YIELD AND CARBON SEQUESTRATION OF PIGEON PEA AT DIFFERENT ENVIRONMENTS IN BANGLADESH

MST. ATQIYA SADIA

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

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BY

MST. ATQIYA SADIA

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APPROVED BY:

Professor Dr. Nazmun Naher
Supervisor

Dr. A.K.M. Mahbubul Alam
Co- Supervisor

Dr. Jubayer-Al-Mahmud
Chairman
Examination Committee

Sher-e-Bangla Agricultural University
Sher-e-Bangla Nagar, Dhaka-1207

PABX: **+88029144270-9**
Fax: **+88029112649**
Web site: **www.sau.edu.bd**

CERTIFICATE

This is to certify that the thesis entitle, **"YIELD AND CARBON SEQUESTRATION OF PIGEON PEA AT DIFFERENT ENVIRONMENTS IN BANGLADESH"** *submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka in partial fulfillment of the requirements for the degree of* ***MASTER OF SCIENCE IN AGROFORESTRY AND ENVIRONMENTAL SCIENCE****, embodies the result of a piece of bona fide research work carried out by* ***MST. ATQIYA SADIA,*** *Registration No.****13-05289*** *under my supervision and my guidance. No part of the 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.

Prof. Dr. Nazmun Naher
Professor Supervisor

Dated: June, 2020
Dhaka, Bangladesh

DEDICATED TO

MY BELOVED Husband

Dr. Md. Mahbul Alam

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ABSTRACT

Pigeon pea is a multi-purpose species for agroforestry systems and subsistence agriculture especially the ability to recover from the losses caused by various biotic and abiotic stresses. So, this experiment was carried out to determine the performance of four pigeon pea genotypes for yield and yield contributing characters, stability and carbon sequestration across different environments of Bangladesh. This experiment was conducted under three different locations viz. Gazipur, Sylhet and Madaripur during the year 2018-2019. The experimental materials comprised of four pigeon pea genotypes namely G1= BPP1502, G2 =BPP1503, G3 = BPP1504 and G4 = BPP1505 and was conducted in randomized complete block design with three replications in each environment. Significant differences were observed for all the genotypes of pigeon pea against number of branches plant^{-1}, pods plant^{-1}, seeds pod^{-1}, plant height, breadth, stem diameter and hundred seeds weight among the environments. Highest plant height (103.33 cm) of pigeon pea genotype was observed in G4 at Gazipur. G3 produced highest no of pods plant^{-1} (188.00) and hundred seed weight (9.10 g) at Gazipur. Carbon sequestration plant^{-1}of pigeon pea (7.63 lbs) and carbon sequestration year^{-1} (15.23 lbs) both were highest in G4 at Gazipur and lowest was found in G2 at Sylhet. For stability of performance across environments, G3 and G4 were identified as most stable genotypes and G1 and G2 were found least stable. On the basis of both stable performance and mean seed yield across environments, the GGE biplot ranked genotype of pigeon pea, G3 as the best among all, followed by G4 while the rest of the genotypes were identified as inferior. Gazipur was identified as most representative environment and highly discriminative as compared to the others.

ACRONYMS

% =Percent
^0C =Degree Celsius
AEZ =Agro Ecological Zone
ANOVA =Analysis of Variance
ATC=Average tester coordinate
B=Boron
BARI =Bangladesh Agricultural Research Institute
BBS =Bangladesh Bureau of Statistics
CEC=Cation exchange capacity
cm =centimeter
cm^2 =Centimeter square
CV =Co-efficient of Variation
DW =Dry weight
E=East
e.g. =For example
et al. =And others
FAO =Food and Agriculture Organization
FAOSTAT =Food and Agriculture Organization Statistics
FW =Fresh weight
g =Gram
lbs= Pound
K =Potassium
LSD =Least Significant Difference
m =Metre
mm =Milimeter
MOP=Murate of potash
N =North
no. =Number
PC1=First principal component
PC2= Second principal component
RARS=Regional Agricultural Research Station
RPRS=Regional Pulse Research Station
S =South
SAU =Sher-e-Bangla Agricultural University
SOC= Soil organic carbon
TSP=Triple super phosphate
viz. =Namely
W=West
Zn=Zinc

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CHAPTER 1

INTRODUCTION

Pigeon pea [*Cajanus cajan (L.) Millsp*.] is one of the major grain legume grown in the tropics and subtropics. It is a minor pulse crop in Bangladesh, mainly grown in the northwestern part of the country (Virmani *et al*., 1991). It is a perennial shrub that can survive for a period of 3-5 years but it is normally cultivated as an annual crop. Perennial pigeon pea is receiving considerable attention in India as a multi-purpose species for agroforestry systems. In Agroforestry system there is a high potentiality of pigeon pea to bring under commercial cultivation as a intercrop with tree which is a main component as it provides the three most important services of agroforestry system namely: food, fuel and fodder (3F) along with its diverse benefits. It is the best versatile food legume, span over a wide area of the world with diversified uses and also benchmark with "sustainable agriculture" with enormous existing wild diversity, India is considered to be the "hot spot" and center of origin for pigeon pea (Van der Maesen, 1990). It is well known as finest nitrogen fixer and nutrient re-cycler (Graham and Vance, 2003; Srivastava *et al*., 2012). Besides its primary use as food, it can also be used as forage, fodder, fuel and medicine. As food, the pods whether consumed as green pea or dry grain consists of 20-22% protein, which plays a vital role in meeting the protein needs of a vegetarian population (Singh *et al*., 1990, Saxena, 2009). Most parts of Asia and Middle-eastern countries are the major market for good-quality pigeon peas for human consumption.

Pigeon pea is known to produce more nitrogen per unit of plant biomass than most other legumes and can nodulate in most soils although it produces fewer nodules than any other legumes (Onim,1987). The crop is deep-rooted, so their ability to release more phosphates means that valuable nutrients are being brought up from the deeper soil layers. The release of phosphorous benefits not only the crop, but also the subsequent crops grown in the same field (Ae *et al.,* 1990). It is also considered to be tolerant to low and high temperatures. Because of these unique characteristics of pigeon pea, it is recognized as an important crop for subsistence agriculture especially so due to its drought tolerance and ability to recover from the losses caused by various biotic and abiotic stresses. In addition, the leaves of this plant can also be used as food for the silkworm (Duke, 1981) and it can also be a substitute for alfalfa in animal feed formulations. The need to substitute fishmeal in animal feed has necessitated the use of plant derived feed stuffs. Since pigeon pea has strong woody stems that grow up to 4m tall and branch freely, its spindly stalks are extensively used as a cooking fuel in energy short villages of several African countries and in India, Nepal and Sri Lanka. In the lac growing areas of China after harvesting the lac resin, pigeon pea plants are chopped and dried for fuel use. The crop produces about 6 t/ha of fuel wood (Zhenghong and Fuji, 1997). Pigeon pea offers the benefits of improving long-term soil quality and fertility when used as green manure (Onim *et al.*, 1990), cover crop (Bodner *et al*., 2007) or alley crop (Mapa and Gunasena, 1995).

A major constraint to the adoption of agroforestry systems in the semi-arid tropics is the severe competition between trees and crops for environmental resources. Pigeon pea can adapt to a wide range of soil types from gravely stones to heavy clay loams of close texture and high moisture content provided there is no standing water on the soil surface or excessive soil salinity. Extensive ground cover of pigeon pea prevents soil erosion, serves as windbreak, hedge, encourages filtration, minimizes sedimentation and smothers weeds. Traditional varieties are highly sensitive to photoperiod (McPherson *et al*., 1985) and they take about 175 to 280 days to reach maturity.

Fortunately, the loss of Soil organic carbon (SOC) can be slowed down by implementing crop management practices such as conservation tillage (Lal, 2004b; Puget and Lal, 2005), converting degraded arable land to perennial grassland (Gentile *et al*., 2005), using diverse rotations, and introducing legume and grass mixtures into the rotation (Lal, 2004c). Therefore, pigeon pea a tall woody shrub with huge branching as a legume crop has the ability to sequester carbon dioxide from atmosphere and plays a great role in stocking carbon in soil.

In Bangladesh, pigeon pea (Arhar) is mostly cultivated in Kushtia, Rangpur, Dinajpur, and Jessore districts. Total acreage of its cultivation is about 5,215 and the annual production is about 1,005 m tons (Banglapedia, 2004). Some short duration lines of pigeon pea were tested in the northern part of the country, but found promising only as intercrop (BARI, 1990). In the southern part of Bangladesh, where winter temperature remains warm enough to support the crop growth, less photosensitive and short duration pigeon pea can be introduced in transplanted aman-fallow cropping system. In the hilly areas of south-eastern part of Bangladesh also, the crop may potentially be grown during the post-rainy season.

Although Bangladesh has suitable land and friendly environment for pulse cultivation, it is heavily imported every year as the domestic production of pulse cannot address the quantity demanded domestically. Considering the above circumstances, pulse production should be increased rapidly to improve the national nutritional status along with less outflow of precious foreign currency. Pulses are in Bangladesh generally called as poor's men protein. But in these days we cannot fulfill our demand of pulse. We should give more attention to this protein source as the demand is close to 2 million tons but the country generates only 0.53 million tons comparing with total demand (Razzaque, 2000). Climate change is manifested by unpredictable rainfall patterns, further complicating the plight of farmers. There is a need to identify varieties that are adaptable to these challenges. As pigeon pea can be grown with relative ease and growing it can uplift farmers' livelihoods especially of it's wide range of adaptability with low cultivation cost and little management practices which also makes it a good crop for helping farmers adapt to climatic variability and change. If farmers select varieties are adaptable to their region they will plant the right varieties and will bring it under commercial cultivation as a result good yield would translate to better income leading to improved livelihoods. So, there is a need to identify suitable pigeon pea varieties for better yield with good carbon sequestration ability and also for make ensure the improvement of farmer's livelihoods.

Considering above facts, the study was conducted with the following objectives:

1. To evaluate the yield performance of pigeon pea in three studied areas Gazipur, Sylhet and Madaripur ;
2. To determine the stability performance of different pigeon pea genotypes and
3. To estimate the amount of carbon sequestration by pigeon pea per year in these areas.

CHAPTER 2

REVIEW OF LITERATURE

In this chapter, an attempt has been performed to review the information about the morphological and yield performances using GGE biplot technique and carbon dioxide sequestration of pigeon pea genotypes.

2.1 Pigeon pea

Pigeon pea [*Cajanus cajan* (L.) Millsp.] which is under the genus of *Cajanus*, subtribe-Cajaninae, tribe haseoleae, order-Fabales, family-Fabaceae and sub-family Faboideae. Several edible beans like Lablab, Dolichos, Phaseolus, Vigna and Cajanus of tribe Phaseoleae but in the sub-tribe Cajaninae, only one species, *Cajanus cajan* has been domesticated and cultivated. The species belonging to Cajaninae have peculiar vesicular glands on the leaves, calyx and pods which accumulate a sticky substance on their surface. The Latin name *Cajanus cajan* came from a Malay word cachang, which was therefore a corrupt form of the Telugu word kandi. The Telugu word has its source of origin in the Sanskrit word kaand (a stem), a reference to the long stem of the pigeon pea plant (Royes, 1976). The name pigeon pea was first reported in Barbados where the seeds were once considered as pigeon feed (Plukenet, 1692).

The term ‘pigeon pea’ was reported in Barbados, where its seeds were considered an important pigeon-feed (Gowda *et al*., 2011). Pigeon pea or red gram or tur is known by different vernacular names in India viz. Tur (Maharashtra and Gujarat), Arhar (Uttar Pradesh, Bihar, Madhya Pradesh), Aral (West Bengal), Kandi (Andhra Pradesh), Harad (Haryana and some parts of western Uttar Pradesh), Rahat (parts of Bihar), Tuvaraparippu (Kerala), Kokh-lan (tribes of Tripura), adhaki and tuvarika (Sanskrit). The alternate (Syn.) botanical names of pigeon pea are as follows: *Cytisus cajan* L.; C. *bicolor* DC.; C. *flavus* DC.; C. *indicus Spreng*.; C. *striatus Bojer* (Van der Maesen,1990).

2.2 Growth and development of pigeon pea

Pigeon pea is adapted to the tropical and subtropical region and it can be grown on marginal land and low fertilizer input, even under drought condition. The growth habit of pigeon pea is predominantly indeterminate but some genotypes show determinate growth. The branching pattern varies from erect to spreading. Pigeon pea is a predominantly photoperiod sensitive shortday plant and exhibit wide variation in days to flower among genotypes (Gooding, 1962; Spence and Williams, 1972).

Pigeon pea is planted commercially for canning in the Dominican Republic, Trinidad and Puerto Rico while it is mostly grown for home consumption and export in Africa, Kenya, Malawi, Tanzania and Uganda. Elsewhere in the tropics, it is more a crop of kitchen gardens and hedges. In India, the yields are dry seeds while in the Dominican Republic, fresh seeds or pods are the yields (Duke, 1981). Pulses, pigeon pea being one, have a wide adaptability to latitudes, longitudes and climate variables but adaptability of individual species is confined to their areas of origin (Kumar and Bourai, 2012). There is a need to encourage more growing of adaptable varieties as pigeon pea market is enormous with its demand outstripping supply (Odeny, 2007).

Distribution of pigeon pea is asymmetric over the world. It is grown in different parts of the globe covering more than 22 countries including India, Myanmar, Tanzania, Malawi and Kenya (FAOSTAT, 2013).

In South-East Asia, pigeon pea is mainly cultivated in India, Myanmar, Nepal, Bangladesh and Phillipines. It is widely grown in India where it plays an important role in pulse based cropping systems and occupies second largest area among the pulse crops. Recently this crop has been introduced in China as well where it is planted on the hilly slopes primarily to check soil erosion (Saxena, 2008).

India occupies the largest area (3.5 – 4.0 million hectares) of pigeon pea in the world, contributing nearly 80% area globally. Although pigeon pea is grown in 315 districts of India, 26 districts account for about 50% area (Bhatia *et al*., 2006). In India, it is a widely cultivated crop covering more than 18 states. About 85% of the pigeon pea is grown in six states namely, Maharashtra, Karnataka, Madhya Pradesh, Andhra Pradesh, Gujarat and Jharkhand. Other states include Uttar Pradesh, Orissa, Tamil Nadu, Bihar and Chattisgarh. To a limited extent, pigeon pea is also grown in Rajasthan, Punjab, Haryana, West Bengal and North-Eastern States.

Although pigeon pea can be grown well on hilly slopes, grass lands, forest lands, degraded lands and ravine areas the cultivated species of pigeon pea does not exist as naturalized population in the wild form in any ecological zone of India. Hence its natural habitat conditions are not known; but it performs on well grassy habitats in tropical, cold free zones with optimum 600-1000 mm annual rainfall. Natural population of various wild species of pigeon pea can be found in Eastern and Western Ghats, North-Eastern states and in forests and hilly areas in almost every state of India (Sardana *et al*., 2011).

2.3 Scenario of pigeon pea production and marketing in Bangladesh and around the world

Pigeon pea is considered as the second most important pulse crop in India. This country has the largest growing area used for this crop cultivation and is the biggest producer thereof. Other countries though consider this crop as their most important crop, like Puerto Rico, which accounts for about 90% of the total pulse production, Trinidad and Tobago 86% and Malawi 36% while others consider it their second such as Panama, Dominican Republic, Jamaica and Uganda (Saxena *et al.,* 2001).

In Bangladesh, pigeon pea is a multipurpose plant. All the plant parts are used in some form or another. The green pods are used as vegetable and the mature seeds are cooked or boiled and eaten as a pulse. The tops of the plant and its fruits provide excellent fodder and are also made into hay and silage. A majority of the people use the pigeon pea after de-husking and splitting of cotyledons to make dal. The husk and pod walls are used as cattle feed. Rural families use the stems as fuel. The dried stalks are used as firewood and for thatching and making baskets. Pigeon pea is also used to rear silkworm and lac insects (Amiruzzaman and Shahjahan, 2000).

Roy *et al.* (1996) evaluated 23 genotypes of variable maturity duration to explore the potentiality of fitting pigeon pea in rice-fallow cropping pattern and found some genotypes well adapted in fallow period although the yields were not satisfactory. Therefore, the potential pigeon pea variety or cultivar selected for growing under such conditions should be of short duration with high yield potential.

In Asia, particularly in India, dal is the dominant form in which pigeon pea is sold to consumers. In India, considered as the world's largest producer of pigeon pea, the annual demand of this crop is always in the shortfall due to the growing population, rise in income and shift of consumer preferences towards high-value products such as processed pulses, combined with the long-term stagnation in domestic production. Pigeon pea is sold directly by farmers in rural markets to middlemen or to local dal millers (Von Oppen, 1981).

Market shortfalls are met by imports from Africa, Nepal and Myanmar. In Myanmar, the consumption of pigeon pea is preferred by people of Indian and Nepalese descent (Nene *et al.*, 1990).

Asia dominated the world production of pigeon pea between 1961-2006 with as much as 90.64% in 2000 and 89.88% in 2006 compared to the other regions. The data gathered since 1961 showing Asia cornering the production of pigeon pea by an average of 91%. Globally, the production was not sufficient to meet the needs of the consumers due to a mismatch in population and production growth in spite of the increase in area. (Mula and Saxena, 2010).

In Africa, pigeon pea marketing is widespread throughout the region with varying degrees of integration into commercial channels. About estimated 65% of regional pigeon pea production is consumed by the farmers themselves. These are consistent with micro-level observation of on-farm consumption, retention of seed for planting and pigeon pea exchanges at community level (Muwalo *et al.*, 1999).

Around 10% of production in Kenya, Malawi and Tanzania are traded in domestic markets. Domestic markets in Tanzania are smaller than in Kenya, particularly for the green and processed forms. Thirty-five percent (35%) of the total production are consumed on farm (Monaco, 2003).

In the Americas and Caribbean, about 8% of the households take dried pigeon peas, especially in areas where there is a concentration of ethnic Indian population while in Trinidad and Guyana, 26% consume green pigeon pea as vegetable. About 60% of the produce is processed into canned pigeon pea, 15% sold as mature, green, fresh peas and the remaining quantities in frozen form (Nene *et al.*, 1990).

The FAOSTAT (2008) reported that Dominican Republic and Malawi were continuously engaged in exporting pigeon peas from 1961 to 2009. The accumulated export in the 20s has substantially expanded owing to the aggressiveness of Myanmar in exporting its pigeon peas around the world. A total of 888,927 t with a value of $390.611 M were exported with the bulk of the export of 887,793 t coming from Myanmar. The three-year aggregate of exported pigeon pea from 1961 to 2009. The period 2006–2008 showed an upsurge in export of pigeon pea with a total quantity of 589,345 t and with a street value of $291,236,278.80.

