EFFECT OF SHADING ON PERFORMANCE OF LEAFY VEGETABLES

MD. RASHEDUL HASSAN

DEPARTMENT OF AGROFORESTRY AND ENVIRONMENTAL SCIENCE
SHER-E-BANGLA AGRICULTURAL UNIVERSITY, DHAKA-1207

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BY

MD. RASHEDUL HASSAN

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APPROVED BY:

Zannatul Firdaus Binte Habib	**Dr. Nazmun Naher**
Assistant Professor	**Professor**
Supervisor	**Co-Supervisor**

Dr. Jubayer-Al-Mahmud
Chairman
Examination Committee

DEPARTMENT OF
AGROFORESTRY & ENVIRONMENTAL SCIENCE
Sher-e-Bangla Agricultural University (SAU)
Sher-e-Bangla Nagar, Dhaka-1207

CERTIFICATE

*This is to certify that the thesis entitled "**EFFECT OF SHADING ON PERFORMANCES OF LEAFY VEGETABLES**" submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE (MS)** in **AGROFORESTRY AND ENVIRONMENTAL SCIENCE**, embodies the results of a piece of bona fide research work carried out by **MD. RASHEDUL HASSAN**, registration no. **13-05509** under my supervision and guidance. No part of this thesis has been submitted for any other degree or diploma.*

I further certify that such help or source of information as has been availed of during the course of this investigation has duly been acknowledged.

Dated:
Place: Dhaka, Bangladesh

Zannatul Firdaus Binte Habib
Assistant Professor
Supervisor

DEDICATED

TO

MY BELOVED PARENTS

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ABSTRACT

A field experiment was conducted at Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka, Bangladesh during the period from March, 2019 to June, 2019. The aim of the study was to select best summer leafy vegetables, suitable for holding under different shade condition in agroforestry systems. The selected vegetables were also grown in control i.e., open field condition or in full sunlight. The vegetables were Indian Spinach, Stem Amaranth, and Red Amaranth and treatments were T_0= planting summer leafy vegetables under full sunlight, T_1= planting summer leafy vegetables under 50% shade condition (reduced light intensity) and T_2 = planting summer leafy vegetables under 75% shade condition. The experiment was laid out following single factor Randomized Complete Block design (RCBD) with three replications. During the study period maximum light intensity reduction was recorded in Red Amaranth (48.28%) in 75% shade condition and minimum light intensity was reduced in case of Indian Spinach (26.14%) under 50% shade condition. The reduced light intensity had substantial effects on various growth parameters such as plant height, number of leaves per plant, number of branches per plant, plant diameter, leaf chlorophyll content, height from base to crown and width of crown of the summer leafy vegetables. From the experiment, significant result was observed in all morphological characteristics for all leafy vegetables under reduced light intensity. Apart from this, highest yield was found in Stem Amaranth (22.33 ton/ha) and Indian Spinach (13.83 ton/ha) in 75% shade condition. Highest yield of Indian Spinach (19.40 ton/ha), Stem Amaranth (27.25 ton/ha) and Red Amaranth (11.30 ton/ha) was recorded under full sunlight. Considering shade condition, Stem Amaranth and Indian Spinach were best suitable for growing in Agroforestry systems.

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LIST OF ABBREVIATIONS AND ACRONYMS

FULL WORD	ABBREVIATION
And others (at elli)	*et al.*
Bangladesh Agricultural Research Institute	BARI
Bangladesh Bureau of Statistics	BBS
Bangladesh Forest Department	BFD
Centimeter	cm
Degree of Freedom	df
Degree Celsius	˚C
ed est (means That is)	i.e.
Exempli gratia (by way of example)	e.g.
Food and Agriculture Organization	FAO
Gross Domestic Product	GDP
Gram	g
Hectare	Ha
Kilogram	Kg
Least significant difference	LSD
Million hectare	Mha
Millimeter	mm
Photosynthetically Active Radiation	PAR
Percentage	%
Randomized Complete Block Design	RCBD
Metric, 1000 kg	Ton

CHAPTER I

INTRODUCTION

Bangladesh is the most densely and over populated countries of the world struggling hard to feed her 16.48 crore people (BBS, 2019). Population will be increased to 180 million by the year 2025, and the country will face huge problems to feed her population if the present population growth rate (1.37%) continues. The economy of the country describes its capacity and durability mostly from agriculture sector for about 13.60% of GDP (BBS, 2019). About 63.33% of the total population live in rural areas and are directly dependent on agriculture for their day to day live (World Bank, 2018). The country has only a land area of 14.39 million hectares, but due to the ever-growing population, per capita land area is decreasing at an average rate of 0.05 ha/cap/year since 1989 (Hossain and Bari, 1996) and therefore steadily declining the land: man ratio.

In Bangladesh, besides agriculture, forest land is also decreasing day by day with the increasing population at an alarming rate. But a country needs 25% of forest land of its total area for ecological stability and sustainability. Unfortunately, Bangladesh is possessed with only 17% (BFD, 2011) of forest lands.

In Bangladesh, the per capita intake of vegetable is only 53 g, which is very lower than the recommended daily requirement of 200 g/head/day. The low intake of vegetables creates a remarkable influence over cereals and also reasons for malnutrition leading to different kinds of health hazards and creates many diseases. Leafy vegetables are not cultivated evenly throughout the year in Bangladesh. About 35% of the vegetables are cultivated in summer season and the rest are produced in the winter season (Rashid, 1999). In summer season, many problems cause in the vegetable production like cloudy sky, low light intensity and excess rainfall are the major problems for vegetable production. The development of high yielding summer leafy vegetables could be one of the attainable efforts to rescue such problems. On the other hand, there is very little scope to increase cultivation area in Bangladesh. So, we need to find out other alternatives that can increase the production.

Agroforestry system is the integration of tree and crop or vegetables on the same area of land is a promising or hopeful production system for increasing yield (Nair, 1990) and sustaining amiable environment. Growing of crops or vegetables in association with trees is becoming very popular day by day in case of their maximum productivity, multipurpose use and environmental consciousness among the peoples. Leafy vegetables or upperstorey crops can be integrated with forestry, orchard, or other in agroforestry systems. But farmers face problems of growing leafy vegetables after 4-5 years of tree plantations and even sometimes fail to grow vegetables under and around trees because in agroforestry systems. In agroforestry systems, different types of species are grown in association. Therefore, there is an inevitable competition for the growth resources like light availability, water and nutrients that may reduce the productivity of the understorey in particular. Among different production limitations, light availability may be the most important limitation to the performance of the crops or vegetables particularly where an upperstorey perennial forms a continuous overstorey canopy (Miah *et al.*, 1995). However, under a given site condition, light availability to the understory crops/vegetables is dependent on the tree’s characteristics such as crown shape and density, sizeof the tree and tree management practices.

In Bangladesh, most of the vegetables grow in winter. Among the very few summers leafy vegetables Indian Spinach, Stem Amaranth and Red Amaranth are very common. During the year 2017-2018, the production of Indian Spinach was 81,903 metric tons covering with 25,611 acres of land (BBS, 2019). In the year 2018, total area covered by Stem Amaranth was 26,881 acres with the production of 74,899 metric tons (BBS, 2018). Red Amaranth covered 29403 acres with the production of 59,150 metric tons (BBS, 2017).

A multiple cropping system is a complex system, however, which requires knowledge of several types of crops and their interactions. When several crops are grown simultaneously on a single piece of land, between-crop interactions must be considered. One such interaction which can have substantial effects on productivity is that of shading by an associated crop, a problem which occurs when crops of different heights are grown together (Nair, 1977; 1983).

A broader scientific knowledge of the effects of shading can be helpful in developing cropping systems and planting methods which will optimize productivity. The deliberate shading of soil, seedlings, plants, and crops is carried out world-wide and especially by smallholders in developing countries to protect them from environmental stresses. The yield capacity of plants can be improved through shading for a number of reasons. Shading by trees can prevent water stresses through evapotranspiration and nutrient stresses by matching growth to available nutrients, stabilize differences in day and night temperatures and protect against rain, hail, and wind impact. A decrease in airflow can beneficially influence the transport of water vapor, heat, movement of CO_2 from or to surfaces, and reduce weed growth and sun scorch. If crops are planted under trees, the leaf litter can form mulch, which decomposes to release plant nutrients, reduce evaporation from the soil, and help to curb soil erosion. Pests and diseases are often discouraged by shade (Stigter, 1984). Trials which use artificial methods (industrially-produced materials) to reproduce natural shade are commonly used to investigate the effects of shade on plant growth.

In Bangladesh, unfortunately very few studies have been found in relation to screening out different summer vegetables in terms of their adaptability and yield under shade condition. In this situation, the present study of interaction performance of three summer leafy vegetables under reduced light level will be a pioneer study to introduce higher yielding and partial shade tolerant summer leafy vegetables. The specific objectives of the study were:

1. To evaluate the yield and yield contributing characters of three summer leafy vegetables under different shade levels;
2. To find out the difference between light and shade in case of yield of summer leafy vegetables; and
3. To identify the most suitable and adaptive summer leafy vegetable species for agroforestry systems.

CHAPTER II

REVIEW OF LITERATURE

This research has been embraced to screening of some summer leafy vegetables like Indian Spinach, Danta (Stem Amaranth) and Red Amaranth (Lal shak) are developed all through the world and their exhibition is to a great extent influenced under agroforestry system in view of improper daylight. Along these lines, literary works identified with the presentation of performance in tree-crop agroforestry system and qualities of tree species which were gathered through checking on of journals, thesis, web perusing, reports, papers, periodicals and other type of publication are presented in this chapter under the accompanying headings-

2.1 Concept of Agroforestry

Agroforestry does not actually mean planting trees in the fields or other places rather provide an effective land management system that can ensure more production in a balanced ecological environment. It assists to overcome shortcoming of traditional agriculture that are regularly described by low output at the cost of relatively high investment bringing about a deterioration of environment (Khalid and Bora, 2000).

Recently International Centre for Research in Agroforestry (ICRAF) defined, "Agroforestry as a dynamic, ecologically based natural resources management system that through the integration of trees on farmland and in the agricultural landscape, diversifies and sustains production or increased social, economic and environmental benefits for land users at all levels (World Agroforestry Centre, 2006)."

Nair (1983) stated that agroforestry is a collective name for all land use systems and technologies where woody perennials (trees, shrubs, palms, bamboo etc.) are deliberately grown on the same land management unit as agricultural crops and/or animals either in spatial mixture or in temporal sequence.

Vergara (1982) characterized agroforestry as an “arrangement of joining agricultural and tree crops of different life span (extending from yearly through biennial and perennial plants), gathered either temporally (crop rotation) or spatially intercropping to expand and support agricultural production.”

Leuscher and Khaleque (1987) stated that “Agroforestry consolidates agriculture and forestry service advancements to make increasingly coordinated, diverse, gainful, beneficial, sound and sustainable land-use frameworks.” Little scope agriculture assumes a significant job in Bangladesh economy. It gives almost half of income to the rural people.

From a business point of view, Saxena (1984) detailed that agroforestry is a monetary undertaking which intends to create a combination of agricultural and woods crops all the while. Agroforestry uses the inter space tree lines for intercropping with agricultural crops this doesn't weaken the development and improvement of the trees yet empowers farmers to infer additional salary in addition to benefits collected from the utilization of fuel and timber from trees.

According to Lundgren and Raintree (1982) that agroforestry is a collective name for land use systems and technologies where woody perennials are deliberately grown on the same land management units as agricultural crops and/or animals in some form of spatial arrangement or temporal sequence.

From a bio-financial perspective, Harou (1983) expressed that agroforestry is a joined agriculture-tree-crop cultivating framework which empowers a farmer or land client to utilize his property which may yield a higher net monetary profit for a sustainable premise.

Ong (1988) detailed that by consolidating trees with arable harvests, biomass creation per unit area could be expanded considerably when the roots of trees misuse water and supplements underneath the shallow roots of crops and when a mixed canopy catches increasingly sun-based energy.

Bhatia and Singh (1994) saw that the agroforestry in India assumes a significant role in expanding biomass production, keeping up soil fertility, saving and improving soil and turning away hazard.

MacDicken and Vergara (1990) reported that agroforestry is a method for overseeing or utilizing land (for example a land use system) that joins trees or shrubs with agricultural/horticultural crops or potentially domesticated animals.

Groot and Sourmare (1995) saw that decay of tree roots and dice substances of the root radiates enormously upgrade soil organic matter and in this way soil fruitfulness. Tree horizontal roots may diminish loss of supplements from the dirt by reusing them that would have been in any case drained from the system. Taproots may take up supplements, which are discharged by enduring from more profound soil layers.

Solanki (1998) found that agroforestry can essentially contribute in expanding request of fuel wood, grain and absence of money and foundation in many creating nations. He additionally expressed that agroforestry can possibly at the same time fulfill 3 significant goals: (i) ensuring and stabling the biological systems, (ii) creating an elevated level of yield of financial matters merchandise (fuel, feed, little timber, organic fertilizer and so forth) and (iii) giving stable work, improved income and essential material to rural populaces.

