Power, 1983; Rauzi and Fairbourn, 1983).

The maximum fresh weight of stem was possibly to long time photosynthesis which lead to more deposition of photosynthates during the vegetative growth of plants. Results obtained for fresh weight in this experiment is also comparable to the results of Talukder (1999). Stem amaranth grown in control condition was superior in respect of dry weight. Among different planting distances, the plants that have grown under 6 inch distance from tree base were highest in dry weight.

The results indicated that the accumulation of nutrient results in the increase of dry matter content of shoot and root. Diaz-ortega *et al.* (2004) observed that with the increasing of nutrient level (mainly Nitrogen) level biomass production of stem amaranth increased significantly that increases the dry matter of stem and root.

The yield was reduced by only 15.01% in T_1 treatment (11.5 t/ha) compared to T_0 treatment. The fresh yield of stem amaranth under T_2 (10.2 t/ha) and T_3 (10.2 t/ha) treatments with association of Moringa was recorded 26.35% lower than the plants which were grown under control condition (T_0 treatment). This might be due to availability of moisture and nutrients in control condition where irrigation was done regularly. Yield of stem amaranth is attributed with available nutrients, moisture content, light interception and ambient temperature. Partial shade during the early establish period of Moringa perhaps created optimum growth condition for stem amaranth by conserving moisture, microbial activities and protecting the plants from scorching heat. Al-Mamun (2009) conducted a study with turnip in association of Boilam tree and found the similar result in respect of yield. As plants had no competitive effect with Moringa tree for growth resources viz. light, water and nutrients, yield was statistically identical for plants grown in different distances from tree base.

CHAPTER V

SUMMARY AND CONCLUSION

The experiment was conducted at Agroforestry field laboratory of Sher-e-Bangla Agricultural University, Dhaka during the period from January to April 2018 to evaluate the suitability of stem amaranth during the early establishment period in Moringa based agroforestry farming system. The results considering the effect of Moringa saplings on growth, yield and yield attributing characters of stem amaranth was interpreted in this experiment. The influence of stem amaranth on growth characters of Moringa (No. of bud tree^{-1}, average length of bud) was also observed. The experiment consisted of four treatments viz., T_0 (Open field referred as control condition), T_1 (6 inch distance from tree base), T_2 (12 inch distance from tree base) and T_3 (18 inch distance from tree base). The experiment was laid out in Randomized Complete Block Design (RCBD) comprising four replications. The seeds of stem amaranth (var. Dhrutoraj) were sown in the main field directly with 15 days old Moringa cuttings on 11 February, 2018 which was harvested on 03 April 2018. Amaranth plant samples were randomly collected from each row of the respective plots. A total of 20 (5 from each replication) plants of amaranth were selected from each plot for data collection. Data were collected on plant height (cm), number of leaf plant^{-1}, leaf length (cm) and leaf breadth (cm), stem girth (cm), shoot and root length (cm), fresh weight (g), dry weight (g), fresh yield (t/ha). The collected data were analyzed statistically and the differences between the means were evaluated by R Core test.

Growth and yield attributing parameters were higher in control condition compared with other agroforestry treatments where plants were grown at different distances from tree base. The results of the experiment showed that the different treatments had significant effect on all the parameters tested. The highest plant height (58.75cm) was observed in the control condition and the lowest plant height of amaranth (49cm) was recorded in T_3 treatment where plants were grown at 18 inch distance from tree base. Among the agroforestry treatments, the height plant height (21.62) was found in T_1 treatment which was 16.5% lower than that of control plants. As expectation, the maximum number of leaf plant^{-1} (24.75), leaf length (9.6cm) and leaf breadth (5.37cm) were observed in the T_0 treatment at harvest, which was significantly higher from other agroforestry treatments. At harvest, the height leaf number plant^{-1}, leaf length and leaf breadth were recorded in the plants belong to T_1 treatment however the least leaf number plant^{-1} (19.75), leaf length

(7.29cm) and leaf breadth (4.28cm) were recorded in T_3 treatment. Among the treatments, T_0 was found to be superior with stem girth (5.71cm) that was 27.84% higher than the stem girth recorded in T_3 treatment (4.12cm). There was no significant variation in respect of stem girth between T_1 (4.68cm) and T_2 treatment (4.43cm). Root length (60.66cm) and shoot length (15.88cm) were also recorded the highest in control condition (T_0) compared to agroforestry system. The highest result in respect of fresh weight was found in open field condition (T_0 treatment) compared to other treatments. The maximum dry weight of root (1.05g) and shoot (4.33g) was superior in T_0 treatment while there was no significant variation of dry weight among other treatments under agroforestry treatments. Respect to fresh yield, highest yield (13.85 t/ha) was recorded in control condition (T_0 treatment) which was found 15.01% and 26.35% higher than T_1 (11.5 t/ha), T_2 (10.2 t/ha) and T_3 (10.2 t/ha) treatments respectively though there was no significant variation in respect of fresh yield among different treatments under agroforestry system. The highest bud number tree^{-1} and bud length (8.07cm) was superior in T_1 treatment where Moringa trees were closely associated with stem amaranth.