According to Joshi *et al.* (2001), besides Myanmar, African countries like Kenya and Tanzania are also important exporters for the last 10-15 years. But the exports made by these two countries were not recorded in the statistics data of FAO. Globally 4.33 million tonnes (mt) of pigeon pea was produced. India alone contributed 2.65 mt followed by Myanmar (0.9 mt), Tanzania (0.3 mt), Malawi (0.24 mt), Kenya (0.09 mt) and Uganda (0.084 mt) (FAOSTAT, 2012). The area and production of pigeon pea for last 6 years in India.

Most countries still do not report statistically their pigeon pea production. Global production trend has had its highs and lows from 1961 to 2005. From 1961 to 1980, pigeon pea production decreased from 2,227,955 t to 1,965,319 t. From 1980 to 1990, production increased to 3,100,287 t then dropped to 2,585,243 t in 1995. Since 1995, the production trend was upward with recorded increase of 3,204,187 tons in 2000, 3,428,166 t and 3,458,166 t in 2006 (FAOSTAT, 2008).

In Bangladesh, Arhar is mostly cultivated in Kushtia, Rangpur, Dinajpur, and Jessore districts. Total acreage of its cultivation is about 5,215 and the annual production is about 1,005 m tons (Banglapedia, 2014).

According to BBS (2018) the total area and production of other pulses like Gari Kalai, Khesari, Maskhali, Mung, Motor, Masur, Arhar, Gram were estimated at 363,182.5 ha and 473497 mt. respectively; of which cowpea contributed with notable number; which brings a total area of 32,000 hectors under cowpea production; the recorded amount of production is 35,000 tons in total.

2.4 Socio-economic importance of pigeon pea

The perennial nature of pigeon pea permits farmers to take multiple harvests with surpluses dealed in both local and international markets. This is partly due to the possible wide range of phenological development, which is influenced by photoperiod and temperature, and response to these factors conducts the ecophysiological adaptation of pigeon pea, from photoperiod sensitive genotypes grown as perennial crop (more than 11 months), long-season (9-11 months), mid-season (6 to 8 months) crops, to short-season (3 to 5 months) crops (Wallis *et al.*, 1988).

The tall and erect pigeon pea varieties are known to provide not only nutritious food, feed and fodder but also provide fuel wood for the rural people, thus it is very popular among small and marginal farmers. The dry sticks of pigeon pea plant are used for making baskets, thatches and storage bins also. In addition to atmospheric nitrogen fixation through root nodulation by a wide range of symbiotic Rhizobia strains (Chikowo *et al.*, 2004), the defoliated leaves also add nitrogen and organic matter to the soil.

Equally important is the optimum utilization of pigeon pea meal in fish production. According to Ogunji *et al*. (2005), soaking of pigeon pea seeds for 16 hours enhanced best the fish weight gain and haematological values of African catfish.

The present high cost of animal sourced protein in feeds makes pigeon pea ideal as a good plant protein substitute as it is less expensive. Singh and Eggum (1984) and Springhall *et al.* (1974) reported that pigeon pea meal (21% crude protein, 9.2% crude fiber) could be included at levels of up to 30% in broiler chick diets with no significant depression in live weight gains. George and Elliott (1986) stated that raw pigeon pea seeds can be included at rates of up to 400 g/kg in a commercial layer diet without affecting egg production performance and health and feed intake of the birds. They suggested that raw, ground pigeon pea can be a valuable energy and protein source in poultry diets and can be included at rates of up to 450 g/kg of the dietary dry matter without adversely affecting the health and productivity of the bird.

Leaf fall at maturity adds to the organic matter in the soil and provides additional nitrogen. The root system is reported to break plough pans, thus improving soil structure, encouraging infiltration, minimizing sedimentation and smothering weeds.

The crop nodulates with wide ranges of Rhizobium and consistently fixes 20 to 140 kgs ha of N in fertile soil (Anderson *et al*., 2001).

Pigeon pea has been used successfully in coffee plantations as a cover crop to improve soil properties, reduce weed competition as well as act as a food source for predators (Venzon *et al.,* 2006). Moreover, in the low mountain range of China, the farmers cultivate pigeon pea on wastelands and field bunds providing relief from the energy shortage and likewise help in arresting deforestation. The quality of fuel wood has been estimated to be excellent yielding energy at the rate of 4,350 K Cal/kg (Yude *et al.,* 1993).

The pigeon pea is well balanced nutritionally and an excellent source of protein whether consumed as a green pea or as dried grain (Faris and Singh, 1990). In addition to protein, pigeon pea provides carbohydrates and 5-fold higher levels of Vitamin A and C (Faris *et al.,* 1987).

Pigeon pea is also a good source of vitamin A and vitamin B complex. Cattle do not relish the forage in the immature stage. Grazing should be deferred to the early green-pod stage (Hosaka and Ripperton, 1944) and in some cases mature plants may cause irritation of the rumen of cattle (Stanton, 1966).

Pigeon pea stems are used in fencing crop fields and livestock and weaving crlbs and baskets. The wood is used in light construction such as roofing, thatch, wattling on carts, tubular wickerwork lining for wells, shelter for barns, huts and other crafts from branches and stems (Morton, 1976 and Van der Maesen, 1989).

Tall perennial pigeon pea is often used as live fences in homesteads of farmers of Africa and the Caribbean (Phatak *et al.*, 1993). In Southeast Asia, pigeon pea is grown as a support for vanilla while in China; pigeon pea is also grown along highways on river banks, mountain, and slopes as substrate for mushroom production.

In some experimentation, pigeon pea has been found to produce a pulp for paper similar to that of hardwoods, which might be suitable for making good quality writing and printing material. In addition, the plant has been observed to be a good source for apiculture. The nectar collected by honeybees produce honey that has a distinctive greenish hue in the comb (World Agroforestry Centre).

In China, Jianyun and Yun (1998) conducted experiment on the processing technology of plywood bond using pigeon pea glue. The results showed that the bond strength of the plywood was 1.28-1.92 Mpa, which parameters meet the National Standards and it was higher than that of soybean glue (Glycine max). The pigeon pea glue processing technology is relatively simpler and economical.

2.5 Intercropping

Pigeon pea is a good alternative crop with low fertilizer requirements and with minimum pesticide use. Due to its hardiness, ability to grow on residual soil moisture, and slow early growth, pigeon pea is an ideal, non-competitive crop to plant with cereals. In traditional cropping systems, throughout the world, pigeon pea is mostly cultivated as secondary or mixed with other crops (Aiyer, 1949; Acland, 1971; Osiru and Kibira, 1981).

High input system in rice growing areas, which has begun showing signs of instability, could become more sustainable with the inclusion of pigeon pea into the rotation by providing farmers with an alternative to rice during periods of water scarcity, price incentives, and problems of soil fertility. It gives additional yield after the first harvest if sufficient moisture is available (ratooning), and it has great flexibility in a wide range of cropping systems. Pigeon pea is a superb intercrop and a non-competitive crop to grow with food crops (cereals, etc), cash crops and other plantation crops. Willey *et al.* (1981) have stated that intercropping systems of pigeon pea have not significantly affected the yields of other crops compared to when the crop is planted as a sole crop. In addition, up to 70% of the yield of pigeon pea alone can also be obtained.

Pigeon pea is alternately planted in rows with rows of wheat (*Triticum aestivum* L.), chickpea (*Cicer arietinum* L.), sorghum (*Sorghum bicolor*), groundnut (*Arachis hypogaea* L.), sesame *(Sesamum indicum*), cotton (*Gossypium spp*.) , pineapple (*Ananas comosus*), pearl millets (*Pennisetum glaucum*), maize (*Zea mays*) and in between plantation crops like coconut (*Cocos nucifera* L.), banana (*Musa species*), mango (*Mangifera indica* L.),and citrus (*Citrus spp*) (Ali and Kumar, 2000; Sekhon *et al*.,1992).

Intercropping of cereals and legumes is a better means of utilizing resources such as light, water and nitrogen. Understanding of how efficiently these three resources are utilized in maize-pigeon pea intercrop system is important to achieve higher productivity. An experiment was conducted at Jomo Kenyatta University of Agriculture and Technology between October 2001 and June 2002 to determine light and water use in maize-pigeon pea intercrop system. Results showed that temporal complimentarily in maize-pigeon pea intercrop reduced competition for light between the two crops hence maize yields were unaffected. Temporal differences in root growth ensured full use of water during the growing season and spatial use of water below the ground could be better by a combination of shallow and deep rooting components in an intercrop system (Wanderi *et al.*,2006)

One hundred germplasm lines were evaluated by (Hamid *et al.*, 2011) for variation in morphological and agronomic traits for selection of cultivar potentially convenient for growing in Bangladesh under rice-based cropping systems during the fallow period after kharif II season. A wide range of disparity was found in twelve quantitative plant traits. The most important correlations corresponded to eight plant traits. Considering these traits, PCA could explain 76.2% of total variance. Pods plant^{-1} played the most dominant role in explaining the highest variance according to DFA. Genotypes grouped in 1, 4 and 7 clusters were early maturing and high yielder as compared to the other cluster members. Genotype 21 (ICP7143) representing group 1 showed promising for its short stature nature. However, genotype 32 (ICP 7989) representing group 4 produced the maximum yield with the shortest maturity duration.

2.6 Importance of legume

Being a deep rooted legume, pigeon pea also improves the physical condition of the soil for the next crop. Krause (1932) considered pigeon pea for soil binding and advocated its plantation in Hawaii Island for checking soil erosion.

Herridge *et al*. (2008) used data on yields and areas of legumes and cereals from FAO (FAOSTAT) to generate global estimates of legume-fixed N per year. These were calculated as 29.5 Tg for pulses and 18.5 Tg for oilseeds. There are no available statistics with respect to the areas and yields of forage, fodder and green manure legumes on a global basis. This is a major gap in our knowledge and thus estimates with respect to these crops have much greater uncertainty attached.

Herridge *et al.* (2008) also gave broad calculations of 12–25 Tg N fixed per year from pasture and fodder legumes. Tropical legumes fix as much N as temperate ones, e.g. 575 kg/ha/year for a pure stand of *Leucaena leucocephala,* and there is greater C storage in legume-based tropical pastures than grass only.

Zhang *et al.* (2009) showed that conversion of reed meadows to alfalfa fields, in response to increased demand for forage for livestock systems in China, could result in increased levels of SOC.

Fornara *et al*. (2009) showed that the presence of legumes and non leguminous forbs and in particular their greater fine root decomposition led to enhanced root N release and increased net soil N mineralization compared with grass only swards. The authors stated that fine roots (less than 2 mm diameter) constitute a large fraction of annual primary productivity in many terrestrial ecosystems and have a significant influence on N and C cycling.

Cadisch *et al.* (1998) emphasized the role of legumes in building up soil organic matter (SOM) and considered that the importance of this in tropical soils may be as great as N supply. Again, persistence was highlighted as the key to realizing the benefits from legume stands.

2.7 Carbon sequestration from different plant

Lynch *et al.* (2005) conducted a study using simulation and spreadsheet analysis, considered changes in soil C sequestration in responses to alterations in grazing, fertilization and seeding of grasses and legumes. They stated that some treatments, e.g. seeding of grasses and legumes combined with continuous grazing, could result in increased soil organic carbon (SOC) of pastures but that this did not translate into improved net returns.

A research was conducted by Mortenson and Schuman (2004) in northwestern South Dakota to evaluate the role of inter seeding a legume, *Medicago sativa* ssp. falcata, in northern mixed-grass rangelands on carbon sequestration. Sampling was undertaken on a chrono sequence of sites interseeded in 1998, 1987, and 1965 as well as immediately adjacent untreated native rangeland sites. Soil organic carbon exhibited an increase of 4% in the 1998, 8% in the 1987, and 17% in the 1965 interseeding dates compared to their respective native untreated rangeland sites. Nitrogen fixation by the legume led to significant increases in total soil nitrogen and increased forage production in the interseeded treatments. Increases in organic carbon mass in this rangeland ecosystem can be attributed to the increase in soil organic carbon storage and the increased aboveground biomass resulting from the increased nitrogen in the ecosystem.

The carbon fixation or carbon concentration estimated in certain trees and shrubs indicated that there are certain tree species with high ability to fix atmospheric carbondioxide into their biomass. The trees and shrubs selected with high carbon concentration were *Eugenia caryophyllata* 51.66%, *Litsea glauscensens* 51.34 %, *Rhus virens* 50.35%, *Forestiera angustifolia* 49.47%, *Gochantia hypoleuca* 49.86%, *Forestiera angustifolia* 49.47%, *Pinus arizonica* 49.32%, *Cinnamomum verum* 49.34%, *Bumelia celastrina* 49.25%, *Tecoma stans* 48.79%, *Acacia rigidula* 48.23%, *Eryobotria japonica* 47.98 %, *Rosamarinus officinalis* 47.77%. Few of these species may be selected for plantation in highly carbon dioxide polluted areas in cities, road sides and factory areas with high emisssion of carbon dioxide (Maiti *et al.*, 2015).

Wang *et al.* (2013) studied variability of *Larix olgensis* in different organs in North-Eastern China. The results showed that the weighted mean carbon concentration by biomass was approximately 48.15%. In this study, the carbon concentration of aboveground tree organs is ranked with descending order as living branch> bark> foliage>dead branch>stem; and in the belowground, it is ranked as large roots> stumps>thick roots>medium roots>small roots. The carbon concentration differed significantly between tree organs, while there was no significant difference between trees with different ages

With respect to the role of plants in capturing CO_2, Jiménez Pérez *et al*. (2013), investigated carbon concentration in pine-oak forest species of the Sierra Madre Oriental. The components of the above-ground biomass considered were stem, branches, bark and leaves of the species *Pinus pseudostrobus*, *Juniperus flaccida*, *Quercus laceyi*, *Quercus rysophyla*, *Quercus canbyi* and *Arbutus xalapens*. The species with the highest carbon concentration was *Juniperus flaccida*(51.18%), while *Q. rysophylla* had the lowest (47.98%). Among the different components of the tree the component i.e., leaves of *Arbutus xalapensis* (55.05%) had the highest carbon concentration. There were highly significant differences between the various components by species group; the highest concentration was found in the bark of conifers (51.91%), compared to the bark of the broadleaf species, which had the lowest (45.75%).

Enhancing C sequestration by increasing forested land areas has been suggested as an effective measure to lower atmospheric carbon dioxide (CO_2) concentration contributing towards the prevention of global warming (Watson, 2000). Nevertheless, conservation of forests having large amounts of C stocks is also a valuable way to reduce CO_2 emissions which is more beneficial than reforestation in the short run (Sharma *et al*. 2010).

It is imperative to improve understanding of the processes regulating C sequestration in order to manage landscapes, maximizing their potential to store C in the future (Jones and Donnelly 2004) and plan policies to mitigate desertification, especially in arid and semiarid lands (Iglesias *et al.* 2012).

The Mediterranean forests and shrublands are heavily utilized by man (Boix-Fayos et al., 2009) with a possible increase in the near future of degraded areas due to coastal urbanization, landscape fragentation, overgrazing and excessive wildfires (Wessel *et al*., 2004; Boix-Fayos *et al.*,2009).

Cannell and Milne (1995) reported the amounts of carbon in different vegetation types and tree species. About 80 per cent of the carbon in British vegetation is in forests and woodlands (92 MtC) although occupying only 11.2 per cent of the rural land area. Broadleaved woodland alone accounts for 47 per cent of the total of 114 MtC because those woodlands are older and contain, on average, 62 tC ha –1 compared with 21 tC ha –1 in conifer forests. Conifers cover 6.1 per cent of the land area, compared with 4.1 per cent by broadleaved woodlands, but contain only 25.3 per cent of the total of 114 MtC.

2.8 Pigeon pea yield

According to Parbery (1967), the unfertilized pigeon pea which is grown for 372 days has yielded 25.45 t/ha of dry matter while 37.96 t/ha was harvested when fertilized with 100 kg N/ha on Cunnunurra clay and 1,071 kg/ha was produced on unfertilized pigeon pea on Cockatoo sand in the Kimberley district of northern Australia. It was also revealed that 100 kg N/ha depressed the crop yield on Cockatoo sand.

A study was conducted to investigate the highest pod yielding percentage of wild and cultivated genotypes of pigeon pea (*Cajanus cajan*) on the basis of intensity of raceme and flower production, pod production and floral abscission. Results showed that total number of racemes and flowers plant^{-1} varied between 84.66 to 140.11 and 707.67 to 1564.70 respectively. Total number of pods plant^{-1} and the reproductive unit existed between 90.80 to 165.30 and 1721.79 to 2753.98 among the wild and cultivated genotypes. (Rahman *et al*., 2011).

2.9 Low yield of Pigeon pea

Pigeon pea has not achieved its production potential largely due to limited use of appropriate inputs and crop management practices (Smith *et al*. 2001).

The low productivity is a major barrier in improving trade forecast. Under small-scale management, yields of local pigeon pea varieties have been found to be significantly lower at 350kg/ha of usable seed weight and inconsistent across areas and seasons (Ritchie *et al.*,2000).

Global yield mainly reflects the situation in Asia especially India, the major producing country, where yields are low at 700 kg/ha (Saxena, 2009). The low productivity was attributed to the following factors, particularly, the crop's low status in the cropping system, its being often relegated to marginal soils, its intercrop with cereals and cotton, its receipt of little or no inputs, and the fact that it attracts much of farmers' crop management attention (Troedson *et al.,* 1990, Müller *et al.*,1990). However, the lack of high yielding cultivars appears to be the major factor for its low productivity (Saxena, 2009).

2.10 Constraints of pulse production in Bangladesh

Among the biotic stresses diseases, pests, seed dormancy and weeds are the main ones. So far 126 diseases have been recorded in these crops of which botrytis gray mold, Fusarium wilt and collar rot in chickpea; foot rot, stemphylium blight and rust in lentil; powdery mildew and downy mildew in lathyrus; yellow mosaic virus, cercospora leaf spot and powdery mildew in blackgram and mungbean (Talukder, 1974; Fakir and Rahman, 1977; Fakir, 1986; Fakir and Rahman, 1991; and Rashid *et al*., 2007).

Among the 30 insect pests, *Helicoverpa armigera* of chickpea and blackgram; *Diacrisia obliqua* of blackgram, mungbean and groundnut; Aphids of lentil, lathyrus and mungbean; *Euchrysops cnejus, Monolepta signata, Bemisia tabaci* of mungbean and blackgram are the major pests (Rahman *et al.,* 1982). Among the storage pests *Callosobruchus chinensis* and *C. maculates* are important. Weeds are very common problem in all legume crops (Rahman *et al.*, 1982).