2.2 Tree-crop based Agroforestry systems and its structure

Tree-crop agroforestry or agrisilviculture implies cultivation of agricultural crops in conjunction with forestry crops over the same unit of land to maximize productivity and sustainability of the land.

As per Miah *et al.* (1995) Agroforestry framework is a framework that consolidates a scope of tree and harvest species offers considerably more extension for helpful administration of light interception and dissemination than monoculture forests and agricultural crops.

Akter *et al.* (1989) stated that farmers likewise considered tree as reserve funds and protection against danger of harvest disappointment and low yield, just as resources for their children. A few farmers expressed that tree would contribute towards costs for marriage of their young girls. In tree crop agroforestry framework tree species are developed and overseen in the farmland alongside agricultural crops. The point is to build the general yield of the land. This framework is likewise founded on the guideline of sustained yield (Nair, 1990).

Jackson (1983) proposed that for intercropping, ideally, the canopy should consist of overstory and C_3 understory, because the light saturated rates of plants are usually greater than those of C_3 plants. Thus, in closed canopies, the greater quantum efficiency of C_3 could become important. Crops with the lowest light saturation levels would appear to be most suited to the understory, with them being able to perform as well under a degree of moderate shade from a tree crop as they could in the open. Single leaves of crops such as maize, do not become light saturated in full sunlight, while sugar beet and soybean leave (C_3 plants) have been found to saturate at about half of full sunlight. With leafy crops, such shading could even be beneficial; redirecting a larger fraction of assimilates towards economic yield (leaf as opposed to total net production. Probably the major area of concern in agroforestry is that of light penetration through the canopy of the tree crop in sufficient amounts to support the growth of the intercrop. Where the understory crop is grown only in the first few years after planting the trees, there is little interference in light interception.

2.3 Crop performances in Agroforestry systems

The exhibition of various crops to the agroforestry systems was extraordinary. The performance of field crops in agroforestry systems is affected by the tree and crop species and their similarity, spacing, similarity; between tree lines, the executive’s practices, soil and climatic elements.

Primak and Shelepora (1989) conducted an experiment in tomato plants developed under a low light power and observed that there was a stamped decline in the photosynthetic surface zone of chloroplasts and a decrease in chloroplast numbers per unit zone in the cotyledons of assortments with high light prerequisites contrasted and cotyledons from plants of similar assortments a high light force. In shade tolerant assortments these distinctions were less marked.

Muthukrishnan and Irulappan (1986) considered the changeability of 95 promotions of *Abelmoschus esculentus* and *Abelmoschus manihot* and he found that critical contrasts among the increase for all the characters contemplated viz. plant stature, plant spread, number of primary branches per plant, days to flowering, hubs when the main flower show up, number of leaves per plant, leaf length, leaf expansiveness, petiole length, number of pod per plant, pod weight and complete yield changeability were most noteworthy.

Jadhav (1987) detailed that fractional concealing (45-50% of normal light) at 15 days in the wake of transplanting diminished grain yield of rice by 73% as a result of decrease in number of panicles per plant (51.5%), number of grain per panicle (16.7%) and increment in number of unfilled spike lets (42.1%) in twenty five rice cultivars.

Akbar *et al.* (1990) detailed that wheat yield under various tree species (Mulberry, Siris, Ipil-ipil) didn't show any huge contrast when contrasted with control yield.

Nasiruddin *et al.* (1995) led a test in two cultivars of tomato under various shading condition and revealed that shading expanded plant tallness, the tallest plants were those of Marglobe (157.82 cm) in complete shade treatment (dark polythene conceal or shade) and the shortest was Rama VF controls (83.38 cm) in characteristic light (no shade). The quantity of fruit per plants diminishes with the expansion of shading. Be that as it may, fruit size was most noteworthy and shading was most splendid under incomplete shade (coconut leaves shade). Shading diminished yields of Rama VF and Marglobe from 2.593 and 2.383 kg/m^2 in controls to 2.303 and 2.114 kg/m^2 separately.

Leonardo (1996) stated that shading (60% light reduction) reduced vegetative and fruit growth. Shading increased plant height shading also reduced chlorophyll content. Stomata density, transpiration rate and photosynthesis rate, yield of peppers decreased with increasing amount of shade levels.

Miah *et al.* (1995) stated that the mean light availability on crop lines decreased as they approached the tree lines 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 conditions (9 kg/ha).

Zheng and Li (1998) detailed that sapling of 8 tomato cultivars in a nursery were shaded to 20% of natural light for 14 days. Shading diminished dry weight by 30.98 to 74.33% with the littlest impact in cv. 1239-F 2121-0. This cultivar demonstrated no impact of shading on explicit leaf weight was diminished by up to 40.03% and the leaf area by up to 32.21%. Shading expanded plant height diminished plant dry weight at flowering.

Cockshull *et al.* (1992) completed a trial less than two shade treatments (light shade and heavy shade) in tomato plants and revealed that both two-shade treatments decreased the all-out crisp weight yield of fruit by 7.5 and 19.95% and the assessed aggregate over the ground biomass by 6.2 and 16.5% individually. Shading or concealing decreased normal fruit size and furthermore lessens the extent of fruit in the bigger size evaluations. Heavy shade likewise diminished the rate of uneven maturing in summer.

Ali (1999) stated that shade has articulated impact on morphological characters of numerous crops. It impacts plant tallness, stem diameter, internodes length, number of primary branches per plant, leaf number per plant, leaf size, thickness and leaf area and so forth. Plant height increments bit by bit with the abatement of light levels in okra.

Solanki (1998) expressed that fruit trees and crops are growth together in different manners. Contingent upon the pattern and configuration, these companion crops are known as intercrops, under planting, hedgerow or alley cropping. In an agroforestry framework where agricultural crops are ordinarily developed between lines of fruit trees, the agricultural crops give occasional income, though fruit trees managed for 30-35 years giving standard returns of fruitand in a few cases fuel wood from pruned wood and grain. A few sorts of crops are likewise under planted to exploit conceal of shade gave by the shelter of fruit trees.

Diverse in number of primary branches per plant because of shading is significant in light of the fact that it contributes most extreme towards the yield of grain legumes. The lower number of branches under concealed or shaded condition may be because of higher auxin creation in plant development under concealed or shaded condition. This ultimately stifled the development of sidelong branches (Miah *et al.*, 1999).

Souza *et al.* (1999) contemplated the impact of 3 degrees of shading (0, 30, and 50%) on the improvement and tuberous root yield of radish (*Raphanus sativus*) under field conditions and announced that 50% degree of shading expanded the plant tallness, life cycle, foliar area and diminish leaf chlorophyll content and the tuberous root yield where the plant was assessed at 7, 14, 21 and 28 days after rise. The 30% degree of shading didn't lessen the size or weight of the root.

An experiment was carried out by Healey *et al.* (1998) and they stated that level of incident radiation decreased by 25% under shade-cloth reduced final yield and final leaf index, but increased canopy leaf, nitrogen concentration and radiation use efficiency. A similar level of decreased incident radiation under solar weave shade-cloth increased final yield and radiation use efficiency (46-50%).

Onwueme and Johnston (2000) considered the impact of shading on stomatal thickness, leaf size, leaf dry matter and leaf lamina thickness in the major tropical root and tuber crops; Tannic (*Xanthosoma sagittifolium*), Sweet potato (*Ipomoea batatas*), Yam (*Dioscorea esculenta*) and Taro (*Colocasia esculenta*). They expressed that shading diminished stomatal thickness in the lower epidermis of tannic, sweet potato, yam and cassava. Taro under shade had an expanded stomatal thickness in both the upper and lower epidermis shading for the most part brought about the creation of bigger size of leaves however more thinner leaves in taro, sweet potato and yam.

Cave *et al.* (2001) revealed that the impact of various fruit expulsion and lighting/shading treatment on the example of amaranth (*Amaranthus lividus*), yields. While the removal of flowering trusses supports brought about a yield misfortune around about two months after the fact, Acre was little misfortune in aggregate yield as absorbs were disseminated to neighboring trusses. Expanded photosynthetic photon flux density (PPFD) for one week resulted in a period of increased yield from 4-6 weeks after the start of the treatments followed by suppressed yields due to smaller fruits on subsequent trees. Fruit size remained genuinely reliable (with the exception of when fruit expulsion medications were applied), though the quantity of fruits picked every week showed a lot more prominent variability.

Reddy *et al*. (2002) examined that under the tree shade plant tallness and root length, girth, dry weight and total chlorophyll content were higher contrasted and those kept in the open. Root length was diminished with 60 g leaf litter/container alone or in blend with 90 g for each root pieces/container. Treatment with 30 and 60g leaf litter per container decreased the shoot yield.

Rahman (2004) revealed that with the exception of plant height all others morphological attributes viz. no. of branches plant^{-1}, no. of fruit plant^{-1}, fruit length, fruit diameter and fruit weight of three vegetables (Tomato, Brinjal, Chili) were most elevated in open field condition. Among the distinctive agroforestry system, best return was acquired in Horitoki - Lemon - Vegetable based agroforestry system.

Zhang *et al.* (2002) announced that the impacts of three levels of irradiance (205.60 and 100% of full daylight at early flowering, top flowering and late flowering stages on the photosynthetic movement and yield of tomato that three levels of irradiance were forced for 8 days swing counterfeit shade net set 2m over the plots shading expanded the stomatal conductance and intercellular carbon dioxide concentrations and decreased early afternoon photosynthetic rates at the early and top flowering stages. However, plants at the flowering stage lighted with 60% of the all-out daylight demonstrated expanded net photosynthetic rates, total dry matter production and yield.

Ravichandran *et al.* (2005) examined that tree development was influenced by both thickness and intercrop in the underlying long periods of development. Photosynthetic photon flux density (PPFD) accessible to the intercrops decreased with expanding densities. Transpiration rate and stomatal conductance in intercrops diminished because of the nearness of trees. No huge changes in leaf temperature were seen till the fifth year of the developing season. Yield was altogether higher in pure crop in correlation with all the densities in mustard. Soybean yield under 200 trees ha^{-1}.

Senevirathna *et al*. (2003) analyzed the development, photosyntehtic execution and shade adjustment of rubber (*Hevea brasiliensis* genotypes PRRIC 100) plant developing in characteristic shade (33, 55 and 77% decrease in approaching radiation) to control plants developing in full sunlight. Stem diameter and plant tallness was most prominent in plants developed in full sunlight and the two parameters diminished with expanding shade. Total plant dry mass was most elevated in control plants and least in plants in 77% shade. Development of the fourth leaf whorl, checked at 5-6 MAP, was slowest in plants in 77% shade and fasted in shade less plants, which had more leaves and higher leaf zones and inter whorl shoot lengths. Expanding shade, explicit leaf zone expanded while leaf weight proportion and relative development rate diminished.

Chipungahelo *et al.* (2007) stated that leaf morphological attributes demonstrated light force unequivocally affected development and advancement of sweet potato. Explicit leaf area esteems in full light were littler than those in under overwhelming shade. The light intensity expanded the cowpea seed yield fundamentally and the interaction between seasons (year) × light systems was critical. In low intensity, pineapple flowered prior and yielded more than in high intensity. These outcomes have given helpful information in arranging intercropping models in coconut based–farming systems.

Islam *et al.* (2009) revealed that morphological attributes of winter vegetables, leaf length, leaf width, stem circumference, new and dry weight diminished reliably with the lessening of good ways from the tree. The development qualities of *Hopea oaiorata* was significantly affected by all the three winter vegetables (red amaranth, stem amaranth and coriander).

Monim *et al*. (2010) detailed that monoculture produce the best return of individual crops, all the intercropped and treatments includes red amaranth, spinach, coriander were found agronomically plausible and monetarily beneficial.

Islam *et al.* (2008) directed an investigation to assess the performance of winter vegetables under Guava-Coconut based multistrata framework. The outcome uncovered that altogether vigorous plant development just as tallest plants were found under decreased light level though greatest yield plot^{-1} and yield ha^{-1} were recorded under full sunlight condition.

Arya *et al.* (2011) recommended that in development and yield exhibitions of trees just as yearly crops developed in mix under tree-crop farming. Plant development and yield of all segment crops were higher when developed under conjugation when contrasted with their sole cropping.

Schwarz *et al.* (2014) found that the development of the single organs requests a specific measure of carbohydrates made from photosynthesis and consequently, requires an adequate every day vital of PPFD. In the event that this isn't accessible, physiological disorders may happen. Plants may turn out to be thinner, leaf thickness can significantly diminish, root development can be decreased bringing about conceivable water and supplement take-up insufficiencies that can make plants progressively sensitive to diseases. Specifically, when development points on fruit or seed creation, a higher pace of starch creation is required when contrasted with plants in their vegetative stage. Carbohydrate shortfalls bring about confined or smothered fruit set. Consequently, when day by day PAR is constrained in the accessible facility, the low carbohydrate production rate must be acquired line with a low improvement rate. This is conceivable in specific imperatives by developing the plants at low temperatures.