The findings of the experiment concluded that open field condition exhibited the highest results in respect of growth and yield of stem amaranth. Again there were positive interactions among different planting distances under Moringa based agroforestry in respect of fresh weight, dry weight and fresh yield. There was significant variation among different treatments in terms of yield parameters of stem amaranth. It can be suggested that the vegetable stem amaranth is suitable in association of Moringa tree as agroforestry practice. The aim of the study was to find out the tree-crop interactions between Moringa and stem amaranth. The results of the experiment revealed that there were negative tree-crop interactions in respect of different planting distances when Moringa tree were at their early stage of establishment. Among different planting distances T_1 (6 inch distance from tree base) appeared as the best treatment.

All the data generated in this study were based on one trail which conducted from 0 to 3 months of Moringa saplings. Therefore, before going to the final conclusion, repeated trail of stem amaranth should be conducted in association with Moring. Moringa-Stem amaranth interactions should be determined in terms of Soil nutrients light and water availability. Moringa should be intercropped with others Rabi and Kharif vegetables to know the Moringa−vegetables interactions more precisely.

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APPENDICES

Appendix I: Monthly meteorological information during the experimental period

Year	Month	Air temperature(^{0}C)		Relative humidity (%)	Total Rainfall (mm)	Sunshine (hr)
		Maximum	Minimum			
2018	January	24.60	13.50	68.50	00	5.7
	February	28.90	18.00	67	30	6.7
	March	33.60	29.50	54.70	11	8.2
	April	33.50	25.90	64.50	119	8.2

Appendix II: Analysis of variance of the data on plant height of stem amaranth influenced by different planting distances

Sources of variation	Degrees of freedom	Mean Square				
		Plant height				
		10DAS	20 DAS	30DAS	40DAS	50DAS
Replication	3	0.0833	0.000	0.099	0.207	0.724
Treatment	3	0.791**	4.916***	3.932***	21.016***	71.057***
Error	9	0.069	0.056	0.182	0.527	2.73

significance at 1% level of probability; * significance at 0.1% level of probability

Appendix III: Analysis of variance of the data on No. of leaves of stem amaranth Influenced by different spacing

Sources of variation	Degrees of freedom	Mean Square				
		Number of leaves plant^{-1}				
		10DAS	20 DAS	30DAS	40DAS	50DAS
Replication	3	0.1822	0.307	1.015	0.541	0.75
Treatment	3	1.39**	3.807**	2.682**	2.75*	17.458***
Error	9	0.15	0.307	0.265	0.541	0.347

*significance at 5% level of probability; **significance at 1% level of probability; *** Significance at 0.1% level of probability

Appendix IV: Analysis of variance of the data on leaf length & breadth of stem amaranth influenced by different spacing

Sources of variation	Degrees of freedom	Mean Square	
		Leaf length	Leaf breadth
Replication	3	0.121	0.235
Treatment	3	3.668***	1.01*
Error	9	0.122	0.168

*significance at 5% level of probability; *** significance at 0.1% level of probability

Appendix V: Analysis of variance of the data on stem length, shoot length and Root length of stem amaranth influenced by different spacing

Sources of variation	Degrees of freedom	Mean Square		
		Stem girth	Shoot length	Root length
Replication	3	0.019	1.228	0.353
Treatment	3	1.892***	56.1***	13.637***
Error	9	0.085	0.571	0.196

*** Significance at 0.1% level of probability

Appendix VI: Analysis of variance of the data on Fresh weight of stem amaranth Influenced by different spacing

Sources of variation	Degrees of freedom	Mean Square	
		Fresh weight	
		Shoot FW	Root FW
Replication	3	4.139	0.174
Treatment	3	20.12**	8.97***
Error	9	2.35	0.14

significant at 1% level of probability; * significance at 0.1% level of probability

Appendix VII: Analysis of variance of the data on Dry weight of stem amaranth Influenced by different spacing

Sources of variation	Degrees of freedom	Mean Square	
		Dry weight	
		Shoot DW	Root DW
Replication	3	0.051	0.001
Treatment	3	0.477^{**}	0.022^{***}
Error	9	0.056	0.001

*significant at 5% level of probability; *** significance at 0.1% level of probability

Appendix VIII: Analysis of variance of the data on Yield of stem amaranth influenced by different spacing

Sources of variation	Degrees of freedom	Mean Square
		Yield
Replication	3	0.85
Treatment	3	11.84^{*}
Error	9	1.73

*significant at 5% level of probability

PLATES

Plate 1: Land Preparation

Plate 2: Preparation of planting materials

Plate 3: Transplanted Moringa cuttings in experimental plot

Plate 4: Stem amaranth at 50DAS in association with Moringa saplings

Plate 5: Fresh weight and dry weight of stem amaranth measured by balance