Among the abiotic constraints, drought causes severe yield reduction. Excess rain and high humidity usually favour vegetative growth but also encourage diseases and pests infestation causing yield reduction. Terminal heat stress, excess rainfall and soil inundation due to tidal flood also cause substantial yield loss or crop failure. In some areas micronutrient deficiency, soil salinity and soil acidity limit pulse production. (Rashid *et al*., 2007).

Socio-economic constraints like low profit, instability in market price, lack of credit that prohibit adopting improved production technologies that leads to poor yields (Rashid *et al.,* 2007).

2.11 GGE-biplot technique

The plant breeding community's aim is to conduct multi-environmental trials on different genotypes, to identify the most superior genotype for wide or specific cultivated zones based on yield and stability. Growing genotypes in diverse environments can be used as a tool to identify high yielding and most stable genotypes (Luquez *et al*., 2002; Fan *et al*., 2007).

Seed yield, an economically important trait and quantitative in nature, routinely exhibits genotype environment interactions (GEI), which necessitates genotypes ×evaluation in multi-environment trials (MET) at advanced stages of selection (Annicchiarico 2002; Kang *et al*., 2004).

Estimation of stability performance becomes an important tool to identify consistently high-yielding genotypes (Kang, 1998). Graphical display of different genotypes for desirable parameters and traits of interest is helpful, easily understandable and even attractive with less hesitation (Yan 2001; Ullah *et al.,* 2007, 2011).

G ×E interaction cannot be avoided, as it is an important limiting factor for testing the efficiency of any breeding program. GGE biplot refers to the genotype main effect (G) and the genotype×environment interaction (GE), which has two sources of variation that are relevant to genotype evaluation. It can be used to identify superior genotypes and target environments that make possible the identification of such genotypes (Gwanama *et al*., 2000; Fan *et al*., 2007).

GEI are often described as inconsistent variation among genotypes across different environments. Furthermore, lack of consistency in performance across environments complicates genotype selection, which could generate useful information for researchers (Busey 1983; Kang 1998; Fan *et al.*, 2007).

Genotype × Environment interaction (GEI) is an important aspect of plant breeding programs. It may arise when certain genotypes are grown in diverse set of environments. A significant G × E interaction for a quantitative trait such as seed yield can seriously limit the efforts on selecting superior genotypes for both new crop production and improved cultivar development (Kang and Gorman, 1989).

The GGE biplot also has a usage in selecting superior cultivars and test environments for a given mega-environment. Provided the genotypic PC1 scores have a near-perfect correlation with the genotype main effects, ideal cultivars should have a large PC1 score (high yielding ability) and a small (absolute) PC2 score (high stability). Similarly, ideal test environments should have a large PC1 score (more discriminating of the genotypes in terms of the genotypic main effect) and small (absolute) PC2 score (more representative of the overall environment) (Yan, 1999; Yan *et al.*, 2000).

Many stability statistics have been used to determine whether or not cultivars evaluated in MET are stable. Because the most stable genotype(s) may not be the highest yielding, the use of methods that integrate yield performance and stability to select superior genotypes becomes important (Kang, 1988; Pham and Kang, 1988; Kang and Pham, 1991; Kang, 1993; Kang and Magari, 1996).

More recently, GGE biplots which show both genotypes and environments as based on Site Regression (SREG) model have been advocated to describe GEI pattern (Yan and Tinker, 2006; Yan *et al*., 2007).

GGE biplot captures both genotype main effects and genotype × environment interaction effects, which are two important sources of variations relevant to genotype evaluation (Yan and Hunt, 2001).

Phenotypes are a mixture of genotype (G) and environment (E) components and the interactions (G×E) between them. G×E interactions complicate the process of selecting genotypes with superior performance. Consequently, multi-environment trials are widely used by plant breeders to evaluate the relative performance of genotypes for target environments (Delacy *et al.*, 1996).

The grain yield measured for a cultivar in a given environment is obtained due to the effect of genotype (G), environment (E) and the G × E interaction (Yan and Kang, 2003).

The progress of a breeding program is therefore limited due to the G × E interaction, especially where genotypes are selected in one environment and used in another (Kearsey and Poony, 1998; Giauffret *et al*., 2000).

GEI are often described as inconsistent differences among genotypes across different environments. GEI in multi-location trials complicates the identification of superior genotypes for a single location, because of the larger magnitudes of genotype-by-location interactions than genotype-by-year interactions (Badu *et al*., 2003).

2.12 Application of GGE-biplot technique on some crop

Pagi *et al*. (2017) conducted an experiment in western India with fifty six pigeon pea genotypes comprising fourteen parents, forty hybrids and two standard checks were evaluated at four environments during kharif season of 2013 and 2014. A significant difference was obtained for yield and yield contributing characters among genotypes in individual as well as pooled environments except for pod length, 100 seed weight and seed protein content (%). For traits like days to maturity, plant height, pods per plant, pod clusters per plant, seeds per pod, 100 seed weight and seed yield per plant Genotypes × Environments (linear) values were significant when tested against pooled deviation.

Kamau (2013) conducted an experiment in Eastern and Southern Africa on medium duration pigeon pea was analyzed for genotype performance. Different stability parameters gave different genotype rankings. Eberhart and Russell model ranked genotypes ICEAP 00550 as the most stable genotypes, AMMI model ranked ICP 6927 as the most stable genotype while ICEAP 00068 was ranked as the most stable genotype by GGE biplot. Considering ranking by the three models the three most stable genotypes were found to be ICEAP 00550, ICP 12734 and ICP 6927.

An experiment was conducted in five pulse growing regions of Bangladesh viz. Ishurdi, Gazipur, Jessore, Barisal and Madaripur during the year 2013-14. Significant differences were observed for all the tested genotypes against days to flowering, days to maturity, plant height, pods plant^{-1} and 100 seeds weight among the environments except Gazipur and Madaripur. BARI Chickpea-5, BCX 06004-10 and BARI Chickpea-9 took lowest mean minimum days (70) to flower but BCX 06004-10 got maturity (124 days) earlier than the others. BCX 06004-10 was the tallest one and BARI Chickpea-5 was the dwarf one. Highest mean of pods plant^{-1} was obtained from BARI Chickpea-5 followed by BARIChickpea-9 and BCX 06004-10. The entry BCX 06004-10 was the highest yielder genotype while BCX 06001-11 showed moderate stability across the environments. (Rahman *et al.,* 2016).

Rahman *et al*. (2017) conducted an experiment at Pulses Research Centre, Ishwardi, Pabna, Regional Agricultural Research Station Jessore and Jamalpur, Regianal Pulse Research Station, Madaripur, Onfarm Research Division, Barind, Rajshahi and Pulses Research Sub Centre, Gazipur during kharif-II, 2015 to find out desirable lines of Blackgram. The genotypes 86337 gave highest average yield (1206 kg ha^{-1}) among the genotypes followed by BBLX-06002-10(1089 kg ha-1) and BBLX-07002-5 (1076 kg ha-1). It also produced highest seed yield in Joydebpur (1334 kg ha^{-1}) across the locations. Out of six locations 86337 genotypes produced a good yield (1206 kg ha^{-1}) on the other hand, the lowest average yield was obtained from the genotypes BBLX-07002-1 (1043 kg ha^{-1}).

The study was carried out in 13 villages under three Upazila’s namely Hathazari, Fatikchari and Satkania of Chattogram District, Bangladesh during 2017-2018 covering 210 farmers in the selected locations. Results revealed that the rate of adoption of cowpea (BARI Cowpea-*1*) was found to be higher (71%) than that of the local and mixed varieties. The highest number of the respondents came to know about BARI

Cowpea^{-1} from DAE (58.6%) followed by seed dealers (31.7%), research stations (19.0%) and NGO's (17.0%) (Uddin *et al*., 2020).

Farshadfar (2013) carried out an experiment of 20 chickpea genotypes under two different rainfed and irrigated environments for four consecutive growing seasons (2008–2011) in the Campus of Agriculture and Natural Resources of Razi University, Kermanshah, Iran. The estimated results showed that genotypes G3, G16 and G10 were highly stable with high grain yield.

An experiment was done among 20 genotypes of chickpea under two different environmental conditions of Pakistan (karak and Peshawar) during 2007 to 2008. Results showed that genotypes at Karak produced significantly greater seed yield than at Peshawar. GGE biplot analysis ranked genotypes on above average seed yield across environments as Lo-3, Lo-2, Pk-2, Lo-4 and Pk-3 as top five genotypes, while the bottom five genotypes were identified as Sy-7, Pk-1, Sy-4, Sy-5 and Pk-5. For stability of performance across environments, Pk-4, In and Pk-3 were identified as most stable genotypes followed by Lo-2, Pk-2, Pk-3 and Lo-3. On the basis of both stable performance and mean seed yield across environment, the GGE biplot ranked genotypes Lo-3 as the best among all, followed by Lo-2, Pk-2, Pk-3 and Lo-4, while the rest of the genotypes were identified as inferior. Karak was identified as representative environment as compared to Peshawar. (Hamayoon *et al.,* 2010)

The experiment was done to explore the effect of genotype; and genotype × environment interaction; on grain yield of mungbean genotypes using GGE (genotype plus genotype by environment) biplots. Based on both grain yield and stability performance NFM113 ranked 1st, followed by NFM713, NFM126 and NM98. In contrast, the worst performing genotypes were NFM145 and NFM 147. Based on discrimination and representation, PR07 was identified as the ideal environment for mungbean genotypes. GGE biplot analysis indicated that genotype NFM113 could be used for cultivation in the plains areas of Peshawar and surroundings of Shabqadar, whereas, genotype NFM713 was site specific but might be used in the upper areas of Swat for general cultivation. (Ullah *et al*., 2011).

Asfaw (2012) was carried an experiment among seven mung bean genotypes for two years (2004 and 2005) at three locations in South Nations, Nationalities and Peoples (SNNP) regional state of Ethiopia. GGE biplot analysis identified MH-96-4, shown to have the potential of combining high yield with stable performance, can be recommended for production in mung bean growing ecologies in southern Ethiopia.

Fifteen genotypes of mungbean were tested at five locations in Pakistan in the Kharif season 2006 to study their yield stability. Pooled analysis of variance and stability analysis were performed. On the basis of these parameters, the top yielding genotype '2 (check) CG-504' exhibited the stable performance over all five locations. Results also showed that the genotypes; BRM-288, NCM-257-2 and BRM-286 gave higher yield. But their performance was unstable due to high deviation from regression. (Akhtar *et al*., 2010).

CHAPTER 3

MATERIALS AND METHODS

The experiment was driven at three locations and the period of September 2018 to May 2019.The test place and season, soil, climate and weather, plant materials, experimental design and treatment combinations, data collection, statistical analysis etc. were described briefly in this chapter.

3.1 Experimental site

The experiment was performed at the research field of Pulse Research sub-center (PRC) in Bangladesh Agricultural Research Institute (BARI), Gazipur; Regional Agricultural Research Station (RARS), Sylhet and also at Regional Pulses Research Station (RPRS), Madaripur. The test site BARI is situated between 23° 59′ N latitude and 90° 25′ E longitude and 11 m elevation of from sea level. Another test location (RARS) is located between 24° 24′ N latitude and 91° 37′ E longitude and 35m from sea level. The test site (RPRS) Madaripur is located between 23° 16′ N altitude and 90° 19′ E longitude and 9 m from sea level. The experimental locations are shown in Appendix I.

3.2 Soil

One experimental site, Bangladesh Agricultural Research Institute (BARI) is pertained Madhupur Tract (AEZ-28) which soil has a texture of clay loam with a pH of 5.5 and cation exchange capacity 9.2 cmol kg^{-1}. Another experimental location, regional Agricultural research station (RAPS) is belonged to northern and Eastern hills (AEZ-29) which soil has contained a PH of 4.7 and cation exchange capacity 5.7 cmol kg^{-1} with a soil texture of sandy clay loam. Madaripur is situated under Low Ganges River Floodplain soil (AEZ 12). The soil type predominantly includes calcareous dark grey and calcareous brown floodplain soils. Soils are calcareous in nature having neutral to slightly alkaline reaction. General fertility level is medium with high CEC and K status and the Zn and B status is medium or low (Rashid 2001; FRG 2005). The morphological characteristic of the experimental sites are mentioned in appendix I.

3.3 Climate

The climate of BARI is subtropical, individualized by three distinct seasons, the monsoon from November to February and the pre monsoon period or hot season from March to April and the post monsoon period from May to October and the climate of RARS is humid subtropical. That climate is generally marked with monsoons, high temperature, considerable humidity and heavy rain fall. The hot season commences early in April and continues till July. The average annual temperature in Sylhet is 24.7°C and 2805 mm precipitation falls annually. The climate here is tropical. In winter, there is less rainfall in Madaripur than in summer. In Madaripur, the average annual temperature is 25.9 °C. Precipitation here is about 1849 mm. The monthly average temperature, humidity and rain fall during the crop growing periods are presented in appendix II.

3.4 Materials

Four pigeon pea genotypes collected from Bangladesh Agricultural Research Institute (BARI) were used in the experiment. These were G1 = BPP – 1502, G2 =BPP – 1503, G3 = BPP – 1504 and G4 = BPP – 1505.

3.5 Experimental Design

The experiment was consisted of two factors. Factor 1: Three locations:- a. BARI, Gazipur; b. RARS, Sylhet and c. RPRS, Madaripur

Factor 2: Four pigeon pea genotypes
The experiment was laid out following the Randomized complete Block Design (RCBD) with three replications. Each treatment combination was replicated three times with plot size 3 rows × 3m and spacing 80 cm × 25 cm.

3.6 Methods

3.6.1 Land Preparation

The land was watered prior to ploughing. Then the land was first uncovered with tractor down disc plough. The soil which was ploughed was brought into suitable fine tilth by four ploughing and cross ploughing. Harrowing and laddering. The stubble and weeds were moved from the land for the convenient germination of pigeon pea seedlings experimental land was divided into unit plots following the design of experiment. The plots were spaded one day before seed sowing and the basal dose of fertilizers was incorporated thoroughly with soil.

3.6.2 Sowing of seeds

At BARI, Gazipur, seeds were sown in rows on 29 September, 2018 and at RARS, Sylhet, seeds were sown on 27 November, 2018 and at RPRS, Madaripur on 1st October, 2018.The pigeon pea seeds were sown at about 3.4 cm depth from the surface of soil.

3.6.3 Fertilizer

Urea, triple super phosphate (TSP), Murate of potash (MOP) and Gypsum were used as source of nitrogen, phosphorus, potassium, Sulphur and boron respectively. Total amount of urea, TSP, MOP and Gypsum were applied at basal doses during final land preparation. The doses of TSP, MOP, Gypsum, Boron and urea were 25g, 15g, 2 g and 25g per meter square respectively.

3.7 Intercultural operations

3.7.1 Weed control

Weeding was done once in the entire unit plots with care so as to maintain a uniform plant population.

3.7.2 Thinning

Thinning was done at 20 days after sowing (DAS) and 30 DAS.

3.7.3 Irrigation and drainage

Irrigation was given to get the maximum germination percentage. During the whole experimental period, there was a heavier of rainfall in earlier part. So it was essential to remove the excess water from the field at later period.

3.7.4 Pest and disease management

Little pest and disease management was taken. Autostin (2g/ml) was sprayed after two month of sowing.

3.8 Harvesting and sampling

Ten plants were selected randomly from each plot and were uprooted for data recording. The rest of the plants of prefixed per m^2 area were harvested plot wise and were bundled separately tagged and brought to the threshing floor.

3.9 Threshing, drying, cleaning and weighing

The crop was sun dried for three days by placing them on the open threshing floor. Seeds were separated from the pods manually. The seeds thus collected were dried in the sun for reducing the moisture in the seeds to a constant level. The dried seeds were cleaned and weighed.

3.10 Data collection:

Samples were collected from each of the location for measuring the following parameters

(i) Plant height (cm): The height of the selected plant was measured from the ground level to the tip of the plant.

(ii) Plant breadth (cm): Plant breadth was taken randomly with a scale.

(iii) Stem diameter (cm): Stem diameter was taken from the selected plant with a measuring tape.

(iv) No. of branch plant^{-1}: From each selected plant number of branches per plant was counted.

(v) No. of pods plant^{-1}: From randomly selected 10 plants of each plot and then mean of pods per plant was calculated.

(vi) No of seeds pod^{-1} (10 pods): Number of seeds/pod was counted from selected 10 plants randomly and mean was calculated.

(vii) 100 seeds weight (g): Cleaned dried one thousand seeds were counted randomly from each harvest sample and that was weighed by using a digital electric balance.

(viii) yield plant^{-1} (g): The grains were threshed from the plants, dried, cleaned and then weighed. The yield of seed in kg plot-1 was adjusted at optimum moisture content.

(ix) CO_2 sequestered/plant (lbs): It was calculated by several steps mentioned below using plant's age, height, breadth and stem diameter.

(x) CO_2 sequestration of plant per year (lbs): It was determined by double the CO_2 sequestered/plant, as it was given half yearly value.

(xi)Total fresh(green) weight of the plant

Based on plant species in the Southeast United States, the algorithm to calculate the weight of a plant was:

W = Above-ground weight of the plant in pounds

D = Diameter of the trunk in inches

H = Height of the plant in feet

For plant width D < 11:

$W = 0.25D^2 H$

For plant width D >= 11:

$W = 0.15D H$

The root system weighs about 20% as much as the above-ground weight of the tree. Therefore, to determine the total green weight of the tree, multiply the above-ground weight of the tree by 120%.

(xii) Dry weight of the plant: To determine the dry weight of the plant, multiply the weight of the plant by 72.5%.

(xiii) Weight of carbon in the plant: The average carbon content is generally 50% of the plant's total volume. Therefore, to determine the weight of carbon in the plant, multiply the dry weight of the plant by 50%.

(xiv) Weight of carbon dioxide sequestered in the plant: To determine the weight of carbon dioxide sequestered in the plant, multiply the weight of carbon in the plant by 3.6663.

(xv) Determine the weight of CO_2 sequestered in the plant per year: Divide the weight of carbon dioxide sequestered in the plant by the age of the plant.

3.11 Statistical analysis

The data obtained for different characters were statistically analyzed following the analysis of variance techniques to obtain the level of significance by using R-STAT. The significant differences among the treatment means were compared by Least Significant Difference (LSD) at 5% levels of probability (Gomez and Gomez, 1984).