Ding and Su (2010) detailed that tree shading diminished the crop yield by 27 and 22% in western and eastern regions, separately, and furthermore, mean yield for western side was 23% lower than eastern side. The immediate explanation of yield variety was transpiration rate (E) variety at booting stage, that is, maize which had higher day by day mean E would acquire better return. In addition, changes of occurrence photosynthetically active radiation (PAR), air temperature (Ta) and CO_2 concentration (Ca) were the fundamental reasons of yield variation among various regions. Since higher PAR, higher Ta and lower Ca, which brought about by the tree shading, would all have prompted higher E lastly higher crop yield.

2.4 Shading effects on plant growth and development

Alley cropping Agroforestry system has been raised as a sound innovation where tree leaves are intermittently pruned to prevent shading the companion crops (Wilson *et al*., 1984).

An experiment was conducted by Yasoda *et al.* (2018) to study the effects of different shade levels on growth and yield performances of cauliflower. Different shade levels such as 25 % (open field), 50 % (single net house) and 75 % (double net house) were used as treatments. The influence of environmental attributes such as temperature, relative humidity and light intensity were also studied. The result revealed that growing of cauliflower in different shade levels showed great influence on plant growth and yield characters. There were marked variations was observed in number of leaves, plant height, curd weight, curd diameter and curd circumference of cauliflower under different light intensities. Light intensity in the shade net house was lower than in the open field. The highest vegetative growth and yield were achieved in cauliflower which was grown in 50 % shade levels and the lowest yield was in 25 % shade level (open field). It can be concluded that cauliflower can be cultivated in 50 % shade levels successfully to produce quality curd.

The partial shading (45-50% of typical light) at 15 days in the wake of transplanting diminished grain yield of rice by 73% on account of decrease in number of panicles per plant (51.50%), number of grains per panicle (16.70%) and increment in number of unfilled spikelet's (41.10%) in 25 rice cultivars (Jadhav, 1987).

Flores *et al.* (2015) conducted an experiment to examine the interaction between the effect of shading and increased N doses over the production and nutritional quality in tomato grown under high temperature conditions (maximum day temperatures up 45 ºC during the fruiting period). Plants were grown under greenhouse conditions in 20L-pots, and irrigated with nutrient solution containing 3, 7 and 14 mM N. These treatments were combined with two different shading treatments: non-shaded (control) and shaded plants covered with AOL S40 shade-cloth that attenuated approximately 50% of the direct sunlight and reduced temperature about 11 ºC during the day time. Under non-shade conditions, decreasing N dose produced a decrease of the total fruit yield. However, under shade conditions, the highest total yield was obtained in plants cultivated with 7 mM N. In addition, the highest value of mean fruit weight among all the shading and N treatments was obtained under shading + 7 mM N treatment. Regards fruit quality, the use of shade-cloth led to an increase in fruit lycopene concentration regardless of the N treatment. The results show that N doses should be adjusted when using shading for reducing air temperature in warm climate zones, in order to avoid excessive fertilization.

Smith and Whiteman (1983) criticized work with pasture legumes which attempted to evaluate the relative tolerances of different species by growing them under artificial shade. They stated that this system neglected the other competitive effects of the natural environment, in this case an established tree crop.

Spinach (*Spinacia oleracea* L. cv. Active) was cultivated four times during the summer season (from June to September) in four plastic houses with different aluminum coated polyethylene nets which had 0%, 30%, 45%, and 60% shading ratios, respectively, to prevent the increase of air and soil temperature in plastic houses. Integrated solar radiation in plastic houses was decreased as shading ratio increased. Air and soil temperatures were kept the same. Spinach growth was the best under 45% shading ratio in June, August, and September and 60% in July. Sugar and ascorbic acid (vitamin C) contents were decreased as shading ratio increased in all seeding times. Nitrate content was highest under 45% shading ratio in July, August and September and 30% in June. Soluble oxalate content was highest in June, July, and August and lowest in September in the non-shaded house (Araki *et al.*, 1999).

Rao and Mittra (1988) saw that shading by taller species for the most part lessens the photosynthetically active radiation which manages photosynthesis, dry matter creation and yield of crop.

Smith and Whiteman (1983) evaluated eight tropical grass species under different coconut densities producing five different shade levels ranging from 100 to 20%. Several of the grass species were well-adapted to the shade in coconut plantations. The productivity and persistence of these grasses depended on their adaptability to shading and to competition from the coconut palms.

Under tropical and subtropical conditions, yields and quality of vegetable crops have been improved by shading. For example, tomatoes, spinach and lettuce yielded more under reduced PPF conditions ranging from 15% to 50% shade in regions with high light intensities (Glenn *et al.,* 1984; Mattei and Sebastiani (1973); Smith *et al.,* 1984).

Singh *et al.* (1989) stated that the shading was liable for concealment of maize yields while in the shorter second season, where rains finished unexpectedly, moisture competition was the fundamental factor causing the definitely low yield.

Jayachandran *et al.* (1998) directed investigations in Kerala, India and demonstrated that the coconut (*Cocos nucifera*)- ginger (*Zingiber officinale*) system under rainfed condition gives great returns since ginger performs well under shade, where scarcely any different crops do. The yield of ginger under 0, 25, 50 and 75% artificial shade was tested.

Laosuwan *et al.* (1992) discovered the better return of mungbean and onion, individually, become under the unshaded condition.

Shading of barley plants during different stages of development also influenced grain yield. Shading during ear development caused considerable yield reductions, while no reduction in grain yield occurred from shading during the grain filling period (Willey and Holliday, 1971).

Impact of reduced light on four summer vegetables, for example, Red Amaranth, kangkong, okra and Indian spinach was accounted for by Wadud (1999). The light levels were 100, 75, 50 and 25 % PAR. Red amaranth and Indian spinach had been found to develop well in full sunlight while kangkong and okra indicated better execution under 75% PAR.

An experiment was conducted by Lopez-Marin *et al.* (2012) to determine the effects of shade, simultaneous comparisons were carried out among greenhouses that were either not shaded (control treatment) or shaded with reflective aluminized shade cloth positioned below the roof, which attenuated 40 (T40) or 60% (T60) of direct sunlight. The shade was applied at the beginning of hot weather in early May. The shading screens were kept until the end of the crop cycle and fruit was picked until August. Leaf CO_2 assimilation rate, relative chlorophyll content (SPAD) and absolute chlorophyll content, Fv/Fm, transpiration rate, stomatal conductance, internal CO_2 concentration and water use efficiency were measured. Plants cultivated under 40 and 60% of shading significantly decreased the net CO_2 assimilation rate, stomatal conductance, and transpiration. Plants cultivated under 60% of shading had higher contents of chlorophyll *a, b*. Under 40% of shading, plants yielded 1.26 kg m^{-2} more than under control. However, the yields of T60 and control treatment were similar (8.9 kg m^{-2}). The use of shading decreased the unmarketable yield.

2.5 Light effects on plant growth and development

The significance of light in the development of plants is an entrenched wonder. Distinctive physiological procedures of plants i.e; photomorphogenesis, evaporation, transpiration and so forth are affected by sun powered radiation. Light plays out a significant capacity in plant development and improvement. It is fundamental in the creation of vitality that supports life through the procedure of photosynthesis, the procedure by which plants fabricate nourishment as sugar (starch). In addition, it impacts or controls other plant development procedures, for example, the synthesis of the different photoreceptors (for example: chlorophyll, different shades), photomorphogenesis (organ arrangement and advancement), phototropism (plant reaction to one-sided light), photoperiodism, translocation, stomatal movement, abscission, mineral assimilation, and transpiration. (Devlin, 1975; Edmond *et al.*, 1978).

An experiment was carried out on a wide range of plants on the effects of reduced photosynthetic photon flux (PPF) have shown that great variability of response exists between and within crop species. Most plants respond to variation in available radiation by some type of morphological and physiological changes. Specific responses, however, depend on a number of factors, including species and cultivar, the light conditions under which a crop was grown, the light saturation point of the leaf canopy, and other environmental factors, especially temperature (Hesketh and Moss, 1963; Knight and Mitchell, 1983; Ketring, 1984; Martin, 1985).

About ninety percent of the dry weight increase of plants arises directly from photosynthesis (Osman and Milthorpe, 1971) indicates that the availability of sunlight can be the most significant determinant of plant productivity. Therefore, it can be argued that a primary means whereby the greatest crop productivity can be attained is to keep the photosynthetic system operating at its optimum capability (Loomis and Williams, 1963; Loomis and Gerakis, 1975). It may be assumed that this indicates providing the crop with the greatest amount of radiant energy available.

Light is the unmistakable bit of the sunlight-based radiation or electromagnetic spectrum. It is a type of kinetic energy that originates from the sun in modest particles called quanta or photons, going in waves. Three properties of this climatic factor that influence plant development and improvement are light quality, light power, and daylength or photoperiod. Light quality alludes to the particular frequencies of light; light power is the level of brilliance that a plant gets; and daylength is the length of the day concerning the night time frame. Sun based radiation instigated plant development and creation additionally relies upon capture attempt of radiation on leaf and shade level, leaf area index and so forth. Sun oriented radiation is significant asset in multistoried creation framework since it is the vitality hotspot for photosynthesis and transpiration, subsequently development and advancement of plants. But extreme thickness just as over the top presentation or exceptional decrease of sun-oriented vitality may discourage economics yield. In any agroforestry framework, trees developed in nearness to crop, frequently significantly more extension for valuable administration of light block attempt and circulation that do monoculture. Light is a fundamental factor on plant development and improvement. The significant light factors influencing plant development are light quality, light intensity, photoperiod and day/night cycle (Goto, 2003).

Full daylight required for ideal development and improvement of numerous plants, especially those developed in summer. Under light intensities of around 20 to 50% of full daylight, most extreme vegetative development is achieved. The leaves arrive at their most noteworthy region, the shelter its greatest width and the stem is greatest tallness (Weaver and Clements, 1973).

Partial shade expands succulence and delicacy of structure. Numerous vegetables and a few spices do best under such a condition. Diffuse light advances the improvement of vegetables structures while extraordinary light favors the advancement of flowers, fruits and seeds. In shorts, it might be expressed that various plants and various pieces of specific plant reaction diversely at various light intensities (Perez-Balibrea *et al*., 2008).

A plant under natural conditions receives light from the sun; the amount, quality and duration greatly depend on the season of the year, hour of the day, geographical location and weather. Plants use light as a source of energy for photosynthesis. It is primary metabolites in plants (Kopsell, 2008). The carbohydrates produced during photosynthesis are stored and used by the plant as a food source. Light intensity can affect plant canopy, flowering, leaf size, and colour in both herbaceous and woody species (Hampson *et al*. 1996).

A multiple cropping system is a complex system, however, which requires knowledge of several types of crops and their interactions. When several crops are grown simultaneously on a single piece of land, between-crop interactions must be considered. One such interaction which can have substantial effects on productivity is that of shading by an associated crop, a problem which occurs when crops of different heights are grown together (Nair, 1977; 1983).

2.6 Effect of colored shade nets on plant growth and development

Efforts to control plant morphology and physiology utilizing photo-selective filters have been progressing for a considerable length of time, particularly in greenhouse situations (Faust *et al*., 2003; Rajapakshe *et al.*, 1999). More recently, colored shade netting (shade cloth) structured specifically for controlling plant advancement and development has opened up. These nets can be utilized outside just as in greenhouse. They can give physical assurance (fowls, hail, bugs, insects, inordinate radiation), influence ecological modification (mugginess, conceal, temperature) (Perez *et al.*, 2006), and increment the general extent of diffuse (dispersed) light just as retain different spectral bands, in this manner influencing light quality.

A field trial was conducted at Central Institute of Post-harvest Engineering and Technology (CIPHET), Abohar (Punjab) during 2011-12 to determine the effect of three green shade nets (35,50 and 75%) along with three height (2, 2.5 and 3.5 metre) bamboo framed structures on yield and quality of tomato. There was no significant difference found in average monthly temperature and humidity inside shade net house and open field (control). Significant difference was recorded in yield. Highest average plant yield of (3.49 kg/plant) was found in 35 % shading net followed by open field (2.27). Lowest yield observed (1.07 kg / plant) in 75 % shading net. The tomatoes grown under shade net structures were glossy in appearance with good colour development as compared to open field (control). Further tomatoes produced in open field were attacked by the pest (Helicoverpa armigera) attack. No significant difference was observed in quality attributes viz. TSS, Acidity and ascorbic acid by shade net structures. However, the higher TSS (6.1 ^{o}Brix), Acidity (0.69) and ascorbic acid (40.86 mg/100gm) was recorded in 35% shade net compare to control, (5.7, 0.61 and 36.42) respectively. Thus, use of 35 % shade net brought improvement in quality and yield of tomato grown in semi-arid region (Nangare *et al.*, 2015).