CHAPTER 4

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 Plant height (cm)

4.1.1 Effect of location on plant height (cm) of pigeon pea

The effect of location on plant height (cm) of pigeon pea was significant (Figure 1). The findings was noted that the maximum plant height (93.08 cm) was observed at BARI, Gazipur which was statistically different from the others. The minimum plant height (52.75 cm) was recorded at RARS, Sylhet and the highest plant height (72.91cm) found at RPRS, Madaripur. Rahman *et al.* (2016) observed that plant height of different genotypes of chickpea was higher in Ishuardi and lower plant height in Madaripur.

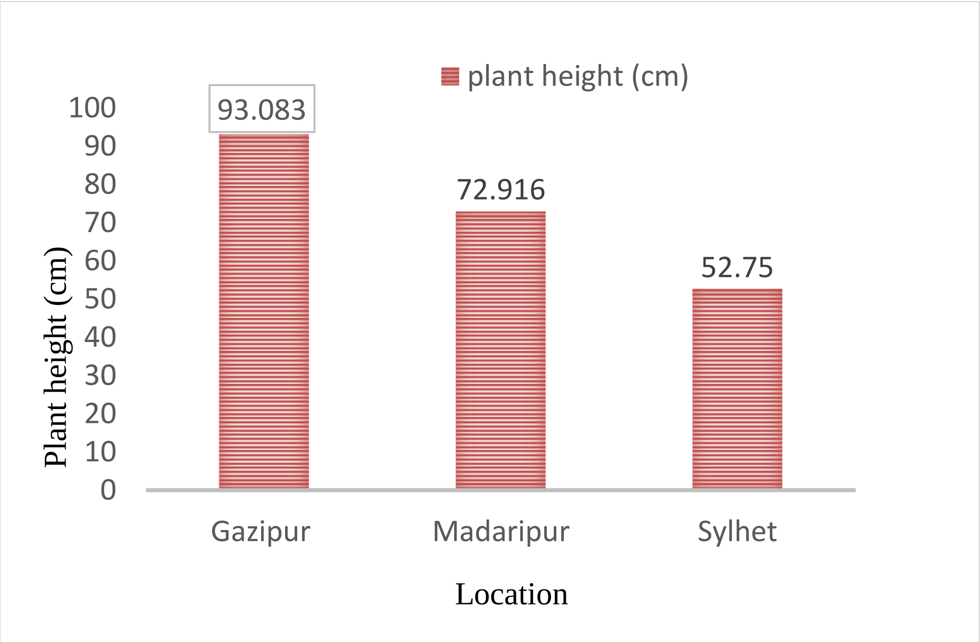

Figure 1. Effect of location on plant height (cm) of pigeon pea (CV -9.502% with LSD$_{(0.05)}$value- 6.920)

The variation of plant height may be due variation in mean temperature and also for availability of irrigation water. Plant height of pigeon pea was significantly affected by temperature with both mean maximum and mean minimum temperature (Kamau, 2013). These results suggested that supplementary irrigation increases the plant height in pigeon pea plants by an average of 34.4 cm (Khourgami *et al*., 2012).

4.1.2 Effect of genotype on plant height (cm) of pigeon pea

Variation of different genotypes of pigeon pea on plant height (cm) was observed significantly (Table 3). It was noted that the maximum plant height (78.33 cm) was obtained from G4 which was statistically close to G1. The minimum plant height (70.33 cm) was recorded at G2 which was statistically similar to G3. The results also support the findings of Rahman *et al.* (2016) who observed significant variation of plant height among different chickpea genotypes. The variation of plant height among the genotypes of pigeon pea might be due to different genetic makeup of the genotypes.

4.1.3 Interaction effect of location and genotype on plant height (cm)

The interaction effect of location and genotypes of pigeon pea on plant height (cm) was varied significantly (Table 1). The maximum plant height (103.33 cm) was found in G4 at BARI, Gazipur which was statistically different from others. It was recorded that the minimum plant height (50.66 cm) was observed in G3 at RAPS, Sylhet which was statistically similar to L2×G1, L2×G4 and L2×G2 interaction.

Plant height was positively and significantly correlated with vegetative growth of pigeon pea. The increase in plant height was associated with prolonged plant growth period and increased vegetative growth, leading to production of taller plants. The significant influence of locations and cultivars on plant height (Table 1) was supported by the observation made by Egbe and Vange (2008), which showed that pigeon pea plant heights are affected by maturity duration, cultivars, and environments.

Table 1. Interaction effect of location and genotype on plant height (cm)

Treatment combination	Plant height (cm)
L1× G4	103.33333 a
L1 ×G1	91.33333 b
L1 ×G3	91.00000 b
L1 ×G2	86.66667 bc
L3× G4	78.33333 cd
L3 ×G1	72.16667 d
L3 ×G3	70.83333 d
L3 ×G2	70.33333 d
L2 ×G2	54.00000 e
L2 ×G4	53.33333 e
L2 ×G3	53.00000 e
L2 ×G1	50.66667 e
CV%	**9.492**
$LSD_{(0.05)}$	**11.872**

Having similar letter (s) means these are statistically similar and those having dissimilar letter (s) differ significantly within a column. L1= Gazipur, L2= Sylhet, L3= Madaripur
G1=BPP1502, G2=BPP1503, G3= BPP1504, G4= BPP1505

4.2 Plant breadth (cm)

4.2.1 Effect of location on plant breadth (cm) of pigeon pea

Remarkable variation was observed on plant breadth (cm) of pigeon pea due to different location (Figure 2). It was observed that the highest plant breadth (60.79cm) was obtained from RPRS, Madaripur which was statistically different from others and the lowest plant breadth (29.66cm) recorded at RARS, Sylhet and the plant breadth (48.66 cm) recorded at Gazipur. Lower plant breadth may be due to poor growth during the days of plant maturity. The days to plant maturity was significantly and positively correlated to plant height, pod length and pod width (David *et al.*, 2016).

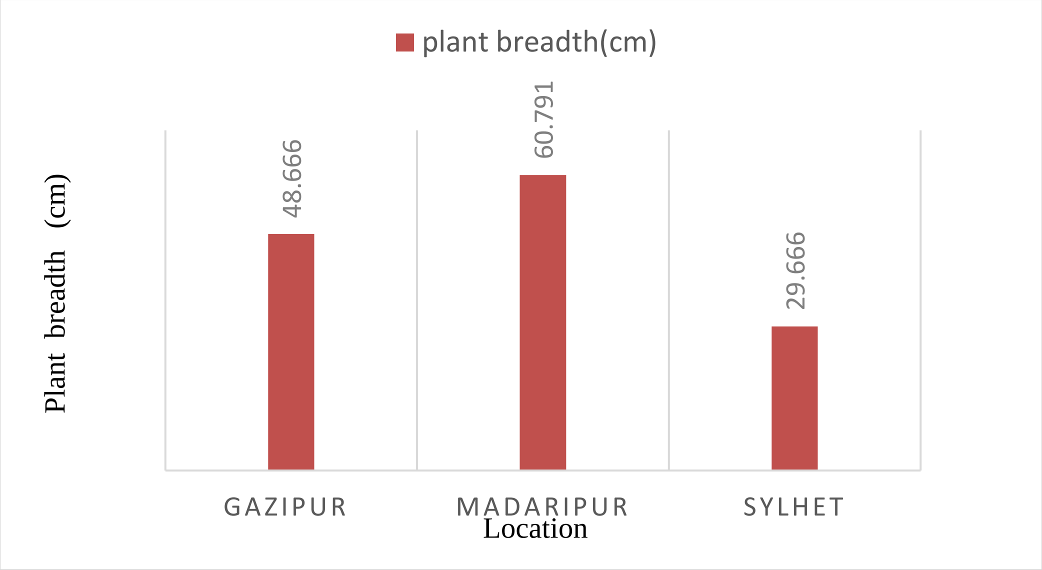

Figure 2. Effect of location on plant breadth (cm) of pigeon pea (CV – 7.952% with LSD$_{(0.05)}$value- 3.684)

4.2.2 Effect of genotype on plant breadth (cm) of pigeon pea

Among the genotypes of pigeon pea, plant breadth (cm) was significantly noted (Table 3). The highest plant breadth (48.72 cm) was recorded at G4 which was statistically similar to G3 and the lowest plant breadth (43.33cm) was found from G2.

4.2.3 Interaction effect of location and genotype on plant breadth (cm)

Significant variation of interaction was observed on plant breadth (cm) between genotypes of pigeon pea and location (Table 2). The highest plant breadth (64.5 cm) was obtained from G4 at Madaripur which was statistically similar to the interaction L3×G3 and L3 × G2. The result was revealed that the lowest plant breadth (26.33cm) was found from G2 at Sylhet which was followed by the interaction L2×G1, L2×G3 and L2×G4.

Studies conducted by Sreelakshmi *et al*. (2010), Sodavadiya *et al*. (2009), and Vijayalakshmi *et al*. (2013) on pigeon pea have reported significant positive correlations between duration to flower development and plant maturity and plant height, pod length and width, as well as primary and secondary branches of the plants.

Table 2. Interaction effect of location and genotype on plant breadth (cm)

Treatment combination	Plant breadth (cm)
L3× G4	64.50000 a
L3 ×G3	61.08333 a
L3 ×G1	59.58333 a
L3 ×G2	58.00000 ab
L1× G3	51.33333 bc
L1 ×G4	50.66667 c
L1 ×G1	47.00000 c
L1 ×G2	45.66667 c
L2 ×G3	31.00000 d
L2 ×G4	31.00000 d
L2 ×G1	30.33333 d
L2 ×G2	26.33333 d
CV%	**9.013**
LSD$_{(0.05)}$	**7.169**

Having similar letter (s) meansthese are statistically similar and those having dissimilar letter (s) differ significantly within a column. L1= Gazipur, L2= Sylhet, L3= Madaripur
G1=BPP1502, G2=BPP1503, G3= BPP1504, G4= BPP1505

4.3 Stem diameter (cm)

4.3.1 Effect of location on stem diameter (cm) of pigeon pea

Stem diameter (cm) of pigeon pea was varied significantly due to different location (Figure 3). The maximum stem diameter (5.11 cm) was found at BARI, Gazipur and the minimum stem diameter (4.04 cm) was obtained at RARS, Sylhet and stem diameter (4.57 cm) was found at RPRS, Madaripur.

Mean temperature is critical during the vegetative phase of growth of pigeon pea variation in stem diameter might be environmental factors. Wet soil due to frequent rain in growth phase cause poor stem growth of plant as well as plant growth.

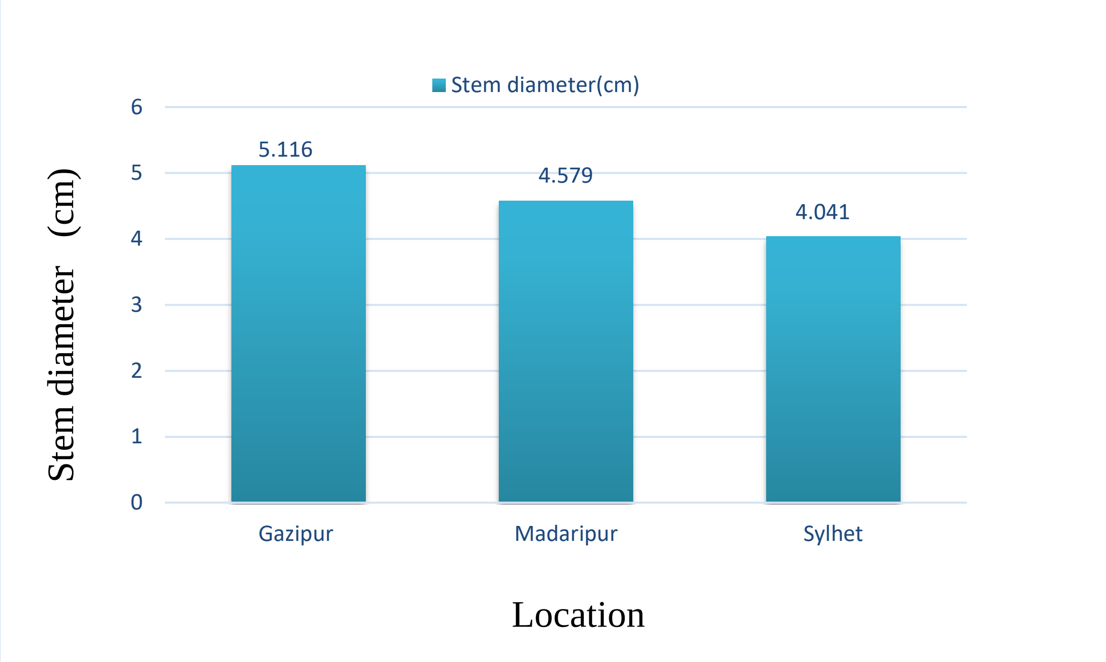

Figure 3. Effect of location on stem diameter (cm) of pigeon pea (CV -11.049% with $LSD_{(0.05)}$value- 0.505)

4.3.2 Effect of genotype on plant breadth (cm) of pigeon pea

Effect of genotypes of pigeon pea on stem diameter (cm) was significant (Table 3). The highest stem diameter (5.10 cm) was noted on G3 which was statistically different than others. The lowest stem diameter (4.30 cm) was recorded at G2 which was followed by G3 and G1.

Table 3. Effect of genotype on plant height, breadth and stem diameter (cm) of pigeon pea

Genotype	Plant height(cm)	Plant breadth(cm)	Stem diameter(cm)
G1	72.166 ab	45.638 ab	4.500 b
G2	70.333 b	43.333 b	4.300 b
G3	70.833 b	47.805 a	4.416 b
G4	78.333 a	48.722 a	5.100 a
CV%	**9.492**	**9.013**	**11.086**
$LSD_{(0.05)}$	**6.854**	**4.139**	**0.503**

Having similar letter (s) means these are statistically similar and those having dissimilar letter (s) differ significantly within a column. G1=BPP1502, G2=BPP1503, G3= BPP1504, G4= BPP1505

4.3.3 Interaction effect of location and genotype on stem diameter

The interaction effect on stem diameter (cm) between location and genotypes was observed significant (Table 4). It was obtained that the highest stem diameter (5.83cm) was found at Gazipur in G4 was followed by the interaction L3×G4, L1×G1 and L1×G3. The lowest stem diameter (3.83 cm) was recorded at Sylhet in G3 which was followed by the interaction L2×G2 and L2×G1.

Table 4. Interaction effect of location and genotype on stem diameter

Treatment combination	Stem diameter/Plant (cm)
L1× G4	5.833333 a
L3 ×G4	5.100000 ab
L1 ×G1	5.066667 ab
L1 ×G3	5.000000 ab
L1× G2	4.566667 bc
L3 ×G1	4.500000 bc
L3 ×G3	4.416667 bc
L2 ×G2	4.366667 bc
L3 ×G4	4.300000 bc
L2 ×G2	4.033333 c
L2 ×G3	3.933333 c
L2 ×G1	3.833333 c
CV%	**11.085**
$LSD_{(0.05)}$	**0.870**

Having similar letter (s) meansthese are statistically similar and those having dissimilar letter (s) differ significantly within a column. L1= Gazipur, L2= Sylhet, L3= Madaripur
G1=BPP1502, G2=BPP1503, G3= BPP1504, G4= BPP1505

4.4 Number of branches plant^{-1}

4.4.1 Effect of location on number of branches plant^{-1} of pigeon pea

Different location of Bangladesh had significant influence on the number of branches per plant of pigeon pea (Figure 4). It was found that the highest number of branches plant^{-1} (12.083) was obtained from the tested location Gazipur (BARI). The lowest number of branches plant^{-1}(5.916) was from the location RPRS, Madaripur which was statistically similar at the location of RARS, Sylhet.

There are positive correlations between plant height and crop yield during the ratoon season could be as a result of increases in the foliage (number of leaves) and production of more branches, leading to greater production of pods. These traits (plant height, leaves, and branches) seem to function in tandem with one another in soybean (*Glycine max*) and this may influence pigeon pea in a similar manner (Udensi *et al*., 2010). Quddus *et al* (2014) stated that the soil of different part of southern belt in Bangladesh are more or less deficient in Boron and Zinc as well as Nitrogen fixing Bacteria (*Rhizobium* sp.) which are main cause of poor yield.

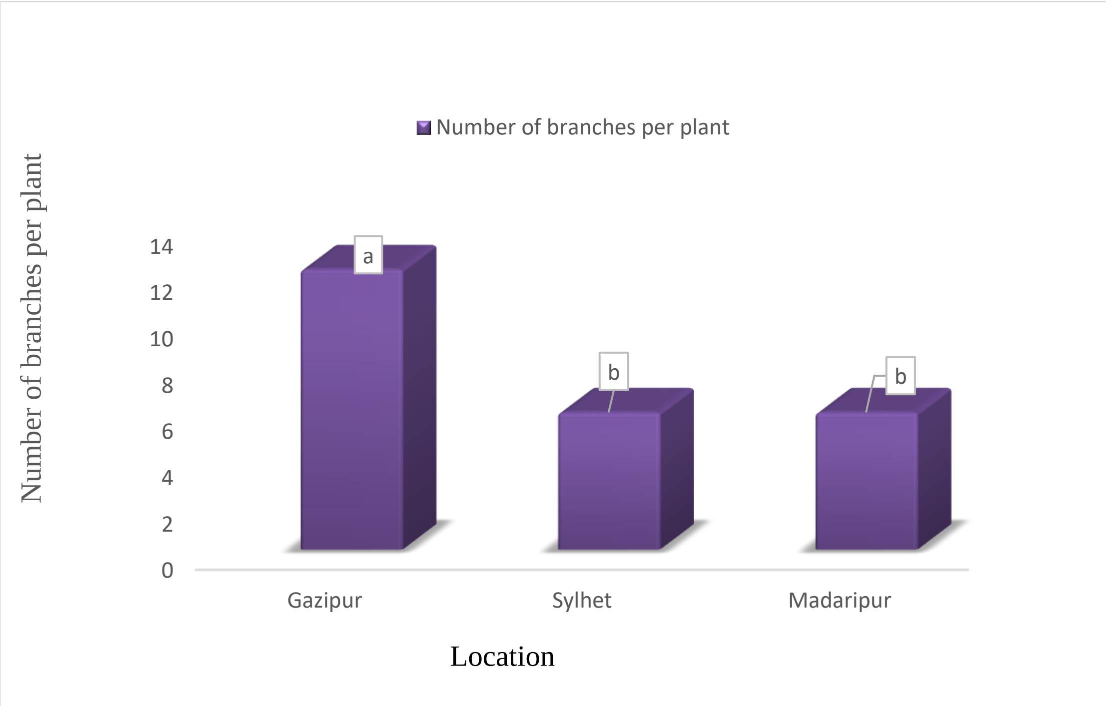

Figure 4. **Effect of location on the number of branches plant^{-1} of pigeon pea (CV – 21.434% with LSD$_{(0.05)}$value- 1.707)**

4.4.2 Effect of genotype on number of branches plant^{-1} of pigeon pea

There was no significant variation for the number of branches plant^{-1} of pigeon pea (Table 5) among the four tested genotypes (G1, G2, G3 and G4). The findings were revealed that the number of branches plant^{-1} of G1, G2, G3 and G4 was 7.77, 8.11, 7.88 and 8.11 respectively.

Table 5. Effect of genotype on the number of branches plant^{-1} and on number of pods plant^{-1} of pigeon pea

Genotype	Number of branches plant^{-1}	Number of pods plant^{-1}
G1	7.777	114.500
G2	8.111	118.833
G3	7.888	135.666
G4	8.111	115.500
CV%	**14.230**	**19.412**
LSD$_{(0.05)}$	**1.123**	**23.287**
Level of Significance	NS	

Having similar letter (s) means these are statistically similar and those having dissimilar letter (s) differ significantly within a column. ns=Non significant
G1=BPP1502, G2=BPP1503, G3= BPP1504, G4= BPP1505

4.4.3 Interaction effect of location and genotype on number of branches plant^{-1}

Significant variation of interaction was observed on number of branches plant^{-1} between location and genotypes of pigeon pea (Table 6). It was noted that the highest number of branches plant^{-1} (13.00) was obtained from the interaction, L1×G4 which was statistically identical with the interaction, L1×G2 (12.33) and L1×G1 (12.00). The lowest number of branches plant^{-1} (5.66) was found from the interaction, L3×G4 which was statistically similar with the remaining interaction except the interaction, L1×G3 (11.00).

The duration to plant maturity was positively and significantly correlated to flower formation, plant height, pod width and primary and secondary branches ((David *et al*., 2016). Positive and significant correlations of pigeon pea branches with plant height have also been reported (Vijayalakshmi *et al*., 2013).

Table 6. Interaction effect of location and genotype on the number of branches plant^{-1}

Treatment combination	Number of branches /plant
L1× G4	13.000 a
L1 ×G2	12.333 ab
L1 ×G1	12.000 ab
L1 ×G3	11.000 b
L2× G3	6.333 c
L3 ×G3	6.333 c
L2 ×G2	6.000 c
L3 ×G2	6.000 c
L2 ×G1	5.666 c
L2 ×G4	5.666 c
L3 ×G1	5.666 c
L3 ×G4	5.666 c
CV%	**14.230**
LSD$_{(0.05)}$	**1.946**

Having similar letter (s) means these are statistically similar and those having dissimilar letter (s) differ significantly within a column. L1= Gazipur, L2= Sylhet, L3= Madaripur
G1=BPP1502, G2=BPP1503, G3= BPP1504, G4= BPP1505

4.5 Number of pods plant^{-1}

4.5.1 Effect of location on number of pods plant^{-1} of pigeon pea

The number of pods is the most important yield contributing character in pigeon pea. The highest number of pods usually leads to higher grain yield and vice versa.

Remarkable variation was observed on number of pods plant^{-1} influenced by different location (Figure 5). It was observed that the highest number of pods plant^{-1} (165.50) was obtained at location Gazipur (BARI) which was significantly different from others, where the lowest number of pods plant^{-1}(76.75) was found at Sylhet (RAPS) and the pods plant^{-1} (121.12) was found at Madaripur (RPRS).

The presence of elevated temperatures during flowering period may result in flower shedding, drop of immature pods as well as inhibition of flower and pod settings. This phenomenon is similar to that reported in broad bean (*Vicia faba*) in which fewer pods per plan were recorded under elevated temperature conditions (Manzer *et al.*, 2015).

The results are in agreement with the findings of Rahman *et al.* (2015) who observed the significant variation on the number of pods per plant in lentil at different location in Bangladesh.

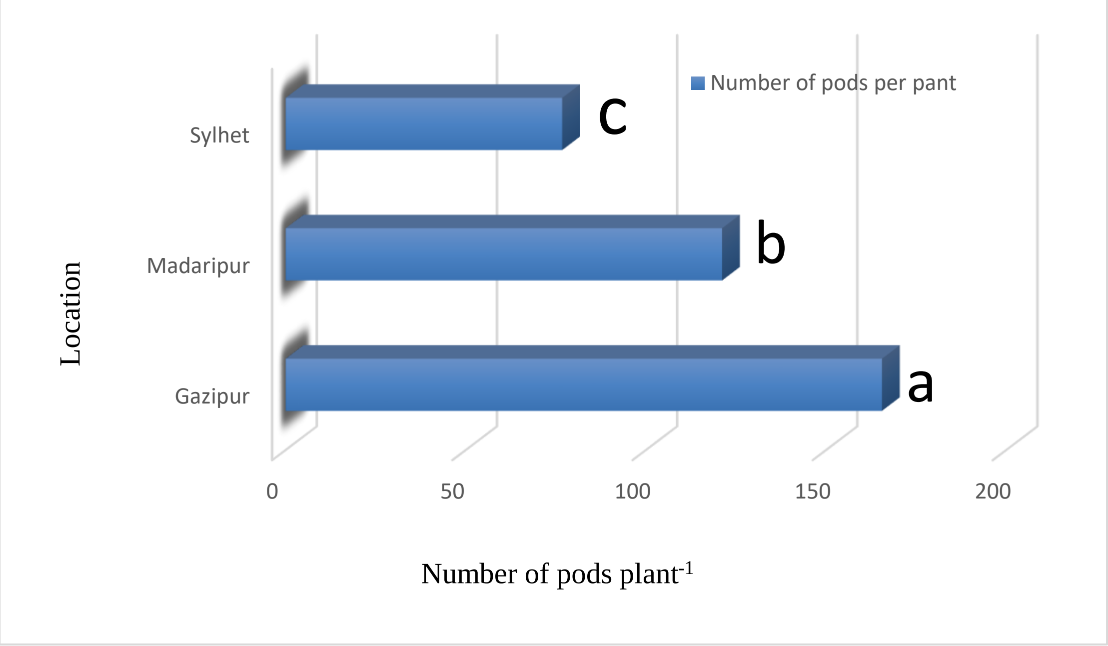

Figure 5. Effect of location on number of pods plant^{-1} of pigeon pea (CV – 14.906% with LSD$_{(0.05)}$value- 18.036)

4.5.2. Effect of genotype on number of pods plant^{-1} of pigeon pea

It was found that the variation of different genotype of pigeon pea on number of pods plant^{-1} was statistically insignificant (Table 5). The number of pods plant^{-1} of G3, G2, G4 and G1 was 135.66,118.83,115.50 and 114.50 respectively. So, the finding was noted that there was no significant variation among the genotype.

4.5.3 Interaction effect of location and genotype on number of pods plant^{-1}

Significant interaction was noted on number of pods plant^{-1} between location and genotypes of pigeon pea (Table 7). Results verified that the highest number of pods plant^{-1} (188.00) was obtained from the interaction, L1×G3 which was statistically close to the interaction L1×G2 (161.33), L1×G4 (159.33) and L1×G1 (153.33). On the other hands the lowest number of pods plant^{-1} (71.66) was recorded from the interaction, L2×G4 which was statistically close to the interaction L2×G1, L2×G2.

Delay sowing of pigeon pea affects the vegetative growth and exposes the plant to high temperature during reproductive phase. Therefore, the immature pods are dropped (MoEF and CC, India).

Table 7. Interaction effect of location and genotype on the number of pods plant^{-1}

Treatment combination	Number of pods plant^{-1}
L1× G3	188.000 a
L1 ×G2	161.333 ab
L1 ×G4	159.333 ab
L1 ×G1	153.333 abc
L3× G3	135.666 bc
L3 ×G2	118.833 cd
L3 ×G4	115.500 cde
L3 ×G1	114.500 cde
L2 ×G3	83.333def
L2 ×G2	76.333 ef
L2 ×G1	75.666 ef
L2 ×G4	71.666 f
CV%	**19.412**
$LSD_{(0.05)}$	**40.335**

Having similar letter (s) means these are statistically similar and those having dissimilar letter (s) differ significantly within a column. L1= Gazipur, L2= Sylhet, L3= Madaripur
G1=BPP1502, G2=BPP1503, G3= BPP1504, G4= BPP1505

4.6 Number of seeds pod^{-1}

4.6.1 Effect of location on number seeds pod^{-1} of pigeon pea

The effect of different location on number of seeds pod^{-1} of pigeon pea was obtained insignificant (Table 8). The primary branches were correlated to secondary branches and seed per pod during crop season. Pigeon pea is very sensitive to low radiation at flowering and pod development. Therefore, flowering during the monsoon and cloudy weather lead to bud drop and poor pod formation. (MoEF and CC, India) which causes lower seeds in pod.

Table 8. Effect of different location on number seeds pod^{-1} of pigeon pea

Location	Number of seeds pod^{-1}
Gazipur	4.133
Sylhet	3.900
Madaripur	4.016
CV%	**8.158**
LSD$_{(0.05)}$	**0.327**
Level of significance	NS

Having similar letter (s) means these are statistically similar and those having dissimilar letter (s) differ significantly within a column. ns= Non significant

4.6.2 Effect of genotypes on number seeds pod^{-1} of pigeon pea

Among the genotype, number of seeds pod^{-1}of pigeon pea was varied significantly (Figure 6).The genotype, G3 was shown the highest number of seeds pod^{-1}(4.25) which was statistically close to the genotype, G4(4.15). The lowest number of seeds pod^{-1}(3.81) was obtained from the genotype, G2 which was statistically similar with the genotype G1(3.85). The variation of number of seeds per pod among the genotypes might be due to different genetic makeup of the genotypes.

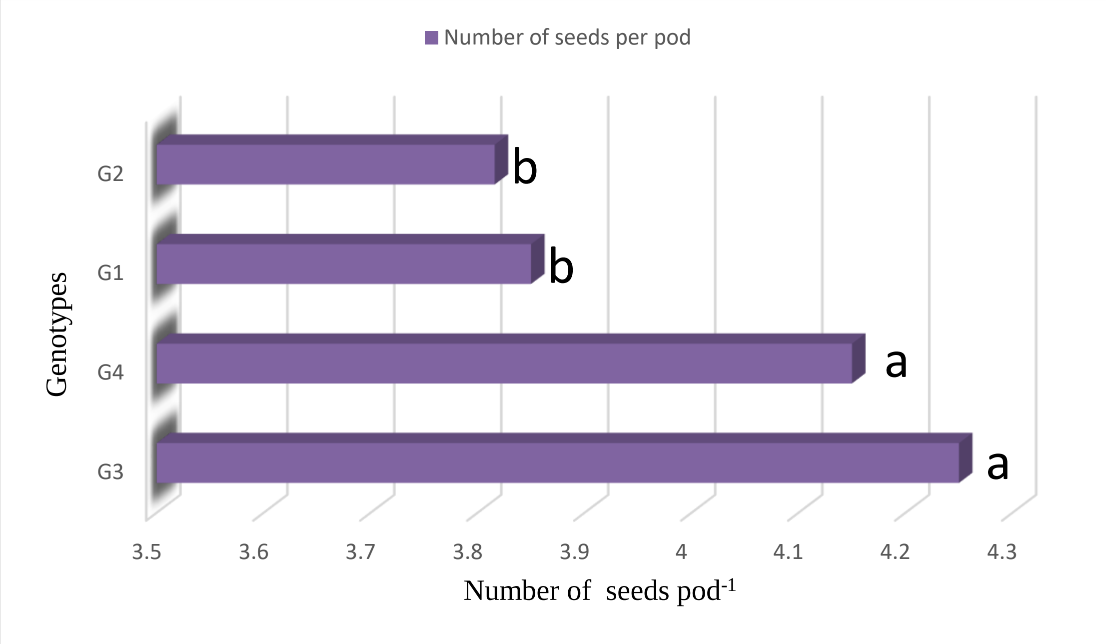

Figure 6. Effect of genotype on number seeds pod^{-1} of pigeon pea (CV -5.533% with LSD$_{(0.05)}$value- 0.220)

4.6.3 Interaction effect of location and genotype on number of seeds pod^{-1}

The interaction effect on number of seeds pod^{-1} between genotypes of pigeon pea and location was found significant (Table 9).From the table it was observed that the highest number of seeds pod^{-1}(4.33) was obtained from the interaction, L1×G4 which was statistically similar with the interaction L2×G24and L3×G3 and the lowest number of pods^{-1} (3.50) was found from the interaction L2×G2 which was statistically closed to L3×G2 and L1×G1.

Increases in mean temperatures during the flowering and pod development phases of plant growth affected many of the yield variables for experiments at different locations (David *et al.*, 2016).

Table 9. Interaction effect of location and genotype on the number of seeds pod^{-1}

Treatment combination	Number of seeds pod^{-1}
L1× G4	4.333 a
L2 ×G3	4.266 a
L3 ×G3	4.250 a
L1 ×G3	4.233 ab
L3× G4	4.150 abc
L1 ×G2	4.133 abc
L2 ×G4	3.966 abc
L2 ×G1	3.866 bcd
L3 ×G1	3.850 cd
L1 ×G1	3.833 cd
L3 ×G2	3.816 cd
L2 ×G2	3.500 d
CV%	**5.533**
LSD$_{(0.05)}$	**0.381**

Having similar letter (s) meansthese are statistically similar and those having dissimilar letter (s) differ significantly within a column. L1= Gazipur, L2= Sylhet, L3= Madaripur
G1=BPP1502, G2=BPP1503, G3= BPP1504, G4= BPP1505

4.7 Hundred seed weight (g)

4.7.1 The effect of location on hundred seed weight (g) of pigeon pea

Size and weight of seed is an important trait which directly correlates with final grain yield. The size of grains differs under different soil moisture regimes and under nutrient availability to crop. The genotypes producing larger seed size do not necessarily produce higher yields because of less in quantity. Hundred seed weight (g) of pigeon pea was varied significantly among different location (Figure 7). The heaviest 100 seed weight (7.91g) was recorded at Gazipur (BARI) which was statistically different than others. The lowest 100 seed weight (5.97g) was obtained from Sylhet and at Madaripur, it was found 6.94 g.

The results also support the findings of Rahman *et al.* (2016) who observed that variation of hundred seed weight (g) among different varieties of chickpea at different location.

Both primary and secondary branches were also shown to increase seed weight and number of seeds per pod at both locations during the crop season. This indicates that under favorable conditions, high number of branches may lead to increased seed weight and seed per pod. Similar results have also been reported by other authors (Bharathi and Saxena, 2013; Saleem *et al*., 2005).

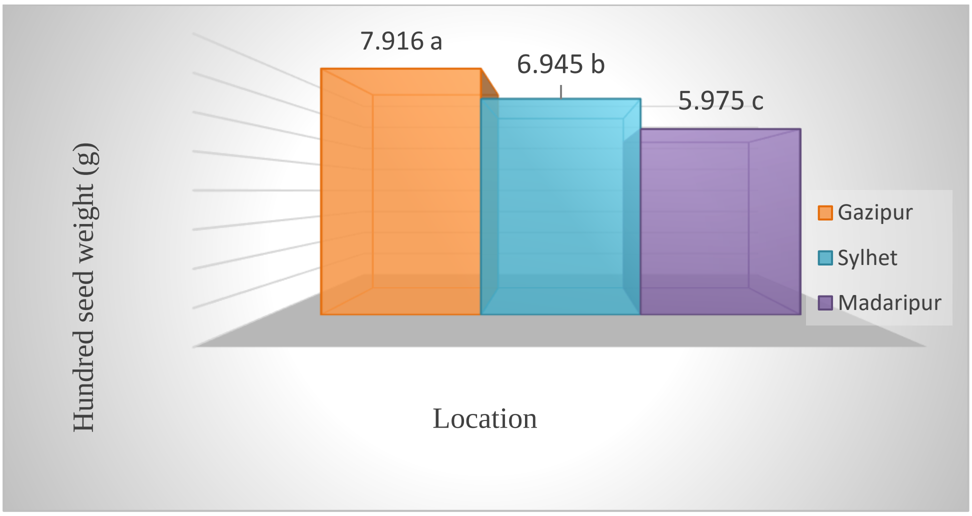

Figure 7. Effect of location on hundred seed weight (g) of pigeon pea (CV – 10.036% with LSD$_{(0.05)}$value- 0.696)

4.7.2 Effect of genotypes on hundred seed weight (g) of pigeon pea

Among the genotypes of pigeon pea, 100 seed weight was significantly varied. Among the genotypes, G3 produced the maximum (7.76 g) seed weight which was statistically similar to G4(7.33 g) and G2 produced the lowest(6.21 g) seed weight (Figure 8).

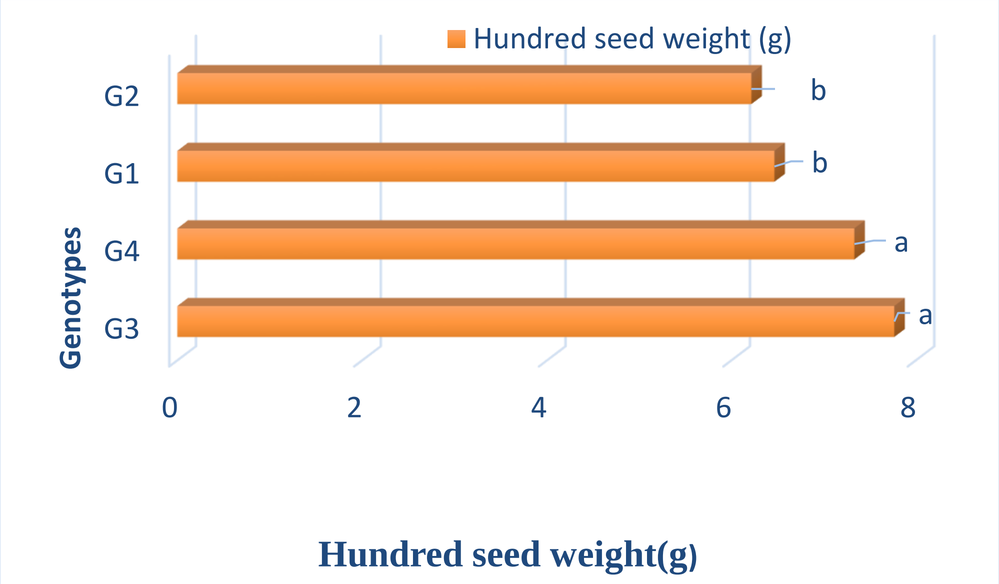

Figure 8. Effect of genotype on hundred seed weight (g) of pigeon pea (CV – 7.964% with LSD$_{(0.05)}$value- 0.547)

4.7.3 Interaction effect of location and genotype hundred seed weight (g)

Hundred seed weight (g) was also varied significantly between the interaction of genotypes of pigeon pea and location (Table 10). The highest 100 seed weight was observed in G3(9.10g) at L1(Gazipur) was similar to G4(8.53 g) at L1 also. The lowest value (5.16g) was recorded in G2 at L2 (Sylhet).