Robert (2009) recommended that colored shaded netting has various impacts other than photo-selective ones, and even photo-selectivity can change after some time, it is significant that researchers give cautious and complete descriptions of test conditions. Radiation quality and amount esteems and microclimate parameters ought to be estimated and answered to help in the assurance of which components may be creating any announced outcomes.

As per Valli *et al.* (1965) approaching radiation in the open is made out of solar and air radiation. Under the shade net there is likewise the net reflected and net transmitted vitality, less the measure of episode vitality which is reflected and radiated by the highest point of the shade once again into the atmosphere. Approaching radiation at the soil surface under the shade is influenced by the shade net. The net reflects a portion of the total energy incident upon it and absorbs some of the energy which is then reradiated out as long wave energy. These impacts can impudence crops just as the organisms related with them. Colored shade netting is a moderately new instrument that can be utilized for a wide assortment of purposes by horticulturists. In any case, the impacts are fluctuated and plant reactions may vary even among cultivars of a similar plant.

2.7 Importance of summer leafy vegetable crops

Vegetables are usually recognized as cheap, easily available sources of carbohydrates, proteins, minerals and vitamins. Importance of three studied summer vegetables namely Indian Spinach, Danta (Stem Amaranth) and Red Amaranth are as follows:

2.7.1 Importance of Indian spinach

Indian Spinach (*Basella alba* L.) commonly known as *pui* and belongs to the family Basellaceae. There are mainly two distinct types. One is *Basella alba* and another is *Basella rubra*. One with green petioles and stems where the other with reddish leaves, petioles and stems. Both the green and red leaved cultivers are consumed as vegetables but green-leaved cultivers are commercially cultivated.

The nutritive value of Indian Spinach is very high with a good content of minerals and a moderate storage of vitamins to the human diet as well as substantial amount of fibre and that of water (Ghosh and Guha, 1933). The plant is stated to contain the following salts and vitamins. Calorie- 27 k cal, Fat- 0.2%, Starch- 4.2%, Moisture- 93%, Protein- 2.2%, Iron- 1.5%, Calcium– 0.16%, Carotin- 12750 IU, Vitamin B1- 0.02 mg, Vitamin B2- 0.36 mg, Vitamin B3- 64 mg and Vitamin A– 3250 IU/100g. Moreover, it is anadyne, sedative, diuretic and expectorant (Kallo, 1986).

2.7.2 Importance of Stem Amaranth (Danta)

Stem Amaranth (*Amaranthus viridus*) belongs to the family Amaranthaceae is commonly known as „Danta‟ and used as leafy as well as stem in Bangladesh. Stem Amaranth is considered to be the cheapest vegetable in the market that is why it is called poor man‟s vegetable (Shanmugavelu, 1989). Stem Amaranth is fairly rich in vitamin A and ascorbic acid. It has an appreciable amount of iron, calcium, phosphorous, riboflavin, thiamine, niacin and iron (Thompson and Kelly, 1988). Per 100 g of edible portion it contains 43 caloric which is higher than those of other vegetables except potato and taro (Chowdhury, 1967). During Kharif season vegetable production in our country is very low.

The maximum production of different vegetables is concentrated during the months of November and April that is especially in winter season. Thus, there is a serious scarcity of vegetables during the months of May to September in the market. As a result, the nation runs short of vegetables, its production should be increased to meet up the shortfall and feed the ever-increasing population of the country.

2.7.3 Importance of Red Amaranth

Red Amaranth (*Amaranthus gangeticus*) belongs to the family Amaranthaceae is commonly known as "Lal Shak" and used as leafy vegetables in Bangladesh. Red Amaranth is one of the most popular and important vegetable in Bangladesh. For their quick growing and higher yield potential it is very popular in Bangladesh. The fresh tender leaves and stem of red amaranth are so delicious when it cooked by boiling and mixing with condiments. Moreover, the seeds of red amaranth have various bakery uses. Red amaranth can play a vital role in elevating the nutritional status specially vitamins and minerals of Bangladesh (Hossain, 1995).

Red Amaranth is the most common leafy vegetable grown during summer and rainy seasons. It fit well in crop rotation because of its very short duration as well as large yield of edible portion per unit area. It is usually grown in kitchen, market gardens and high lands. It can be grown as mixed crops along with cereals, pulses and vegetables (Muthukrishnan and Irulappan, 1986).

The leaves and tender stems of red amaranth are rich in protein, vitamin A & C, minerals. However, the nutritive values of red amaranth have been shown by Aykroyd (1963) as follows: (Per 100g of edible portion)

Moisture- 85.7%, Fat- 0.5%, Fibre-1.0 g, Minerals- 2.7 g, Carbohydrates- 6.3 g, Phosphorus- 83 mg, Sodium- 230 mg, Calcium- 397 mg, Vitamin A- 9200 IU, Vitamin C- 99 mg, Thiamin- 0.03 mg, Riboflavin- 0.10 mg, Nicotinic Acid- 1.00 mg, Iron- 25.5 mg, Potassium- 341 mg and Sulphur- 61 mg.

The fresh tender leaves and stem of red amaranth are so delicious when cooked like other leafy vegetables. The tiny seed of grain red amaranth are propped or parched and milled for flour or gruel. In taste, nutritional value as well as yield, the grain compares favorably with maize and other true cereals (Aykroyd, 1963).

CHAPTER III

MATERIALS AND METHODS

The experiment was conducted to evaluate higher yielding and partial shade tolerant summer vegetables under reduced light levels i.e., full sunlight and reduced light intensity-based agroforestry system during the period from March to June, 2019. This chapter deals with the materials and methods of the experiment with a brief description on experimental site, soil, climate, planting materials, land preparation, fertilizer application, experimental design and treatment combination, seed sowing, intercultural operation, harvest, data collection, data recording and their statistical analysis etc. are included here. The details of investigation for stated objectives are described below:

3.1 Site description

The experiment was conducted at Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka, Bangladesh during the period from March to June, 2019. The experimental site was located between $23^{0}74^{/}$N latitude and $90^{0}35^{/}$E longitudes with an altitude of 8.2 m. (Anon., 1989).

3.2 Soil characteristics

The experimental site belongs to the agro-ecological zone of “Madhupur Tract”, AEZ-28 (Anon., 1988a). For better understanding, the experimental site is shown in the AEZ Map of Bangladesh in Appendix I. This was an area of complex alleviation and soils created over the Madhupur clay, where floodplain sediments covered the analyzed edges of the Madhupur Tract leaving little hillocks of red soils as 'islands' encompassed by floodplain (Anon., 1988b). The soil was sandy loam with pH 5.6 and Cation Exchange Capacity (CEC) 2.64 meq 100 g soil^{-1}, respectively. The morphological characteristics of the experimental field and physical and chemical properties of initial soil are given in Appendix II (Khatun, 2014).

3.3 Climate and weather

The geographical location of the experimental site was under the sub-tropical climate characterized by three particular seasons namely the monsoon or rainy season broadening from May to October which is associated with high temperature, high humidity and heavy rainfall; the winter or dry season from November to February which is associated with moderately low temperature and the pre- monsoon period or hot season from March to April which is associated with some rainfall and occasional gusty winds. Information respect to monthly maximum and minimum temperature, rainfall, relative humidity and sunshine during the period of study of the experimental site was collected from Bangladesh Meteorological Department, Agargaon and is presented in Appendix II.

3.4 Shade and plant materials

In this experiment artificial shading was created by dark green colored mosquito net. Four pieces of bamboo stakes were pegged at four corners of the shade treatment plots. The dark green colored mosquito net was then spread over the stakes to cover the plants from all sides. Care was taken to keep the mosquito net shade in appropriate condition with dynamic pace of development and yield of the plants.

As leafy vegetable V_1= Indian Spinach, V_2= Stem Amaranth (Danta), V_3= Red Amaranth were used and the seeds of these vegetables were collected from Siddique Bazar, Dhaka. These three summer leafy vegetables were used as planting materials in this experiment.

3.5 Experimental treatments

1. T_0 - Planting summer leafy vegetables under full sunlight (open field condition)
2. T_1 – Planting summer leafy vegetables under reduced light intensity (50% shaded condition).
3. T_2 – Planting summer leafy vegetables under reduced light intensity (75% shaded condition).

In treatment T_0 - sunlight was allowed to fall over the leafy vegetables without any barrier which was considered as full sunlight level.

In treatment T_1 and T_2 - plants were grown under dark green colored mosquito net which permitted reduced light intensity or PAR (Photosynthetically Active Radiation) to reach to the vegetables under artificial shade.

3.6 Experimental design and layout

Three summer leafy vegetables viz. Indian Spinach (V_1), Stem Amaranth (V_2) and Red Amaranth (V_3) were sown under full sunlight (100% PAR) and shade following the Randomized Complete Block Design (RCBD) with single factor experiment. Three treatments were used in this experiment. Three replications were used for each treatment for each vegetable. So, there were in total 9 (3×3) treatment combinations such as V_1T_1, V_1T_2, V_2T_1, V_2T_2, V_3T_1, V_3T_2, V_1T_0, V_2T_0, V_3T_0 and total 27 (9×3) plots were set up. Individual plot sizes for vegetables were 2.85 m × 2 m. Adjacent plots and neighboring blocks were separated leaving by 0.5 m and 1 m respectively (Appendix IV).

3.7 Preparation of land

The selected plot for the experiment was opened in 13th March 2019 with a power tiller and was exposed to the sun for a week. On 20th March 2019, the selected land was harrowed, ploughed and cross-ploughed several times followed by laddering to obtain a good tilth. Weeds and stubbles were removed and a desired tilth was obtained finally land was proper leveled. Land layout design and seedbed preparation was done on 20th March, 2019.

3.8 Crop establishment and management

3.8.1 Sowing of seed

Among three summer leafy vegetables Indian Spinach, Danta and Red Amaranth were directly sown in the experimental plot on 25th March, 2019. Seeds of Indian Spinach, Danta (Stem Amaranth) and Red Amaranth were sown in line sowing method. The leafy vegetable (Indian Spinach, Danta, Red Amaranth) seeds were sown maintaining the spacing of 50 cm from one line to another. One day after sowing of seeds, light irrigation was given to facilitate and enhance the germination process.

3.8.2 Application of fertilizers and manures

Recommended dose of well decomposed cowdung were applied for all the crop species. Chemical fertilizer was applied as per the Islam and Haque (1992) recommendation fertilizers of this crop. Full amount of TSP, MP and well decomposed cowdung was incorporated during the final land preparation. Urea fertilizers were applied in three equal installments.

For Indian Spinach

Name of Fertilizer	Doses/ha	Application (%)			
		Basal	15 DAS	30 DAS	45 DAS
Cowdung	4 ton	100	- -	- -	- -
Nitrogen (as Urea)	280 kg	--	33.33	33.33	33.33
P_2O_5 (as TSP)	80 kg	100	- -	- -	- -
K_2O (as MP)	75 kg	100	- -	- -	- -

For Stem Amaranth

Name of Fertilizer	Doses/ha	Application (%)			
		Basal	15 DAS	30 DAS	45 DAS
Cowdung	5 ton	100	- -	- -	- -
Nitrogen (as Urea)	250 kg	- -	33.33	33.33	33.33
P_2O_5 (as TSP)	100 kg	100	- -	- -	- -
K_2O (as MP)	80 kg	100	- -	- -	- -

For Red Amaranth

Name of Fertilizer	Doses/ha	Application (%)			
		Basal	15 DAS	30 DAS	45 DAS
Cowdung	5 ton	100	- -	- -	- -
Nitrogen as Urea	220 kg	- -	33.33	33.33	33.33
P_2O_5 (as TSP)	70 kg	100	- -	- -	- -
K_2O (as MP)	60 kg	100	- -	- -	- -

3.8.3 Thinning and Gap filling

In case of Stem Amaranth and Red Amaranth thinning was done after the emergence to maintain the proper plant stand. In case of Indian Spinach, Gap filling was done 10 days after the emergence to assure the uniform plant growth.

3.8.4 Protection of plant

At early stage of plant growth few leaf miners infested the young plants as well as at later stage of growth borer attacked the plant. To control the insects, Ripcord 10 EC was sprayed at the rate of 1 ml with 1 litre water for two minutes at 15 days interval after seedling germination.

3.8.5 Weeding and irrigation

To keep the plots free from weeds, weeding was done five times for experimental plots. The plots were irrigated seven times by using hose pipe and water cane to supply sufficient soil moisture for the leafy vegetables.

3.9 Harvesting

Indian spinach was harvested for 3 times; first harvesting was done after 60 days of seed sowing. Stem Amaranth and Red Amaranth were harvested for 1 time for final harvesting.

3.10 Procedures of sampling and data collection

Plant samples were collected randomly from all rows of the respective plots. Five representative sample plants were selected from each row per plot for data collection. Sample plants were collected based on suitable size for consume.

In case of Indian Spinach, Stem Amaranth and Red Amaranth

- Plant height, number of leaves per plant, number of branches per plant, plant diameter, leaf chlorophyll content, height from base to crown, width of crown was recorded at 15, 30, 45 and 60 DAS (Days After Sowing).
- In case of Indian Spinach yield/plot and yield/hectare was recorded at 30, 45 and 60 DAS.
- In case of Stem Amaranth yield/plot and yield/hectare was recorded at 60 DAS.

3.11 Light measurement

Lux meter was used to measure light on each leafy vegetable crop rows. It was done to determine the extent of shading by the artificially created shade and expressed as lux. The intensities of light were measured above the canopy of leafy vegetable crops at 9.00- 10.00 am, 1.00- 2.00 pm and 4.00- 5.00 pm using the Lux meter at three times per month and collected data were averaged and expressed as lux.

3.12 Soil moisture measurement

Soil Moisture Meter was used to measure Soil moisture on each leafy vegetable crop rows and expressed as percentage (%). Soil moisture was measured 10 cm depth of soil adjacent to main root of leafy vegetable crop rows at 9.00- 10.00 am, 1.00- 2.00 pm and 4.00- 5.00 pm in 3 times per month and collected data were averaged and expressed as percentage (%).

3.13 Soil temperature measurement

Soil Temperature Meter was used to measure Soil temperature on each leafy vegetable crop rows and expressed as degree centigrade (˚C). Soil temperature was measured 10 cm deep soil adjacent to main root of leafy vegetable crop rows at 9.00-10.00 am, 1.00- 2.00 pm and 4.00- 5.00 pm in 3 times per month and collected data were averaged and expressed as degree centigrade (˚C).

3.14 Leaf chlorophyll content measurement

SPAD meter was used to measure Leaf chlorophyll content whose model number was SPAD-502 Plus. Foliar chlorophyll content was measured by placing the SPAD meter at three positions of the particular leaf from which data were taken at 15 days interval. Then collected data were averaged.

3.15 Statistical analysis

The data obtained for different parameters were statistically analyzed to find out the significant difference of summer leafy vegetables under different shading conditions. The mean values of all the characters were calculated and analysis of variance techniques to obtain the level of significance by using a computer program STATISTIX 10. The significant differences among the treatment means were compared by Least Significant Difference (LSD) at 5% levels of probability (Gomez and Gomez, 1984).

CHAPTER IV

RESULTS AND DISCUSSION

This chapter comprises of the presentation and discussion of the results obtained from the present study. The results have been presented, discussed and possible interpretations were given in tabular and graphical forms. The results obtained from the experiment have been presented under separate headings and sub-headings as follows:

4.1 Crop Environment

4.1.1 Light availability on crops

Plants need daylight for their photosynthesis, and their development rate is relative to the amount got, taking into account that other environmental attributes are not constraining for their development and improvement. Noticeable light is a composite of frequencies somewhere in the range of 400 and 700 nanometers (nm), and this particular waveband is characterized as PAR. PAR comprises of frequencies that are used by the plant in the procedures of photosynthesis to change over light energy into biomass (i.e; carbon molecules (sugars) that are then used to build progressively complex compound, and eventually plant cells and organs (root, leaf, stem, flower, fruit).

Light availability was estimated to decide the degree of limiting radiation by conceal or shade net on the understorey vegetable lines. Light for various crops in sun and shade conditions which was estimated as introduced underneath-

Table 1: Light availability in the different crops from March to June 2019

Light condition (kilolux)	Indian Spinach		Stem Amaranth		Red Amaranth	
	Light	% Reduction	Light	% Reduction	Light	% Reduction
50% Shade	52.02	26.14%	48.27	30.00%,	46.01	28.97%
75% Shade	40.08	43.09%	36.08	47.67%	33.50	48.28%
Full Sun	70.43		68.96		64.78	

From this Table 1 it is observed that during the study period maximum light intensity reduction was recorded in Red amaranth (48.28%) in 75% shaded condition and minimum light intensity was recorded in Indian Spinach (26.14%) under 50% shade. This may happen as Red amaranth plants don't grow well in 75% shaded condition and absorbs little light in 75% shade. On the other hand, Indian Spinach absorbs maximum light and grows well in 50% shaded condition.

4.1.2 Soil temperature

In March, the mean monthly soil temperature was 32.0°C in the 50% shade compared to 30.3°C in the 75% shade and 33.6°C in the open. The maximum temperature was recorded in April- 35.7°C in sun and 34.2°C in 50% shade and 33.5°C in 75% shaded condition. In the months of May and June soil temperature was diminished from 35.1°C to 34.5°C in open condition and from 34.0°C to 32.9°C in 50% shaded condition and 33.3°C to 32.1°C in 75% shaded condition. This has been presented as the graphical presentation as below –

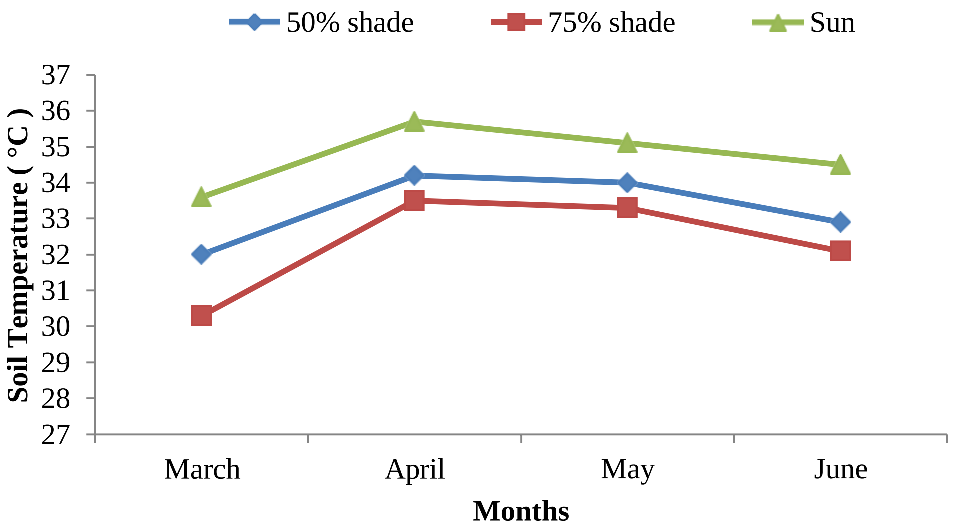

Figure 1: Sun and Shade effects on soil temperature from the months of March to June 2019

4.1.3 Soil moisture

In March, mean monthly soil moisture was 15.6% in the 50% shaded condition compared to 14.8% in the 75% shaded condition and 19.3% in the open. In April, the soil moisture was reduced in sun to 14.2% and increased to 15.7% in the 50% shaded condition and 17.1% in the 75% shaded condition. The highest soil moisture was recorded in June among in open, 50% shade and 75% shade as 38.3%, 32.6% and 28.5% followed by May where soil moisture was 29.8%, 25.1% and 22.3% in sun, 50% shade and 75% shade respectively. This is presented as the graphical presentation as below-

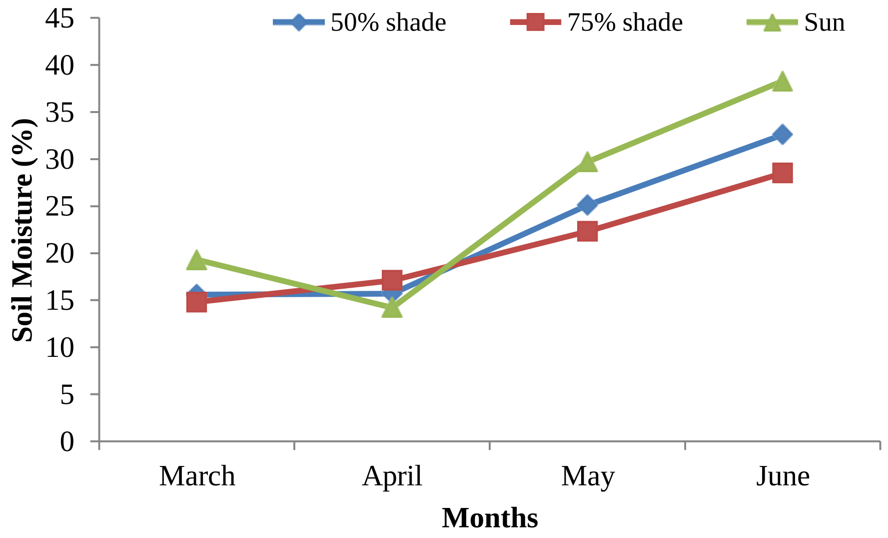

Figure 2: Sun and Shade effects on soil moisture from the months of March to June 2019

4.1.4 Soil moisture and temperature effects on three summer leafy vegetables in May 2019

Impacts of Sun and shade on soil moisture and ultimate effect on Indian spinach, Stem Amaranth and Red Amaranth were recorded and significant variations were found. In case of Indian Spinach, highest soil moisture in 75% shaded condition 28.3% was observed while the highest soil moisture in 50% shaded condition and in open or sun was recorded in Red amaranth 22.1% and 20.3%. In sun, the lowest soil moisture was recorded in Stem amaranth 19.0% while in 50% shaded condition was recorded 21.5% (Figure 3).

Impacts of sun and shade in soil temperature on Indian spinach, Stem amaranth and Red amaranth were recorded and found significant differences. In sun, the highest soil temperature was recorded in Stem amaranth 34.6°C. In 50% shaded condition, the highest soil temperature was recorded in Red amaranth 32.2°C and in 75% shaded condition the highest soil temperature was recorded in Stem amaranth 30.5°C (Figure 4).

Soil moisture and temperature effects on three summer vegetables in May 2019 was recorded which has been shown as the graphical presentation as below-

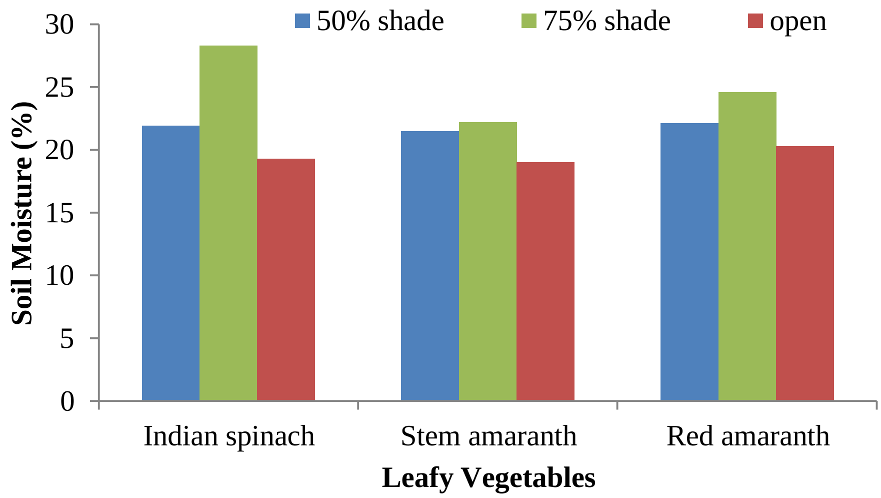

Figure 3: Soil moisture effects on three summer leafy vegetables in May 2019

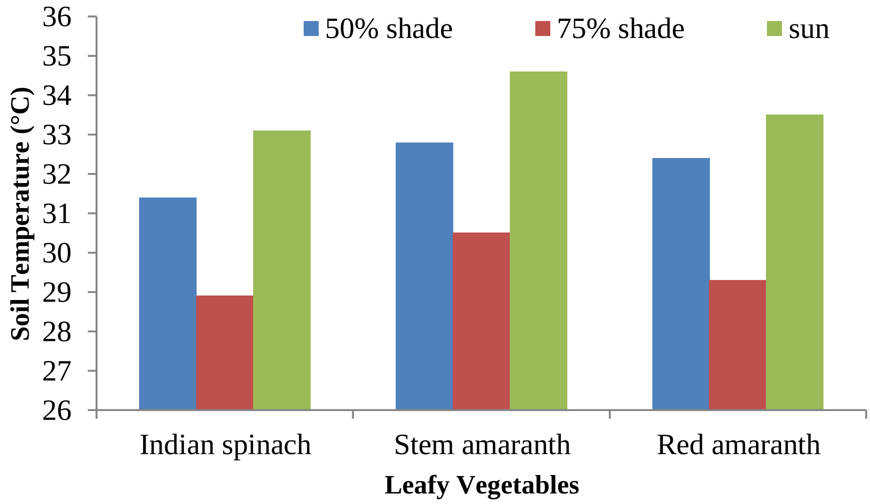

Figure 4: Soil temperature effects on three summer leafy vegetables in May 2019

4.2 Effect of shading on morphological features of the three summer leafy vegetables

4.2.1 Indian Spinach

Plant height

Significant effect on plant height of Indian Spinach was found in reduced light condition-based agroforestry system. Indian Spinach grew under shade condition produced more vigorously than those cultivated in the open field. It was found significantly the highest plant height in shaded condition (Appendix V). The highest plant height of Indian Spinach was found in T_2 (58.80 cm) which was reduced significantly as the shading condition reduced. This was occurred probably due to the higher apical dominance under shade condition (Hillman, 1984). With the increase of shade levels plant height increased significantly. The minimum plant height (45.00 cm) was found in T_0 which was full sunlight condition under this study (Table 2). Same results observed in mungbean as crop showed higher plant height under shaded condition was in mungbean (Islam, 1996) and in chickpea (Murshed, 1996). This result of the experiment also coincided with the findings of Schoch (1972) who stated that stimulation of cellular expansion and cell division may be attributed under reduced light levels.