Agronomic practice like plant population is known to affect crop environment, which influence the yield and yield components. Optimum population levels should be maintained to exploit maximum natural resources such as nutrient, sunlight, soil moisture and to ensure satisfactory yield (Sharifi *et al.*, 2009). If plant population is lower than optimum, then per hectare production will be low and weeds will also be more (Allard, 1999). Plant population plays an important role in pigeon pea production and its response to varied population levels due to its elastic nature in adjusting to different spacing.

Table 10. Interaction effect of location and genotype on hundred seed weight (g)

Treatment combination	Hundred seed weight (g)
L1× G3	9.100 a
L1 ×G4	8.533 ab
L3 ×G3	7.766 bc
L3 ×G4	7.333 cd
L1× G2	7.266 cd
L1 ×G1	6.766 de
L3 ×G1	6.466 de
L2 ×G3	6.433 de
L3 ×G2	6.216 e
L2 ×G1	6.166 e
L2 ×G4	6.133 e
L2 ×G2	5.166 f
CV%	**7.964**
$LSD_{(0.05)}$	**0.948**

Having similar letter (s) means these are statistically similar and those having dissimilar letter (s) differ significantly within a column. L1= Gazipur, L2= Sylhet, L3= Madaripur
G1=BPP1502, G2=BPP1503, G3= BPP1504, G4= BPP1505

4.8 Yield plant^{-1} (g)

4.8.1 Effect of location on yield plant^{-1} (g) of pigeon pea

The effect of location on yield plant^{-1} (g) of pigeon pea was statistically significant (Figure 9). It was revealed that the maximum yield plant^{-1} (41.29 g) was obtained from BARI, Gazipur and the minimum yield plant^{-1}(18.40 g) was recorded at RARS, Sylhet and the yield plant^{-1} (29.84 g) was found at RPRS, Madaripur.

This is in agreement with previous studies, which showed that cultivars of pigeon pea and chickpea differed in flower development and plant maturity across locations (Makelo *et al.*, 2013). Increases in mean temperatures during the flowering phase in vegetable pigeon pea may lead to reduction in the duration to flowering, maturity, and plant yield. This finding is supported by Prasad *et al*. (2003) who observed that decreased number of fruit set at higher temperature was mainly due to poor pollen viability, reduced pollen production, and poor pollen tube growth, all of which lead to poor fertilization of flowers in peanuts. Wang *et al*. (2006) associated grain yield reduction to reduced pollen viability, reduced number of seeds per plant and weight per seed in chickpea (*Cicer arietinum*).

Nazrul *et al.* (2012) conducted an experiment and reported in Sylhet region, vast areas of lands remain fallow during Rabi season in each year because, soil moisture goes down quickly after harvest of T. aman rice and due to lack of irrigation facilities under the present circumstances, the system of single and double cropping has failed.

Fallow-T. aus-T. aman rice is the dominant cropping pattern under rainfed condition in this region. The delayed transplantation of aus rice due to dependence on rainfall and usually transplanting is done in early May. This delayed transplantation of aus rice, hampered the timely cultivation of subsequent T. aman rice and resulting delay sowing of Rabi crops (Nazrul *et al*., 2015).

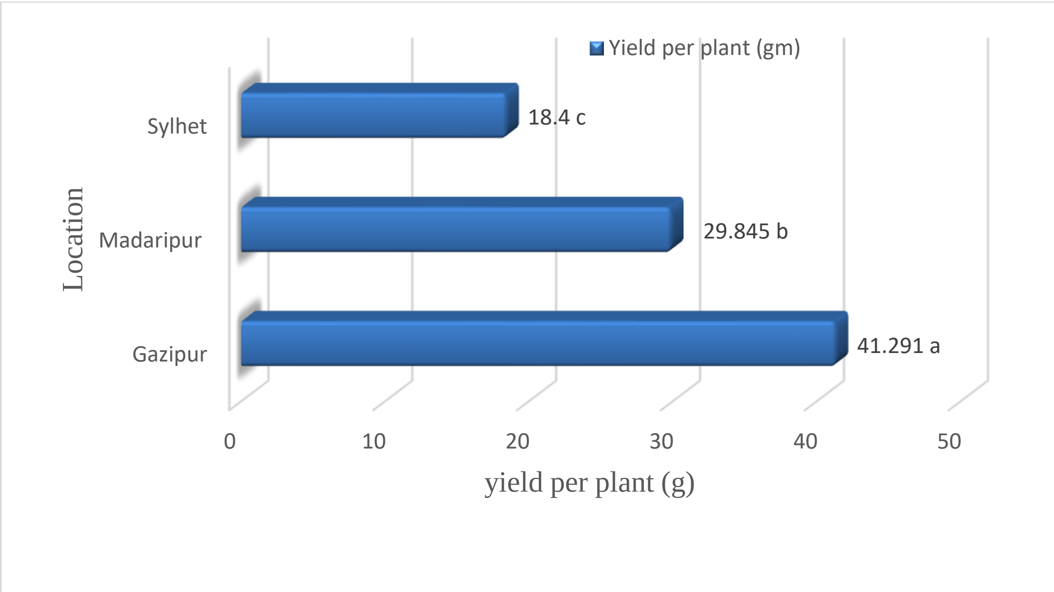

Figure 9. Effect of location on yield plant^{-1} (g) of pigeon pea (CV -16.103% with LSD$_{(0.05)}$ value- 4.801)

4.8.2 Effect of genotype on yield plant^{-1} (g) of pigeon pea

Among the genotype, yield plant^{-1}(g) of pigeon pea was statistically significant (table 11). The maximum yield plant^{-1}(36.73g) was found from G3 and the minimum yield plant^{-1} (25.10 g) was recorded at G1 which was statistically similar to G2 (26.76 g) and G4(30.74 g).

Table 11. Effect of genotype on yield plant^{-1} (g) of pigeon pea

Genotype	**Yield plant^{-1} (g)**
G1	25.100 b
G2	26.766 b
G4	30.785 b
G3	36.735 a
CV%	**20.086**
LSD$_{(0.05)}$	**5.937**

Having similar letter (s) means these are statistically similar and those having dissimilar letter (s) differ significantly within a column.
G1=BPP1502, G2=BPP1503, G3= BPP1504, G4= BPP1505

4.9 Carbon dioxide sequestration plant^{-1}(lbs)

4.9.1 Effect of location on carbon dioxide sequestration plant^{-1} (lbs) of pigeon pea

Remarkable variation was observed on carbon dioxide sequestration plant^{-1} (lbs) of pigeon pea influenced by different location (Figure 10).It was observed that the highest carbon dioxide sequestration plant^{-1} (5.416 lbs) was obtained at location Gazipur (BARI) which was significantly different from others, where the lowest carbon dioxide sequestration plant^{-1} (1.958 lbs) was found at Sylhet (RARS) and carbon dioxide sequestration plant^{-1} (3.687 lbs) was found at Madaripur (RPRS).

The sequestration of carbon depends on plant height, plant breadth and stem diameter. Therefore, variation of carbon sequestration by pigeon pea might be due to variation of those following factors.

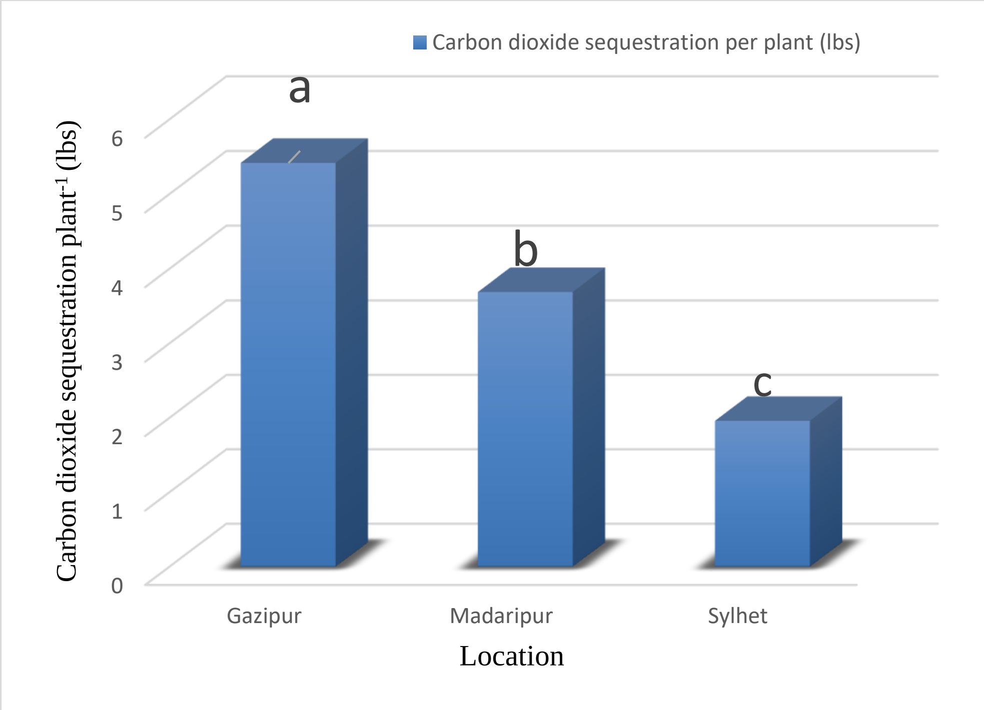

Figure 10. Effect of location on carbon dioxide sequestration plant^{-1}(lbs) of pigeon pea (CV –33.979% with LSD$_{(0.05)}$value- 1.251)

4.9.2 Effect of genotype on carbon dioxide sequestration plant^{-1}(lbs) of pigeon pea

It was found that the variation of different genotype of pigeon pea on carbon dioxide sequestration plant^{-1} was statistically significant (Table 13). The highest amount of carbon dioxide sequestration plant^{-1}(5.00 lbs) was obtained from G4 and the lowest amount of carbon dioxide sequestration plant^{-1} (3.083 lbs) was recorded on G2 which was statistically similar to G1.

4.9.3 Interaction effect of location and genotype

The interaction effect of location and genotypes of pigeon pea on carbon dioxide sequestration plant^{-1} (lbs) was varied significantly (Table 12). The maximum amount of carbon dioxide sequestration plant^{-1} (7.633 lbs) was found in G4 at BARI, Gazipur which was statistically close to G3 and G1 at the same location and different from other interaction. It was recorded that the minimum amount of carbon dioxide sequestration plant^{-1} (1.566 lbs) was observed in G2 at RARS, Sylhet which was statistically similar to L2×G1 interaction.

Table 12. Interaction effect of location and genotype on carbon dioxide sequestration plant^{-1} (lbs)

Treatment combination	CO_2 sequestration plant^{-1} (lbs)
L1× G4	7.633333 a
L1 ×G1	5.000000 b
L1 ×G3	5.000000 b
L3 ×G4	5.000000 b
L1× G2	4.033333 bc
L3 ×G1	3.383333 bcd
L3 ×G3	3.283333 bcd
L3 ×G2	3.083333 bcd
L2 ×G4	2.366667 cd
L2 ×G3	2.133333 cd
L2 ×G1	1.766667 d
L2 ×G2	1.566667 d
CV%	**30.561**
LSD$_{(0.05)}$	**1.933**

Having similar letter (s) meansthese are statistically similar and those having dissimilar letter (s) differ significantly within a column. L1= Gazipur, L2= Sylhet, L3= Madaripur
G1=BPP1502, G2=BPP1503, G3= BPP1504, G4= BPP1505

4.10 Carbon dioxide sequestration year^{-1}(lbs)

4.10 .1 Effect of location on carbon dioxide sequestration year^{-1}(lbs) of pigeon pea

The effect of location on carbon dioxide sequestration year^{-1}(lbs) of pigeon pea was significant (figure 11).The findings was noted that the maximum amount of Carbon dioxide sequestration year^{-1}(10.816 lbs)was observed at BARI, Gazipuz which was statistically different from the others. The minimum amount of Carbon dioxide sequestration year^{-1}(3.891 lbs) was recorded at RARS, Sylhet and carbon dioxide sequestration year^{-1} (7.354 lbs) was found at RPRS, Madaripur.

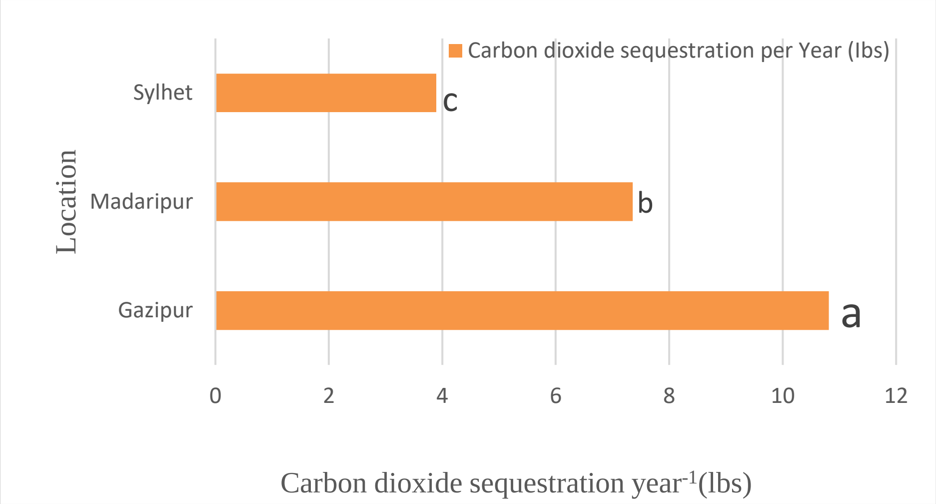

Figure 11. Effect of location on carbon dioxide sequestration year^{-1} (lbs) of pigeon pea (CV – 33.803% with LSD$_{(0.05)}$value- 2.483)

4.10.2 Effect of genotype on carbon dioxide sequestration year^{-1}(lbs) of pigeon pea

Variation of different genotypes of pigeon pea on carbon dioxide sequestration year^{-1}(lbs) was observed significant (Table 13). It was noted the highest amount of carbon dioxide sequestration year^{-1} (9.933 lbs) was obtained from G4 and the lowest amount of carbon dioxide sequestration year^{-1} (6.183 lbs) was recorded on G2 which was statistically similar to G1.

Table 13. Effect of genotype on carbon dioxide sequestration plant^{-1} (lbs) and year^{-1} of pigeon pea

Genotype	Carbon dioxide sequestration plant^{-1} (lbs)	Carbon dioxide sequestration year^{-1} (lbs)
G1	3.383 b	6.766 b
G2	3.083 b	6.183 b
G3	3.283 b	6.533 b
G4	5.000 a	9.933 a
CV%	**30.561**	**30.659**
LSD$_{(0.05)}$	**1.116**	**2.233**

Having similar letter (s) means these are statistically similar and those having dissimilar letter (s) differ significantly within a column. G1=BPP1502, G2=BPP1503, G3= BPP1504, G4= BPP1505

4.10.3 Interaction effect of location and genotype

The interaction effect of location and genotypes of pigeon pea on carbon dioxide sequestration $year^{-1}$ (lbs) was varied significantly (table 14). The maximum amount of carbon dioxide sequestration $year^{-1}$ (15.233 lbs) was found in G4 at Gazipur which was statistically different from other interaction. It was recorded that the minimum amount of carbon dioxide sequestration $year^{-1}$ (3.100 lbs) was observed in G2 at Sylhet which was statistically similar to L2×G1 interaction.

This might be due to sowing season. September is the optimum time for post rainy season sowing. At Gazipur, pigeon pea plants are sowing in September which causes better growth and development and delay sowing (last of November) at Sylhet causes poor growth of plants.

Table 14. Interaction effect of location and genotype on carbon dioxide sequestration $year^{-1}$ (lbs)

Treatment combination	CO_2 sequestration $year^{-1}$ (lbs)
L1× G4	15.233333 a
L1 ×G1	10.000000 b
L1 ×G3	9.966667 b
L3 ×G4	9.933333 b
L1× G2	8.066667 bc
L3 ×G1	6.766667 bcd
L3 ×G3	6.533333 bcd
L3 ×G2	6.183333 bcd
L2 ×G4	4.633333 cd
L2 ×G3	4.300000 cd
L2 ×G1	3.533333 d
L2 ×G2	3.100000 d
CV%	**30.659**
$LSD_{(0.05)}$	**3.867**

Having similar letter (s) means these are statistically similar and those having dissimilar letter (s) differ significantly within a column. L1= Gazipur, L2= Sylhet, L3= Madaripur
G1=BPP1502, G2=BPP1503, G3= BPP1504, G4= BPP1505

4.11 GGE biplot

The GGE biplot was constructed by plotting the primary effect scores of each genotype and each environment against their respective secondary scores. Biplots can be used to evaluate specific cultivars in specific environments; the environment centered the yield approximated by the product of the genotypic PC1 score and the environment PC1 score, plus the product of the genotypic PC2 score and the environment PC2 score.

The figure 12 showed a biplot for yield where four pigeon pea genotypes were tested three location and figure 13 depicted a biplot for carbon dioxide sequestration where four pigeon pea genotypes tested three location, BARI, Gazipur; RARS, Sylhet and RPRS, Madaripur.