Number of leaves per plant

Total number of leaves per plant of Indian spinach was also significantly influenced by different shade condition (Table 2). This characteristic showed an inverse trend to that of plant height as it decreased with decreasing shade condition. The higher number of leaves per plant was found in T_0 (190.00) compared to that of T_1 and T_2 (117.36 and 110.80). The findings of the study were also coincided with the findings of Schoch (1972) who reported that number of leaves per plant decrease at reduced sunlight may be due to the lower production of photosynthates under shade conditions for a longer period.

Table 2. Growth and yield contributing attributes of Indian spinach under control (full sunlight) and reduced light

Treatment	Plant height (cm)	No. of leaves / plant	No. of branch/plant	Plant diameter (mm)	Leaf chlorophyll (SPAD value)	Height from base to crown (cm)	Width of crown (cm)	Yield (kg/ plot)
T_0	45.00	190.00	7.65	18.00	41.73	16.36	24.23	7.20
T_1	50.28	117.36	6.42	15.60	50.37	16.58	35.20	6.53
T_2	58.80	110.80	5.87	13.50	54.00	16.95	42.58	5.70
CV%	7.17	11.38	7.46	8.31	7.53	7.33	7.86	13.80
$LSD_{0.05}$	3.00	12.95	0.40	1.07	2.99	0.99	2.18	0.72
Level of significance	*	**	**	*	*	NS	**	*

T_0 = Planting summer vegetables under full sunlight
T_1 = Planting summer vegetables under 50% shade condition
T_2 = Planting summer vegetables under 75% shade condition
* = 5% level of significance
** = 1% level of significance
^{NS}= Non-significant

Number of branches per plant

The effect of shade on the number of branches per plant was almost similar to the number of leaves per plant (Table 2 and Appendix V), where the higher number of branches was recorded under T_0 (7.65) compared to T_1 (6.42) and T_2 (5.87). The results of the experiment were also coincided with the findings of Miah *et al*. (1999) who stated that the lower number of branches under different shaded condition might be due to higher Auxin production in plant grown under different shaded condition which ultimately suppressed the growth of lateral branches.

Plant diameter

Plant diameter was significantly influenced by shade in Indian spinach (Table 2). Plant diameter of Indian spinach grown under T_0 was recorded as 18.00 mm but it was decreased when grown under T_1 (15.60 mm) and T_2 (13.50 mm).

Leaf chlorophyll content

Significant difference was found in leaf chlorophyll content on Indian Spinach. Leaf chlorophyll content was lower (41.73) in T_0 level than that of T_1 (50.37) and T_2 (54.00). The findings of the study were as par with the results of Miah *et al*. (1999) who stated that due to in severe shaded condition the leaves of Indian spinach were greener for a longer period of time than full sunlight condition. In full sunlight leaves were gained in more sunlight so they were yellowed in nature.

Height from base to crown (cm)

There were no significant responses on height to base of crown in Indian spinach statistically under the different shade condition (Table 2). The highest height to base of crown was found in T_2 (16.95 cm) and lowest height to base of crown was observed in T_0 (16.36 cm)

Width of crown (cm)

Significant influence was found on the width of crown in Indian Spinach under different shade condition (Table 2). The highest width of crown was found in T_2 condition (42.58 cm) and the lowest width of crown was found in T_0 condition (24.23 cm).

Yield per plot and per hectare

Significant variations were found in Indian spinach in respect of yield/plot and yield/hectare under different shade condition (Table 2). The highest yield/plot were found in T_0 (7.20 kg) and yield/hectare (19.40 t) were found when Indian spinach grown under full sunlight condition (T_0). On the other hand, the lowest yield/plot (5.70 kg) and yield/hectare (13.83 t) were recorded in T_2 when Indian spinach was cultivated under 75% shade condition (T_2). The findings of the study were also coincided with the findings of Miah *et al*. (1999) who reported that reduced light intensity (different shade condition) impacted on yield of leafy vegetables.

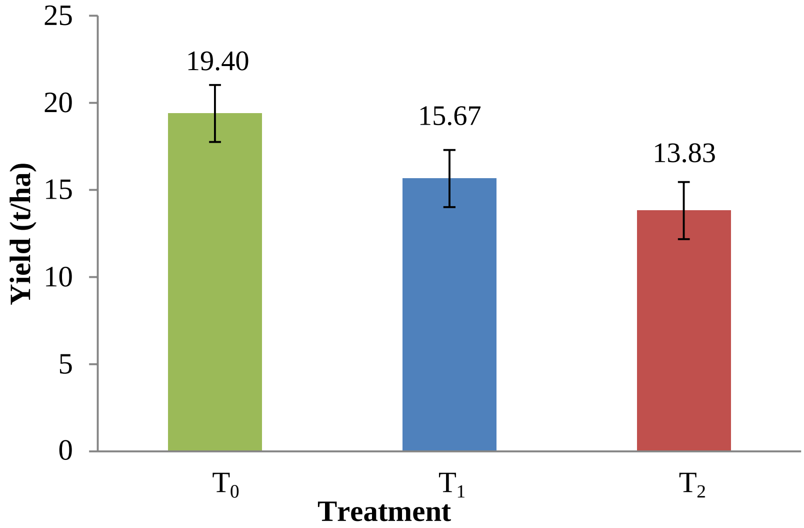

Figure 5: Yield of Indian spinach at Full sunlight (T_0), 50% shade condition (T_1) and 75% shade condition (T_2)

Plate 1: Indian spinach in full sunlight condition

4.2.2 Stem Amaranth

Plant height

Significant effect on plant height of Stem Amaranth was found in shade condition based agroforestry system (Table 3). The plant height increased with increased shade level. This was occurred probably due to higher apical dominance under different shade condition (Hillman, 1984). In 100% light or in full sunlight (T_0) plant height was 82.26 cm whereas in 50% shade condition (T_1) it was increased to 100.11 cm and it was further increased in 75% shade condition (T_2) to 109.90 cm. The findings of the study were also as par with Leonardo (1996) who observed increased plant height, stomata density, transpiration rate and photosynthesis rate in Peppers at low PAR condition or in shade condition. This may be occurred due to the stimulation of cellular expansion and cell division under different shaded condition (Schoch, 1972).

Table 3. Growth and yield contributing characters of Stem Amaranth under control (full sunlight) and under reduced light

Treatment	Plant height (cm)	No. of leaves /plant	No. of branch /plant	Plant diameter (mm)	Leaf chlorophyll (SPAD value)	Height from base to crown (cm)	Width of crown (cm)	Yield (kg/plot)
T_0	82.26	114.00	24.29	34.80	44.72	43.13	36.87	13.83
T_1	100.11	84.33	19.04	25.21	51.20	46.23	44.72	12.78
T_2	109.90	74.10	16.00	22.69	55.05	51.29	48.80	10.69
CV%	7.85	7.25	7.52	7.30	11.23	11.78	8.40	9.03
$LSD_{0.05}$	6.28	5.37	1.21	7.75	4.61	4.51	2.98	0.92
Level of significance	*	**	**	*	*	NS	*	*

T_0 = Planting summer vegetables under full sunlight
T_1 = Planting summer vegetables under 50% shade condition
T_2 = Planting summer vegetables under 75% shade condition
* = 5% level of significance
** = 1% level of significance
^{NS}= Non-significant

Number of leaves per plant

Significant differences were found in number of leaves per plant of Danta or Stem amaranth due to the effect of shade (T_1 and T_2 = Planting summer vegetables under partial and severe PAR). The higher number of leaves per plant was recorded in T_0 (114.00) compared to that of T_1 (84.33) and T_2 (74.10). The findings of the study were coincided with Miah *et al*. (1999) who reported that the number of leaves per plant decreased with reduced light condition. This may be occurred due to the lower production of photosynthates under different shade conditions or low light conditions for a longer period of time.

Number of branches per plant

The effect of shade on the number of branches per plant was significantly different (Table 3 and Appendix VI), where the higher number of branches was recorded under 100% light level ($T_{0)}$ (24.29) compared to that of shaded (T_1 and T_2) condition (19.04 and 16.00). Result of the study was as par with the findings of Miah *et al*. (1999) who stated that the number of branches decreased with the reduced light levels. This condition might be occurred due to higher Auxin production in plant grown under different shaded condition which ultimately suppressed the growth of lateral branches.

Plant diameter

Plant diameter of Stem amaranth was significantly influenced by shade condition (Table 3 and Appendix VI). Maximum plant diameter of Stem amaranth was observed under full sunlight (T_0) as 34.80 mm and minimum plant diameter was found when reduced light levels. The minimum plant diameter was found in (T_2) level (22.69 mm). The finding of the study was as par with the findings of Schoch (1972) who stated that due to the stimulation of cellular expansion and cell division under different shaded condition plant diameter was influenced remarkably.

Leaf chlorophyll content

Significant effect on leaf chlorophyll content was found in Stem amaranth under different shade condition. Leaf chlorophyll content of Stem amaranth was lower (44.72) in full sunlight (T_0) than that of shade condition (reduced light level under T_1 and T_2) 51.20 and 55.00 SPAD value respectively. Miah *et al*. (1999) found the similar results of the study who reported that due to in partial or severe shaded condition leaves were greener for a longer period of time than in full sunlight condition. In full sunlight leaves were gained in lighter so they became yellowed.

Height from base to crown (cm)

Significantly influence was observed on height from base to crown in case of Stem amaranth by shade condition (Table 3 and Appendix VI). Highest height from base to crown (51.29 cm) was found under severe shade condition under the treatment (T_2) while the lowest height to base of crown (43.13 cm) was observed in full sunlight condition under the treatment T_0.

Width of crown (cm)

Significant effect on the width of crown of Stem amaranth was observed in reduced light level (Table 3). From the Table 3 it was found that the highest width of crown (48.80 cm) was found in severe shade (T_2) condition and lowest (36.87 cm) in full sunlight level under the treatment T_0.

Yield per plot and per hectare

Significant difference was found in yield per plot of Stem amaranth under different light levels (Table 3). The highest yield per plot (13.83 kg) was found when Stem amaranth cultivated under full sunlight condition (T_0). On the other hand, the lowest yield per plot (10.69 kg) was recorded when Stem amaranth was cultivated under severe shade condition (T_2) (Table 3 and Appendix VI). As well as yield per hectare was significantly respond with the shade treatment (T_1 and T_2). Highest yield per hectare (27.25 ton) was recorded in full sunlight (T_0) and lowest (22.33 ton) was in T_2 or in severe shade condition. The findings of the study were also coincided with the findings of Miah *et al*. (1999) who reported that reduced light intensity (different shade condition) impacted on yield of leafy vegetables.

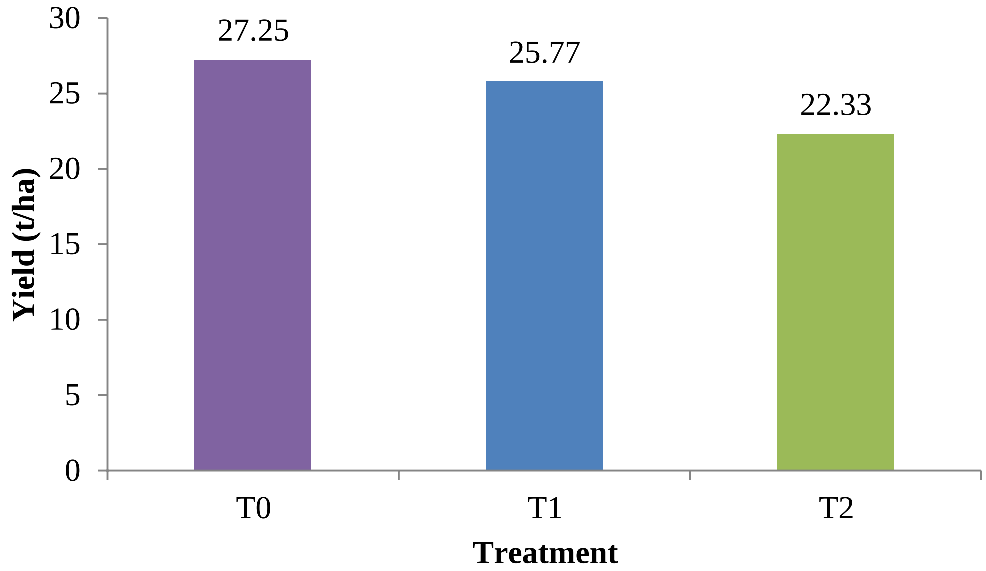

Figure 6: Yield of Stem Amaranth at Full sunlight (T_0), 50% shade condition (T_1) and 75% shade condition (T_2)

Plate 2: Danta (Stem amaranth) plants growing under 75% shade condition

4.2.3 Red Amaranth (Lal shak)

Plant height

Plant height of Red Amaranth cultivated under different light levels was influenced significantly (Table 4). The plant height decreased with increased shade level. This was occurred probably due to lower apical dominance under shade condition (Hillman, 1984). In 100% light or in sunlight (T_0) plant height was 30.85 cm whereas in shade condition (T_1 and T_2) it was decreased to 25.77 cm to 18.69 cm. The findings of the study were also coincided with Leonardo (1996) who found decreased plant height, stomata density, transpiration rate and photosynthesis rate in Peppers at low PAR condition.

Table 4. Growth and yield contributing characters of Red Amaranth under control (full sunlight) and reduced light

Treatment	Plant height (cm)	No. of leaves / plant	No. of branch /plant	Plant diameter (mm)	Leaf chlorophyll (SPAD value)	Height from base to crown (cm)	Width of crown (cm)	Yield (kg/plot)
T_0	30.85	16.49	8.88	20.34	47.53	18.69	15.27	4.77
T_1	25.77	11.27	7.69	18.90	49.28	15.43	13.53	4.00
T_2	18.69	9.61	6.20	15.52	55.60	12.06	11.00	3.30
CV%	6.16	7.10	8.12	7.30	13.93	6.53	8.84	9.88
$LSD_{0.05}$	3.48	2.63	0.50	0.32	5.77	2.43	2.57	0.32
Level of significance	*	*	**	*	NS	*	NS	*

T_0 = Planting summer vegetables under full sunlight
T_1 = Planting summer vegetables under 50% shade condition
T_2 = Planting summer vegetables under 75% shade condition
* = 5% level of significance
** = 1% level of significance
^{NS}= Non-significant

Number of leaves per plant

Significant differences due to the effect of reduced light on number of leaves per plant of Red amaranth was recorded and found The higher number of leaves per plant was observed in sunlight T_0 (16.49) compared to that of different shade condition T_1 (11.27) and T_2 (9.61) (Table 4). The findings of the study were also coincided with Miah *et al*. (1999) who stated that number of leaves per plant decreased at reduced light condition may be due to the lower production of photosynthates under low light conditions for a longer period of time.

Number of branches per plant

The impact of reduced light level on the number of branches per plant was significantly difference to the number of leaves per plant (Table 4 and Appendix VII), where the higher number of branches was recorded under 100% light level ($T_{0)}$ (8.88) compared to that of different shaded (T_1) condition (7.69) and T_2 (6.20). The result of the experiment was as par with Miah *et al*. (1999) who reported the lower number of branches under different shaded condition might be due to higher Auxin production in plant cultivated under shaded condition which ultimately suppressed the growth of the lateral branches.

Plant diameter

Plant diameter of Red amaranth was significantly affected by shade condition (Table 4 and Appendix VII). Maximum plant diameter of Red amaranth was seen under full PAR (T_0) as 20.34 mm and minimum plant diameter was found when grown under shade (T_2) condition (15.52 mm). The finding of the study was as par with the findings of Schoch (1972) who stated that due to the stimulation of cellular expansion and cell division under different shaded condition plant diameter was influenced remarkably.

Leaf chlorophyll content

Significant effect on leaf chlorophyll content was found in Red amaranth under different shade condition. Leaf chlorophyll content of Red amaranth was lower

(47.53) in full sunlight (T_0) than that of shade condition reduced light level treatment under T_1 (49.28) and T_2 (55.60) respectively. The similar results were also found by Miah *et al*. (1999) who reported that due to in partial or severe shaded condition leaves were greener for a longer period of time than in full sunlight condition. In full sunlight leaves were gained in lighter so they became yellowed.

Height from base to crown (cm)

Height from base to crown was significantly affected in case of Red amaranth by reduced light level or shade condition (Table 4 and Appendix VII). Highest height from base to crown (18.69 cm) was found under full sunlight condition under the treatment T_0 while the lowest height to base of crown (12.06 cm) was observed in severe shade condition under the treatment T_2.

Width of crown (cm)

Significant influence on the width of crown of Red amaranth was found under reduced light level (Table 4). From the Table 3 it was observed that the highest width of crown (15.27 cm) was seen in full sunlight (T_0) condition and lowest (11.00 cm) in reduced light level- severe shade condition under the treatment T_2.

Yield per plot and per hectare

Yield per plot of Red amaranth was significantly with the different light levels (Table 4). The highest yield per plot (4.77 kg) was found when Red amaranth cultivated under full sunlight condition (T_0). On the other hand, the lowest yield per plot (3.30 kg) was recorded when Red amaranth was grown under severe shade condition (T_2) (Table 4 and Appendix V). As well as yield per hectare was significantly respond with the different shade treatment. Highest yield per hectare (11.30 ton) was recorded in full sunlight (T_0) and lowest (7.60 ton) was in shade condition (T_2). The findings of the study were also coincided with the findings of Miah *et al*. (1999) who reported that reduced light intensity (different shade condition) impacted on yield of leafy vegetables.

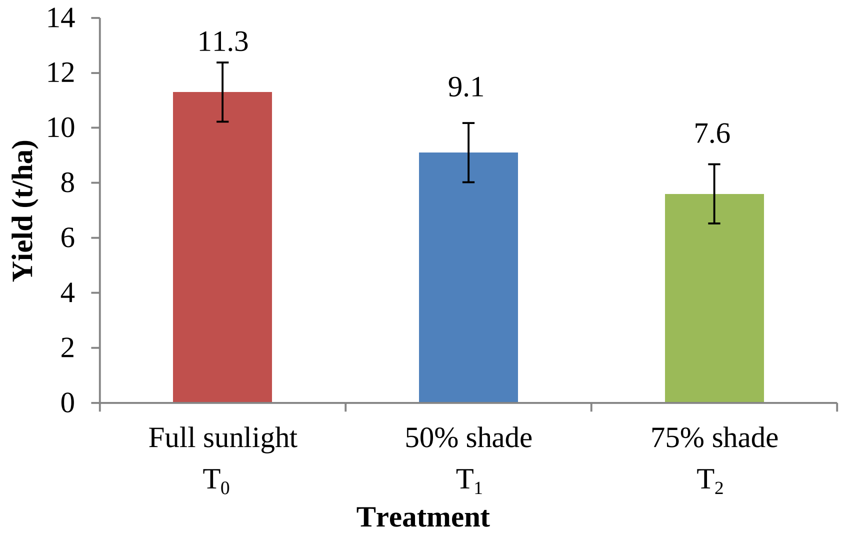

Figure 7: Yield of Red Amaranth at Full sunlight (T_0), 50% shade condition (T_1) and 75% shade condition (T_2)

Plate 2: Red amaranth plants growing under full sunlight condition

4.3 Comparative yield performance of the three summer leafy vegetables under reduced light and sunlight condition

In figure 7, comparative yield performance of three summer leafy vegetables under reduced light and sunlight condition was shown. From the figure, it is clear that among leafy vegetables Stem Amaranth gave the highest yield (27.25 ton/ha) in the full sunlight condition (T_0). Among leafy vegetables Stem Amaranth gave the highest yield (22.33 ton/ha) in severe shade treatment (T_2). Stem amaranth showed promising result both in sunlight (27.25 ton/ha) and partial (T_1) and severe shade (22.33 ton/ha and 25.77 ton/ha) condition. Yield of Indian spinach (19.40 ton/ha) in full sunlight (T_0) and (15.67 ton/ha) and (13.83 ton/ha) was significantly different under partial shade (T_1) and severe shade (T_2) level. So, Indian Spinach and Stem Amaranth under agroforestry systems allowing reduced light intensity might be encouraged in rural Bangladesh.

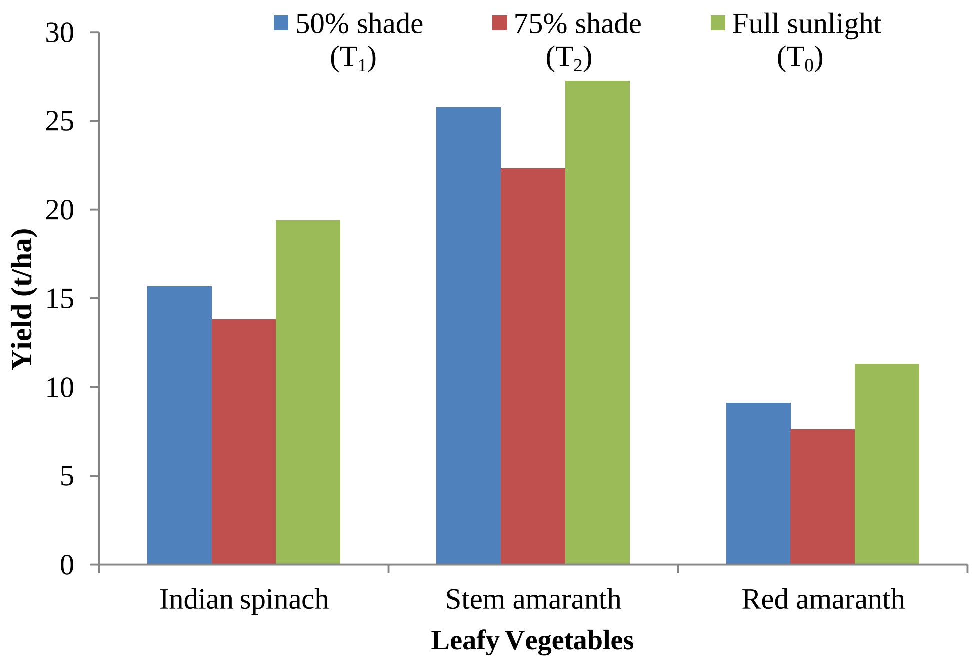

Figure 8: Comparative yield performance of three summer leafy vegetables under reduced light and sunlight condition

CHAPTER V

SUMMARY AND CONCLUSION

SUMMARY

Agroforestry system is one of the diversification systems which can balance this problem by maximum utilization of homesteads and other shaded places of the country. The experiment was conducted to find higher yielding and shade tolerant summer leafy vegetables under reduced light levels-based agroforestry system during the period from March to June, 2019 at Sher-e-Bangla Agricultural University, Dhaka. The three summer leafy vegetables such as Indian Spinach, Danta (Stem Amaranth) and Red Amaranth were grown under (i) open field condition (Full sunlight, T_0), (ii) partial shaded condition, T_1 (reduced light intensity which was created by using dark green colored mosquito net) and (iii) severe shaded condition, T_2 (reduced light intensity which was created by using dark green colored mosquito net) following the single factor Randomized Complete Block Design (RCBD) with three replications.

The actual light intensities inside the net and in open field condition were recorded and the maximum average light intensity reduction (%) was found in case of Red Amaranth (48.28%) and minimum average light intensity reduction (%) was observed in case of Indian Spinach (43.09%) in severe shade condition (T_2). In case of Indian Spinach, Stem Amaranth and Red Amaranth light intensity reduction was 26.14%, 30.00% and 28.97% in partial shade condition (T_1) respectively. Soil temperature and moisture were also recorded during the study period. The Highest soil temperature was recorded in April-35.7˚C in sun (T_0) and 34.2˚C in partial shade condition (T_1) and 33.5˚C in severe shade condition (T_2) while the highest soil moisture was recorded in June among in open (T_0), partial shade (T_1) and severe shade condition (T_2) as 38.3%, 32.6% and 28.5% respectably.

Performances of three summer leafy vegetables under different shade condition are summarized below:

In case of Indian Spinach plants, all the selected parameters except height from base to crown showed significant difference in reduced light level (T_2). Morphological behaviors such as plant height (58.80 cm), chlorophyll content of leaves (54.00 SPAD unit), width of crown (42.58 cm) were gradually increased with the increase of shade level (T_2). But number of leaves per plant (190.00), number of branches per plant (7.65), plant base diameter (18.00 mm), yield per plot (7.20 kg) and per hectare yield (19.40 t) were found progressively increased under open field condition or full sunlight (T_0).

In case of Stem Amaranth plants, all the selected parameters except height from base to crown (51.39 cm) showed significant difference in reduced light level (T_2). Morphological characters like plant height (109.90 cm), leaf chlorophyll content (55.05 SPAD unit) and width of crown per plant (48.80 cm) of Stem Amaranth (Danta) were found maximum under severe shaded condition (T_2). On the other hand, number of leaves per plant (114.00), branches per plant (24.29), plant diameter (34.80 mm), yield per plot (13.83 kg) and per hectare yield (27.25 t) were found progressively increased under open field condition or in full sunlight (T_0).

In case of Red Amaranth plants, all the selected parameters except leaf chlorophyll content (55.60 SPAD unit) showed significant difference in reduced light level (T_2). Morphological characters like plant height (30.85 cm), width of crown per plant (15.27 cm) of Red Amaranth were found maximum under open field condition (T_0). As well as number of leaves per plant (16.49), branches per plant (8.88), plant diameter (20.34 mm), yield per plot (4.77 kg) and per hectare yield (11.30 t) were found progressively increased under open field condition or in full sunlight (T_0).