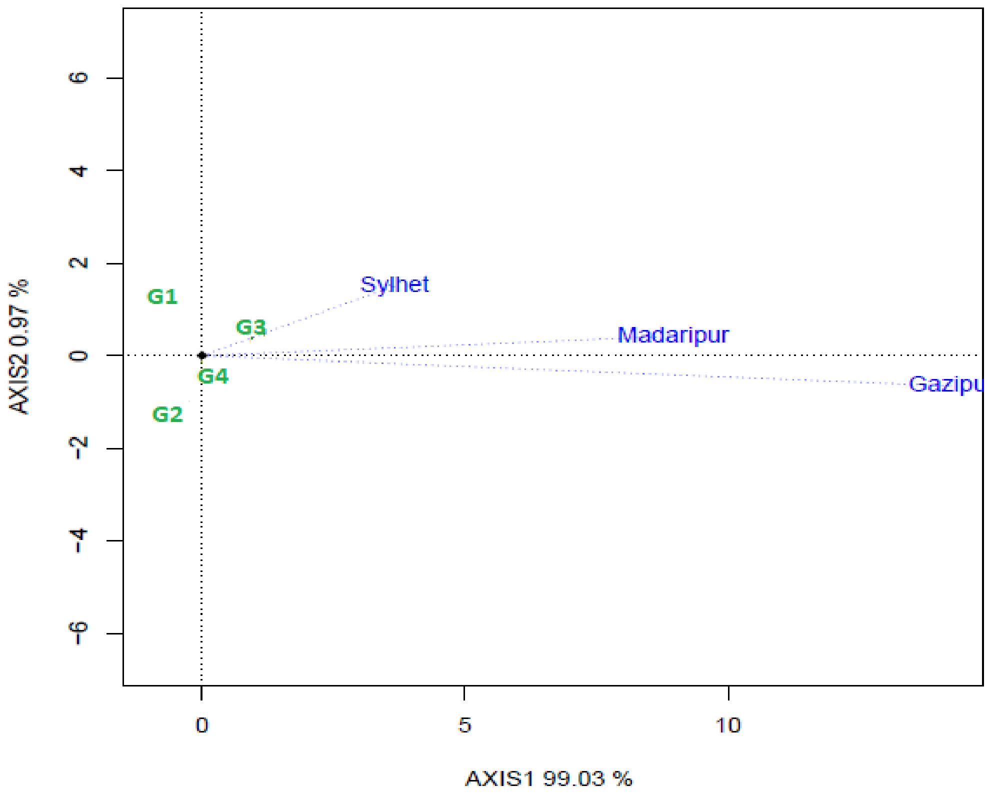

Figure 12. GGE biplot exhibiting four pigeon pea genotypes across three environment for yield performance

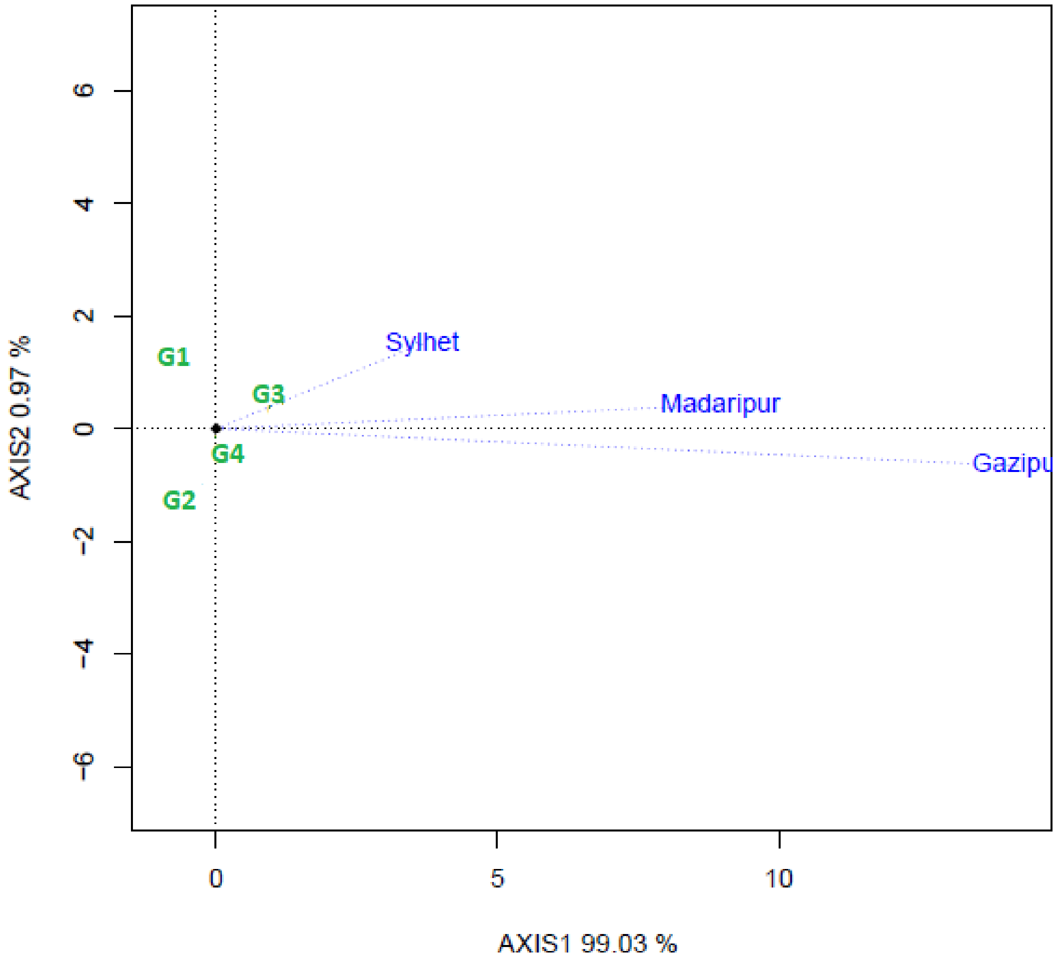

Figure 13. GGE biplot exhibiting four pigeon pea genotypes across three environment for carbon sequestration

4.11.1 Ranking ideal genotype of pigeon pea for yield

Ranking genotypes relative to ideal genotype of pigeon pea, a genotype is more desirable if it is situated closer to the ideal genotypes. Concentric circles were drawn to help visualize distance between each genotype and ideal genotype by using the ideal genotype as the center. Figure 14 revealed that G3 and G4 were felled into the center of concentric circles, ideal genotypes in terms of higher yielding ability and stability, compared with the rest of the genotypes.

Kaya *et al.* (2006) reported similar results in case of ranking genotypes different varieties of wheat.

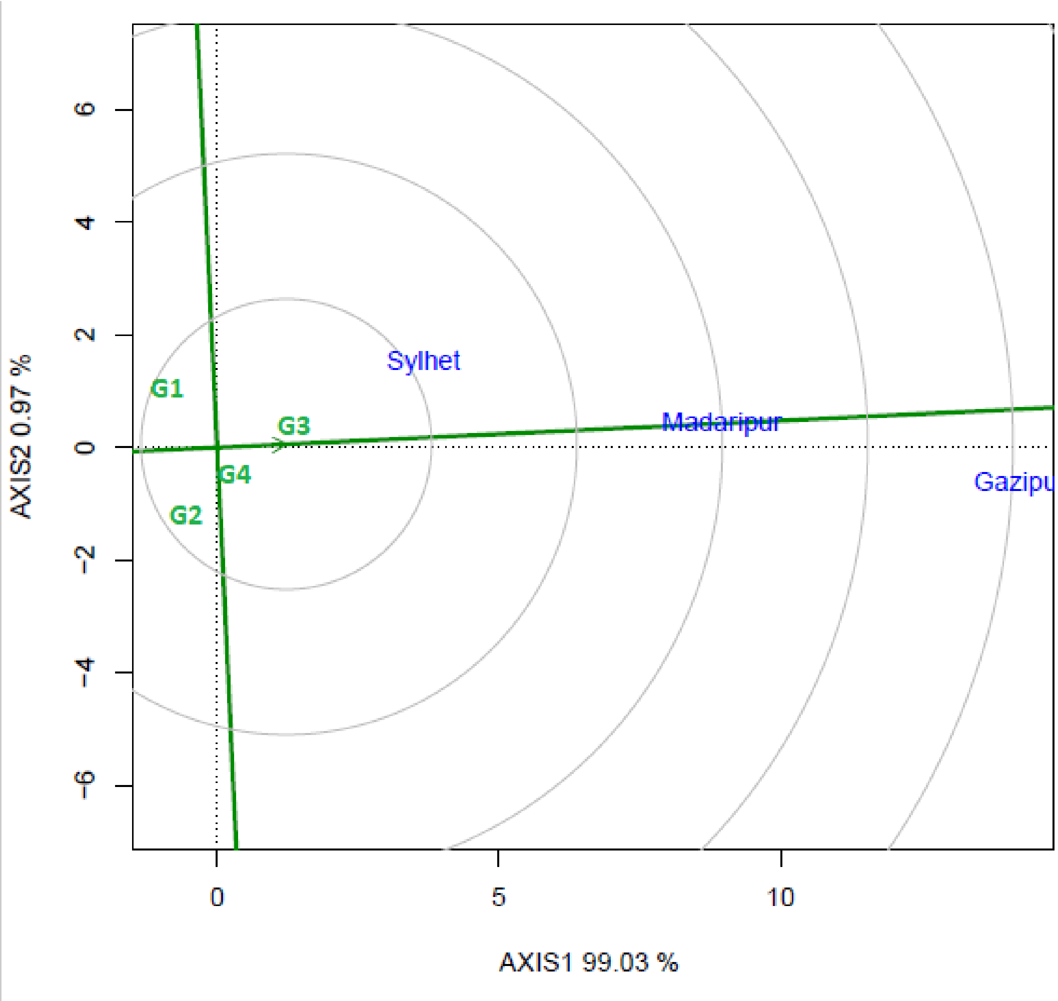

Figure 14. Ranking of ideal genotype of pigeon pea for yield

4.11.2 Ranking ideal genotype of pigeon pea for carbon dioxide sequestration

The genotypes have the highest mean performance and be absolutely stable (i.e. perform the best in all environment) is termed as ideal genotype. From the figure 15, it was observed that the genotype G3 located at the center of the concentric circle was the ideal genotype in terms of carbon dioxide sequestration among the other genotypes. The genotype, G4 was located on the next concentric circle, regarded as desirable genotype for carbon dioxide sequestration. The rest genotypes situated at the fourth and fifth concentric circle were termed as undesirable and lower capacity for carbon dioxide sequestration.

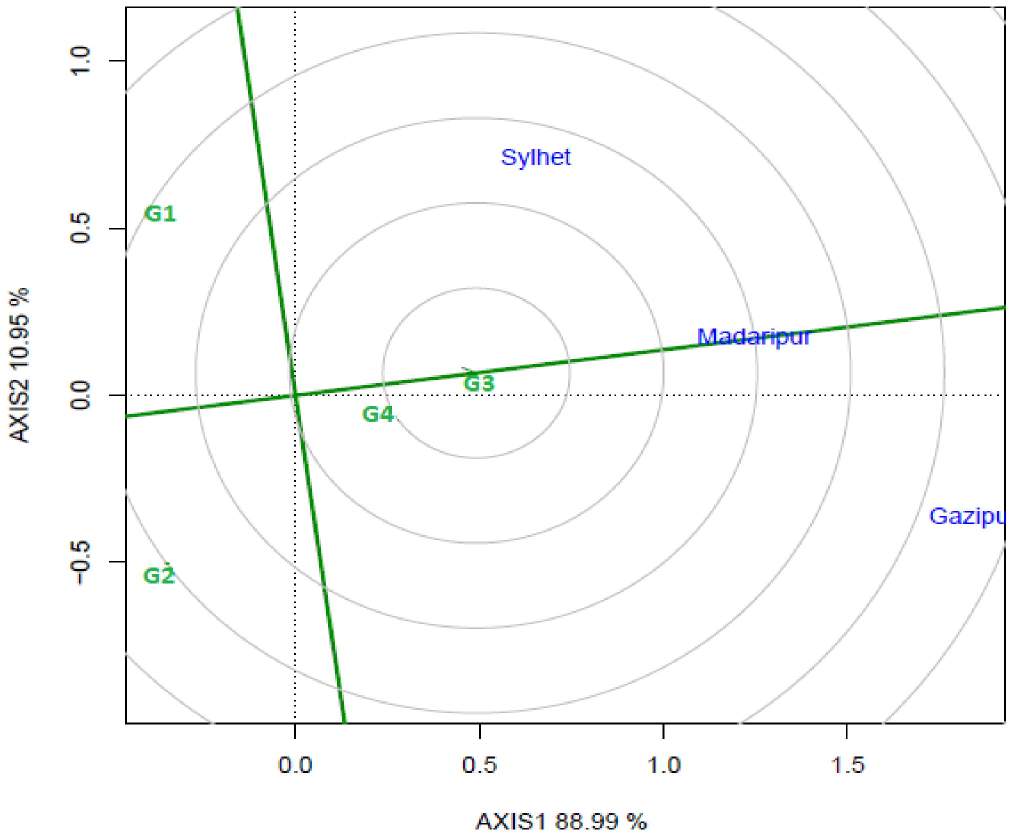

Figure 15. Ranking ideal genotype of pigeon pea for carbon dioxide Sequestration

4.11.3 Mean vs stability performance for yield of pigeon pea

Based on Figure 16, it is possible to assess both mean yield and stability performance of pigeon pea through a biplot. An average tester coordinate (ATC) horizontal axis was passed through the biplot origin and the average location and the oval was shown the positive end of the ATC horizontal axis. The average yields of genotypes were determined by projections of their markers on to the ATC horizontal axis. Therefore, it was found that the genotype of pigeon pea, G3 had the highest average yield and the G2 the lowest (figure 16).

Stability of each genotype was explored by its projection onto the ATC vertical axis. The smaller the absolute length of projection of a genotype, the more stable it is. Thus, it recorded that genotype G1 and G2 were the least stable and genotypes G3 and G4 the most stable. Therefore, considering both mean yield and stability performance, genotypes G3 following to G4 could be regarded as the most favorable.

The results obtained by Karimizadeh *et al.* (2003) was in agreement with findings of present study.

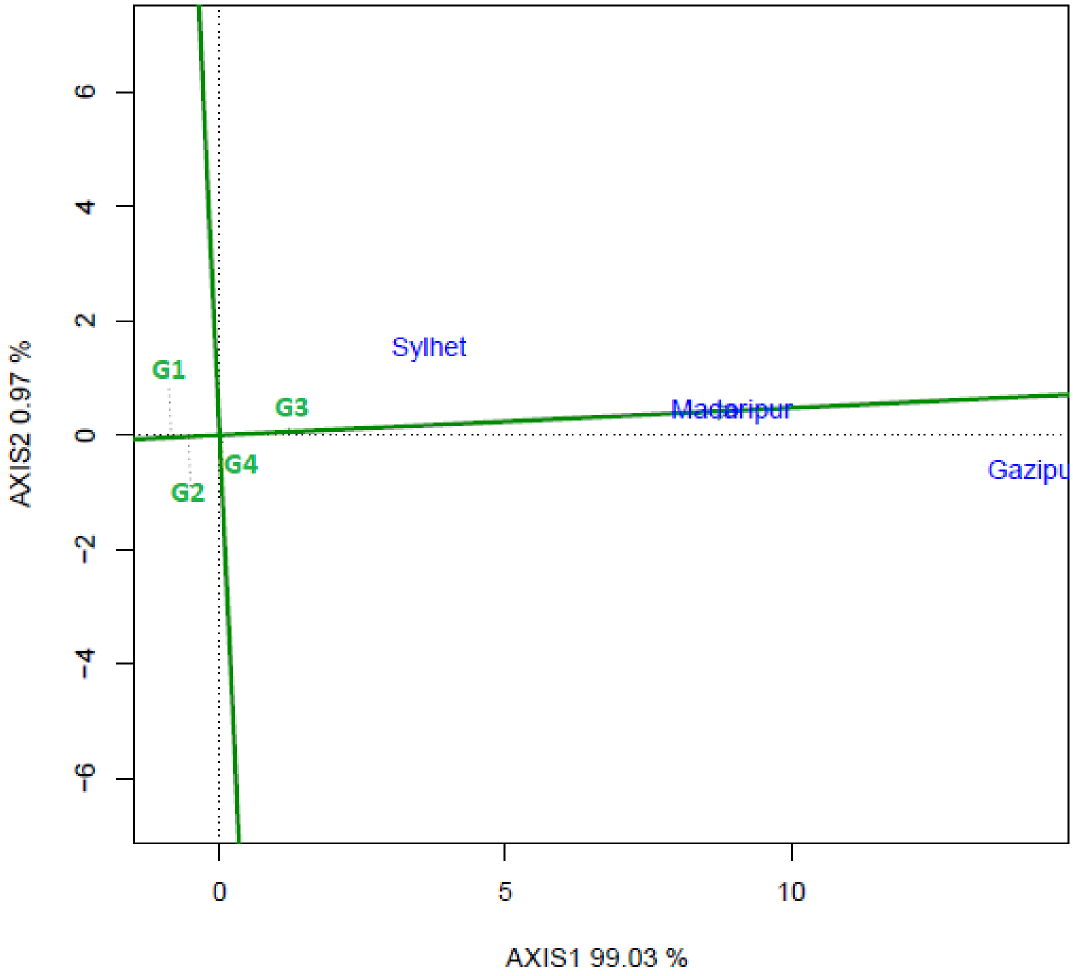

Figure 16. GGE-biplot showing the ranking of pigeon pea genotypes for both mean performance and stability over environments

4.11.4 Mean performance vs stability for carbon sequestration of pigeon pea

From the figure 17, it was obtained that the genotype of pigeon pea, G3 had the highest value for carbon dioxide sequestration and G2 the least value. It recorded that the genotype, G3 was the most stable genotype for carbon dioxide sequestration.