CONCLUSION

i. From the experiment it was clear that among leafy vegetables Stem Amaranth gave the highest yield in the open field condition or in full sunlight.

ii. Stem Amaranth and Indian Spinach showed promising result both in sunlight and reduced light condition.

iii. Red Amaranth cannot grow well in reduced light levels.

iv. So, Stem Amaranth and Indian Spinach should be encouraged to cultivate under reduced light levels as agroforestry systems.

v. Further studies are suggested at different agro-ecological regions of Bangladesh to evaluate the compatible summer leafy vegetables production under reduced light conditions for regional adaptability.

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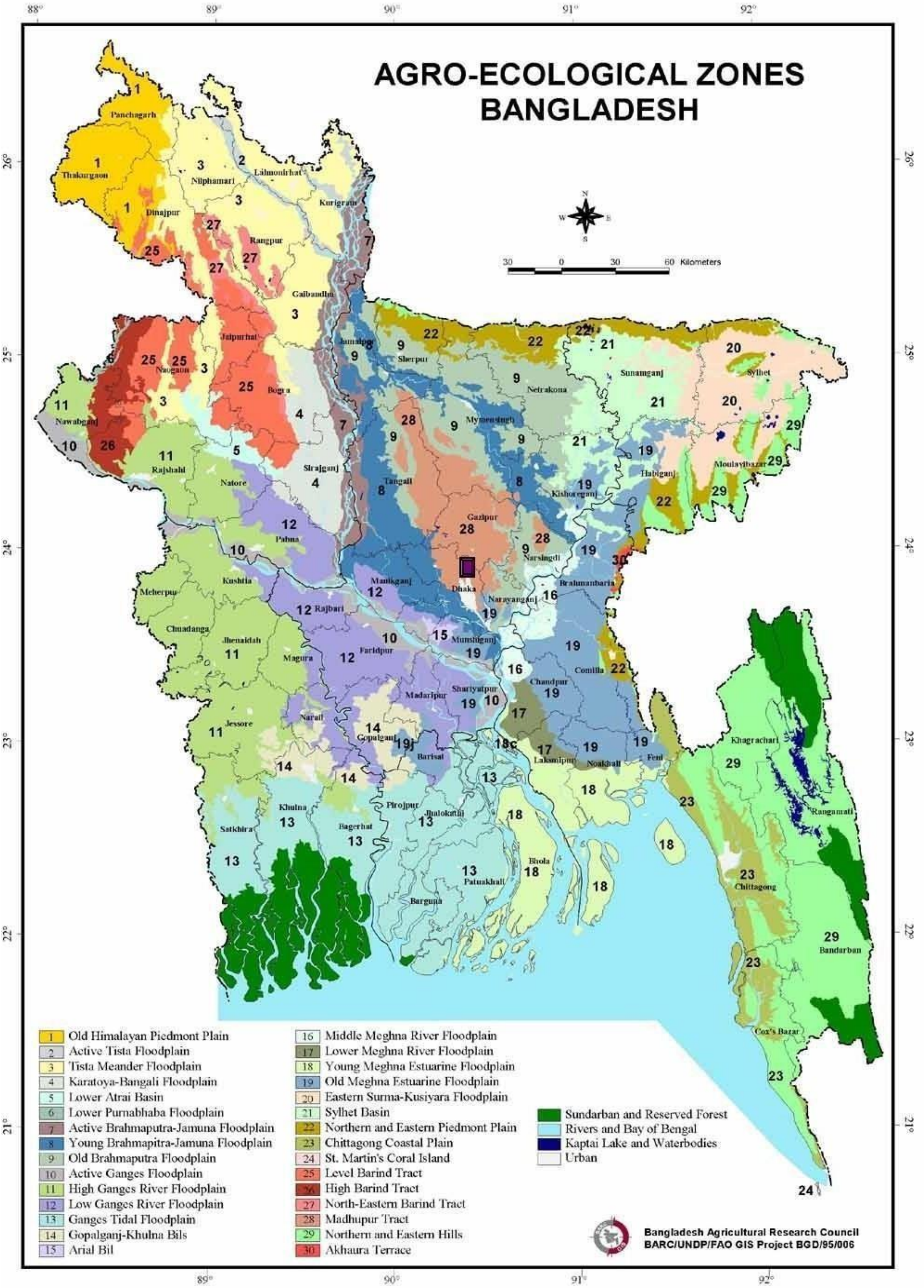
APPENDICES

Appendix I: Map showing the experimental sites under study



The experimental site under study

Appendix II: Characteristics of soil experimental field

A. Morphological characteristics of the experimental field

Morphological features	Characteristics
Location	Central 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

B. Physical and chemical properties of the initial soil

Characteristics	Value
% Sand	27
% Silt	43
% Clay	30
Textural class	Silty-clay
pH	5.6
Organic matter (%)	0.78
Total N (%)	0.03
Available P (ppm)	20.00
Exchangeable K (me/100 g soil)	0.10
Available S (ppm)	45

Source: Khatun, 2014

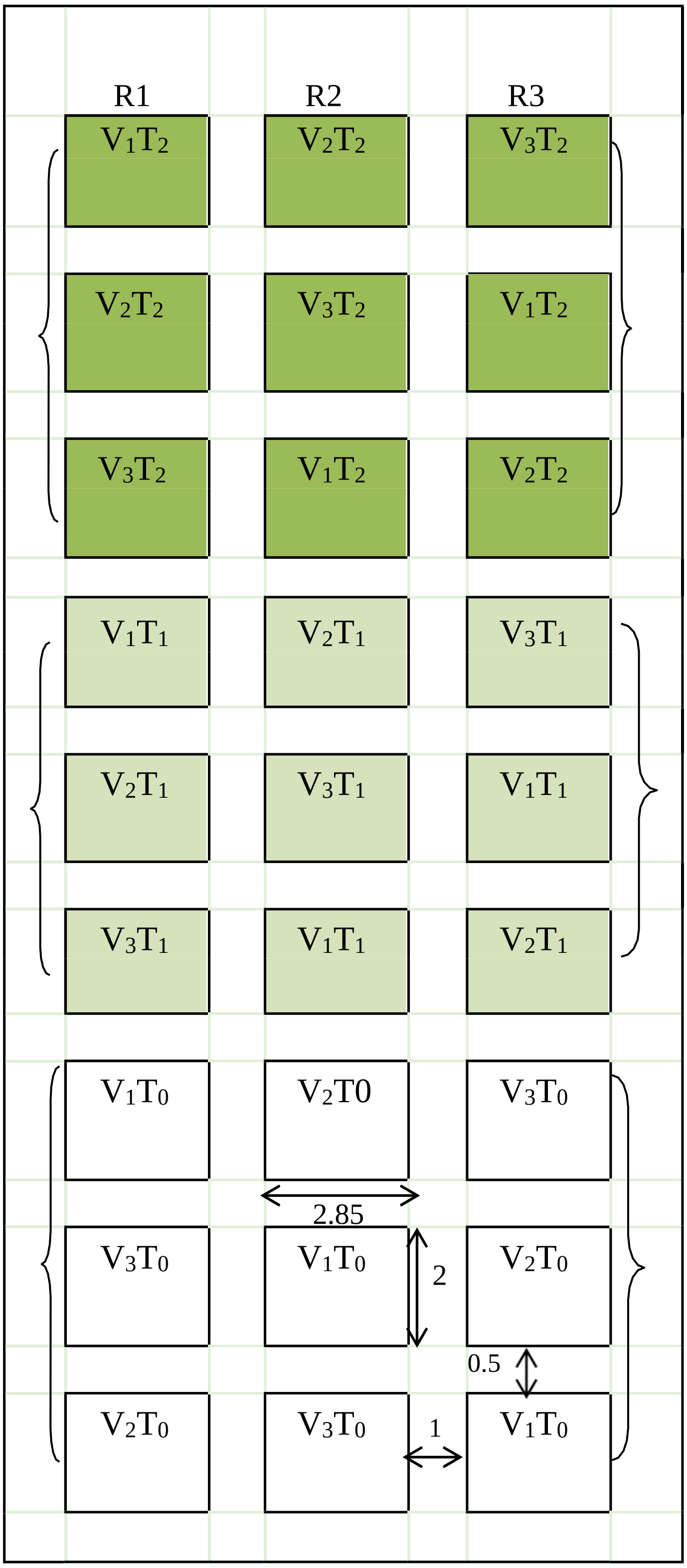
Appendix III: Monthly average of air temperature, relative humidity and total rainfall of the experimental site during the period from March to June, 2019

Month (2014)	*Air temperature (˚C)		*Relative Humidity (%)	*Total rainfall (mm)
	Maximum	Minimum		
March	34.2	23.4	61	112
April	34.7	25.9	70	185
May	35.4	22.5	80	577
June	36.0	24.6	83	563

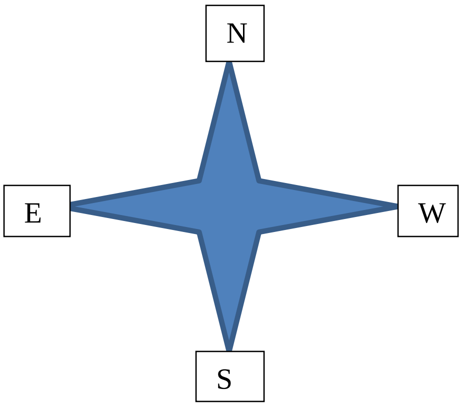
*Monthly average

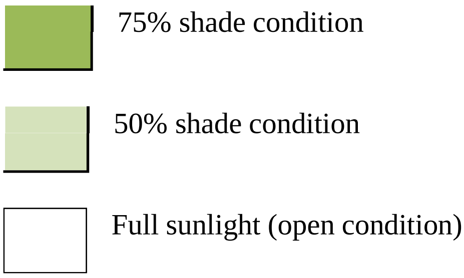
*Source: Bangladesh Meteorological Department (Climate & weather division) Agargaon, Dhaka-1212

Appendix IV: Layout of the experimental field



Legends





Vegetables:

V_1= Indian Spinach

V_2= Stem Amaranth

V_3= Red Amaranth

Length of plot: 2.85 m, **Width of plot:** 2 m

Replication to replication distance: 1 m

Plot to plot distance: 0.5 m,

Unit plot size: 2.85 m × 2 m (5.70 m^2)

Appendix V: Analysis of variance (ANOVA) of growth and yield contributing characters of Indian spinach under different shade condition

Source of variation	df	Plant height (cm)	No. of leaves/ plant	No. of branch/ plant	Plant diameter (mm)	Leaf chlorophyll (SPAD unit)	Height from base to crown (cm)	Width of crown (cm)	Yield (kg/ plot)	Yield (ton/ha)
Replication	**2**	99.99	8.60	1.84	13.65	206.0	8.37	34.00	0.19	22.96
Treatment	**2**	145.45*	5796.1**	2.49*	15.21*	119.19*	0.27^{NS}	255.76**	1.69*	24.16*
Error	**4**	13.55	254.41	0.25	1.70	13.46	1.49	7.14	0.79	1.83

*Significant at 5% level
**Significant at 1% level
^{NS} Non-significant

Appendix VI. Analysis of variance (ANOVA) of Growth and yield contributing characters of Stem Amaranth under different shade condition

Source of variation	df	Plant height (cm)	No. of leaves/ plant	No. of branch /plant	Plant diameter (mm)	Leaf chlorophyll (SPAD unit)	Height from base to crown (cm)	Width of crown (cm)	Yield (kg/ plot)	Yield (ton/ha)
Replication	**2**	624.38	653.64	64.99	6.16	20.85	3.37	74.12	34.68	0.91
Treatment	**2**	589.22*	1288.49**	52.76**	122.49*	81.70^{NS}	50.89^{NS}	110.36*	7.66*	19.11*
Error	**4**	58.55	43.30	2.20	12.51	31.94	30.49	13.33	1.26	9.09

*Significant at 5% level
**Significant at 1% level
^{NS} Non-significant

Appendix VII: Analysis of variance (ANOVA) of growth and yield contributing characters of Red Amaranth under different shade condition

Source of variation	df	Plant height (cm)	No. of leaves / plant	No. of branch /plant	Plant diameter (mm)	Leaf chlorophyll (SPAD unit)	Height from base to crown (cm)	Width of crown (cm)	Yield (kg/ plot)	Yield (ton/ha)
Replication	**2**	84.25	12.54	60.25	13.65	23.91	86.08	0.61	0.07	0.75
Treatment	**2**	113.41*	5.85*	52.76 **	15.21*	54.06^{NS}	43.54*	42.39^{NS}	1.62*	10.39*
Error	**4**	13.05	1.26	2.02	1.70	50.06	8.79	37.22	0.15	1.48

*Significant at 5% level
**Significant at 1% level
^{NS} Non-significant