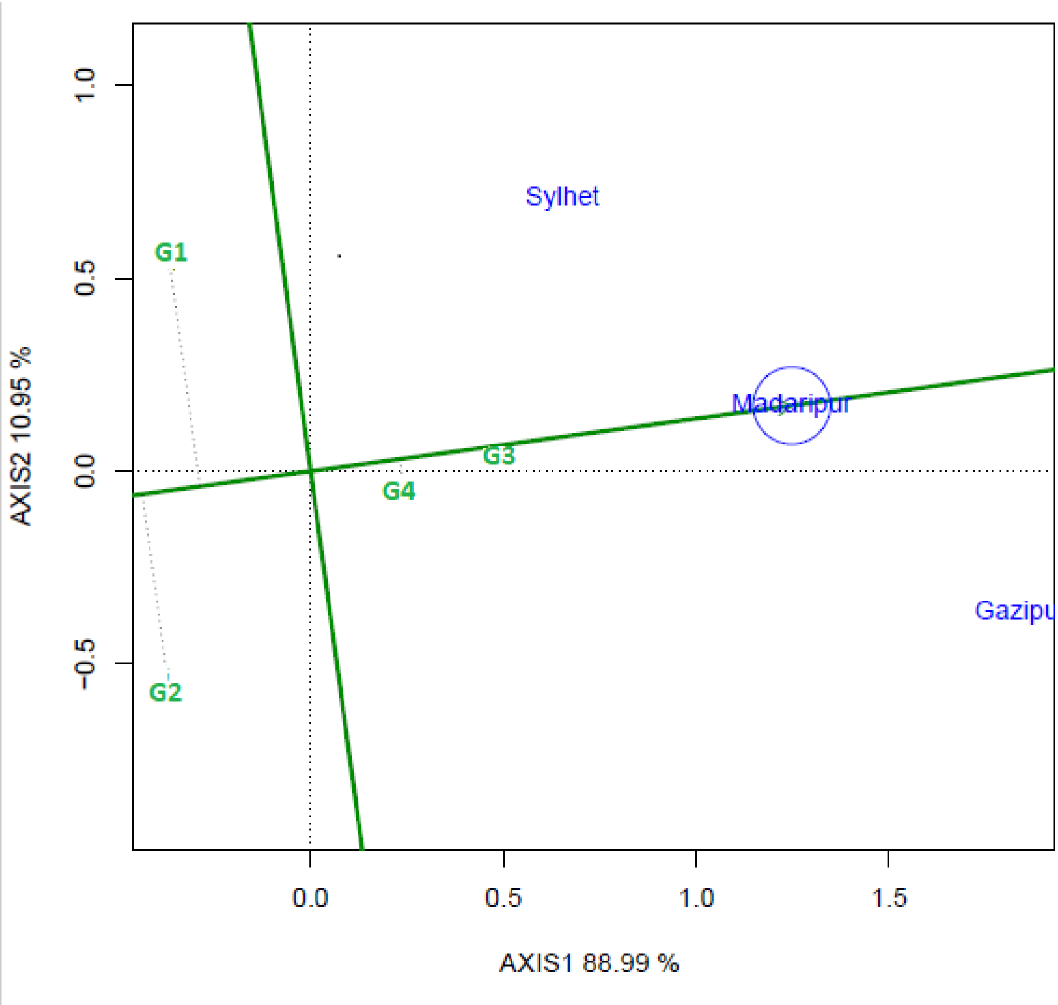

Figure 17. GGE-biplot showing the ranking of pigeon pea genotypes for both mean performance and stability over environments

4.11.5 Discriminativeness vs representativeness of location for yield of pigeon pea

Discriminating ability and representativeness of the test environments can be measured as the absolute distance of an environment from the biplot origin and the length of the projection from the marker of an environment onto the ATC Y-axis was shown in Figure 18. Thus, environment of BARI, Gazipur was the best as it had small projection onto ATC Y-axis (representative of test environments) and large projection onto ATC X-axis (highly discriminating ability for genotypes).

The results obtained by Ullah *et al*. (2011) was in agreement with findings of present study.

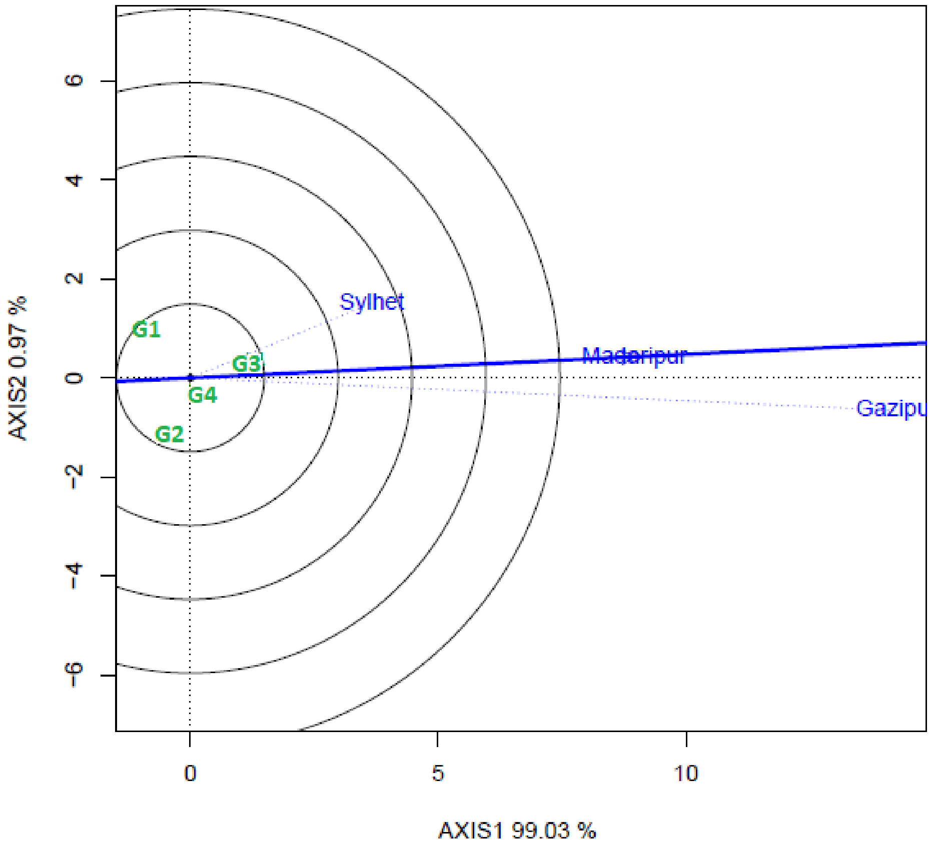

Figure 18. The vector view of the GGE-biplot to show relationship among environments for yield of pigeon pea

Another important measure of a test environment is its representativeness of the target environment. The bi-plot way of measuring representativeness is to define an average environment and use it as a reference. The angle between the vector of an environment and the ATC axis is a measure of the representativeness of the environment. Hence BARI, Gazipur was noted as most representative, whereas RARS, Sylhet as least representative of the average environment.

4.11.6 Discriminativeness vs representativeness of location for carbon sequestration of pigeon pea

Another interesting observation from the vector view of the bi-plot is that the length of the environment vectors approximates the standard deviation within each environment, which is a measure of their discriminating ability (Yan and Kang, 2003). It was found that BARI, Gazipur was most discriminating as it had small projection onto ATC Y-axis (representative of test environments) and large projection onto ATC X-axis (highly discriminating ability for genotypes). RARS, Sylhet was least in terms of discriminativeness and representativeness (Figure 19).

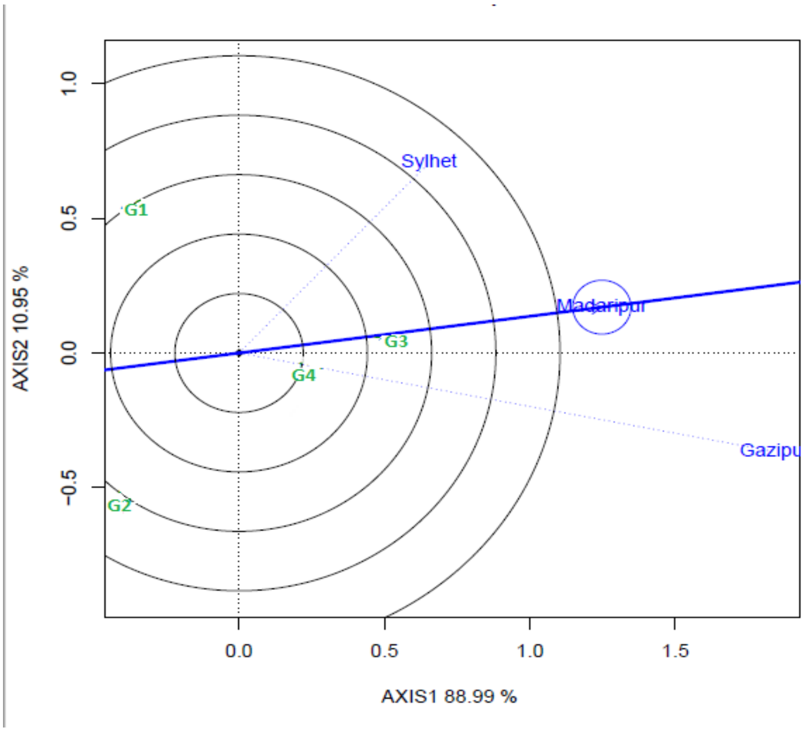

Figure 19. The vector view of the GGE-biplot to show relationship among environments for carbon sequestration of pigeon pea

CHAPTER 5

SUMMARY AND CONCLUSION

SUMMARY

The experiment was done at research field of the three different location in Bangladesh viz. Bangladesh Agricultural Research Institute (BARI), Gazipur; Regional Agriculture Research Station (RARS), Sylhet and Regional Pulse Research Station (RPRS), Madaripur during 2018-2019 to determine the stability performance of different pigeon pea genotypes and amount of carbon sequestration by pigeon pea per year. This experiment comprised of four pigeon pea genotypes (G1 = BPP- 1502, G2 =BPP – 1503, G3 = BPP –1504 and G4 = BPP–1505). The experiment was laid out with two factors Randomized complete Block Design with three replications. Data on different growth parameters, yield and yield contributing parameters were noted and analyzed statistically. Significant variation was observed on different growth, yield and yield contributing parameters due to three different environments.

Considering growth performance of pigeon pea, the tallest plant (93.08 cm) was obtained at Gazipur where the shortest plant (52.75 cm) was recorded at Sylhet. The maximum plant breadth (60.79 cm) was recorded at Madaripur and the minimum (29.66 cm) at Sylhet. Maximum stem diameter (5.11 cm) was noted at Gazipur and minimum (4.04 cm) at Sylhet. The number of branches per plant was highest (12.083) at Gazipur and lowest (5.916) at Sylhet which was similar to Madaripur.

Regarding yield and yield contributing parameters of pigeon pea genotypes, number of pods plant^{-1} was recorded highest (165.50) at Gazipur and lowest (76.75) at Sylhet. No significant variation was found on the number of seeds per pod. The highest hundred seed weight (7.91g) was recorded at Gazipur and the lowest (5.97 g) at Sylhet. Similar result was recorded in case of yield plant^{-1}, highest (41.29 g) at Gazipur and lowest (18.40 g) at Sylhet. Carbon sequestration plant^{-1}and carbon sequestration year^{-1} both were found highest (5.416 lbs), (10.816 lbs) at Gazipur and lowest at Sylhet(1.958 lbs), (3.891lbs) respectively. The highest plant height (78.33 cm), breadth (48.72 cm) and stem diameter (5.10 cm) was found at G4 and the lowest plant height (70.33 cm) ,

breadth (43.33 cm) and stem diameter (4.30 cm) was found at G2. Similar results were obtained in case of carbon sequestration per plant (lbs) and carbon sequestration per year (lbs).The number of branches plant^{-1} and number of pods plant^{-1} were found insignificant among the genotypes. The number of seeds was recorded highest (4.25) at G3 and lowest (3.81) at G1. Hundred seed weight and yield plant^{-1} was found highest (7.76g) and (36.73 g) at G3 respectively. The lowest hundred seeds weight (6.21 g) was recorded at G2 and yield plant^{-1} (25.10g) at G1 which is similar with G2.

The interaction effect of location and genotype was statistically significant in case of all parameters of pigeon pea. Highest plant height (103.33 cm) was observed in G4 at Gazipur. Similar results were found on stem diameter (cm), no. of branch/plant, no. of seeds/pod. Plant breadth was highest in G4 (64.50 cm) at Madaripur and lowest at Sylhet in G2 (26.33 cm). G3 produced highest no of pods/plant (188.00) and hundred seed weight (9.10 g) at Gazipur. Carbon sequestration per plant (7.63 lbs) and carbon sequestration per year (15.23 lbs) both were highest in G4 at Gazipur and lowest was found in G2 at Sylhet. Number of pods/plant was (71.66) lower in G2 at Sylhet, no. of branches/plant was (5.66) lower in G4 at Madaripur than the other varieties. In maximum cases G2 and G1 showed lower growth and yield. The lowest plant height (50.66 cm) was recorded in G1 at Sylhet, similar results was obtained in case of stem diameter. G2 produced the lowest no. of seeds/pod(3.50) and hundred seed weight (5.16 g) at Sylhet.

For stability of performance of pigeon pea across environments, G3 and G4 were identified as most stable pigeon pea genotypes and G1 and G2 were found least stable. On the basis of both stable performance and mean seed yield across environment, the GGE biplot ranked genotype G3 as the best among all, followed by G4 while the rest of the genotypes were identified as inferior. Gazipur was identified as most representative environment and highly discriminative as compared to the others.

CONCLUSION

Pigeon pea a tall woody shrub, is the best versatile food legume, span over a wide area of the world with diversified uses and also benchmark with “sustainable agriculture” with enormous existing diversity. Based on the experimental results, it may be concluded that-

1. Genotype G3(BPP 1504) had the highest average yield and the G2(BPP 1503) had the lowest.
2. Thus, environment of BARI, Gazipur was the best (representative of test environments and highly discriminating ability for genotypes).
3. Considering both mean yield and stability performance, genotypes G3(BPP 1504) following to G4(BPP1505) of pigeon pea could be regarded as the most favorable for any location.
4. It was obtained that the genotype G4(BPP1505) of pigeon pea had the highest value for carbon sequestration.

CHAPTER 6

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APPENDICES

Appendix I. Characteristics of soil of experimental field

(i) Table A. Morphological characteristics of the experimental field of Bangladesh Agricultural Research Institute (BARI) Research Farm, Gazipur

Morphological features	Characteristics
Location	Bangladesh Agricultural Research Institute (BARI)Research Farm, Gazipur
AEZ	AEZ-28, Modhupur Tract
General Soil Type	Deep Red Brown Terrace Soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly leveled

(ii) Table B. Morphological characteristics of the experimental field of Regional Agricultural research station (RAPS),Sylhet

Morphological features	Characteristics
Location	Regional Agricultural research station (RAPS),Sylhet
AEZ	AEZ 29 Northern and Eastern hills
General Soil Type	Non calcareous grey flood plain soil
Land type	High land
Soil series	Kushiyara

(iii) Table C. Morphological characteristics of the experimental field of Regional Pulses Research Station (RPRS), Madaripur

Morphological features	Characteristics
Location	Regional Pulses Research Station (RPRS), Madaripur
AEZ	AEZ-12, Low Ganges River Floodplain soil
General Soil Type	Calcareous brown flood plain soil
Land type	Medium High land
Soil series	Ghior

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

(i) Table D. Monthly records of air temperature, relative humidity and rainfall during the period from September 2018 to April 2019 of BARI, Gazipur

Month	Air temperature (^{0}C)		Relative humidity (%)	Rainfall (mm)
	Maximum	Minimum		
September	31.6	25.9	71	300.4
October	31.6	23.8	65	172.3
November	29.6	19.2	53	34.4
December	26.4	14.1	50	12.8
January	25.4	12.7	46	7.7
February	28.1	15.5	37	28.9

Source: Bangladesh Meteorological Department (Climate and weather division), Agargoan, Dhaka- 1212

(ii) Table E. Monthly records of air temperature, relative humidity and rainfall during the period from September 2018 to April 2019 of RARS, Sylhet

Month	Air temperature (^{0}C)		Relative humidity (%)	Rainfall (mm)
	Maximum	Minimum		
November	29.9	18.4	77	30
December	26.3	14.00	75	13
January	25.2	12.9	75	8
February	27.1	14.2	68	31
March	30.4	18.1	68	146
April	30.8	20.8	76	372

Source: Bangladesh Meteorological Department (Climate and weather division), Agargoan, Dhaka- 1212

(iii) Table F. Monthly records of air temperature, relative humidity and rainfall during the period from September 2018 to April 2019 of RPRS, Madaripur

Month	Air temperature (^{0}C)		Relative humidity (%)	Rainfall (mm)
	Maximum	Minimum		
October	32.5	24.8	82	149.6
November	29	20.7	78	32.3
December	26.2	13.8	78	5.4
January	24.4	11	77	9.7
February	27.8	14.9	72	34.2
March	33.5	18.8	70	60.9

Source: Bangladesh Meteorological Department (Climate and weather division), Agargoan, Dhaka- 1212.

Appendix III. Layout of the experimental field

E

S

R_1	R_2	R_3
E_2	E_3	E_5
E_3	E_2	E_4
E_4	E_5	E_2
E_5	E_4	E_3

N

W

Appendix IV. List of necessary tables for results and discussion.

Table1. Effect of location on plant height, breadth and stem diameter (cm)

Location	plant height (cm)	plant breadth(cm)	Stem diameter(cm)
Gazipur	93.083 a	48.666 a	5.116 a
Madaripur	72.916 b	60.791 b	4.579 b
Sylhet	52.75 c	29.666 c	4.041 c

Having similar letter (s) means these are statistically similar and those having dissimilar letter (s) differ significantly within a column

Table 2. Effect of genotype on plant height, breadth and stem diameter (cm)

Genotype	Plant height(cm)	Plant breadth(cm)	Stem diameter(cm)
G1	72.166 ab	45.638 ab	4.500 b
G2	70.333 b	43.333 b	4.300 b
G3	70.833 b	47.805 a	4.416 b
G4	78.333 a	48.722 a	5.100 a

Having similar letter (s) means these are statistically similar and those having dissimilar letter (s) differ significantly within a column
G1=BPP1502 , G2=BPP1503, G3= BPP1504, G4= BPP1505

Table 3. Effect of location on the number of branches per plant of pigeon pea

Location	Number of branches per plant
Gazipur	12.08 a
Sylhet	5.916 b
Madaripur	5.916 b

Having similar letter (s) means these are statistically similar and those having dissimilar letter (s) differ significantly within a column

Table 4. Effect of Genotype on the number of branches plant^{-1}

Genotype	Number of branches /plant	Number of pods / plant
G1	7.777 a	114.500 a
G2	8.111 a	118.833 a
G3	7.888 a	135.666 a
G4	8.111 a	115.500 a

Having similar letter (s) means these are statistically similar and those having dissimilar letter (s) differ significantly within a column
G1=BPP1502 , G2=BPP1503, G3= BPP1504, G4= BPP1505

Table 5. Effect of location on Number of pods plant^{-1}

Location	Number of pods per pant
Gazipur	165.5 a
Madaripur	121.125 b
Sylhet	76.75 c

Having similar letter (s) means these are statistically similar and those having dissimilar letter (s) differ significantly within a column

Table 6. Effect of different location on number of seeds pod^{-1}

Location	Number of seeds /pod
Gazipur	4.133 a
sylhet	3.900 a
Madaripur	4.016 a

Having similar letter (s) means these are statistically similar and those having dissimilar letter (s) differ significantly within a column

Table 7. Effect of genotype on Number of seeds/pod

Genotypes	Number of seeds per pod
G3	4.25 a
G4	4.15 a
G1	3.85 b
G2	3.81 b

Having similar letter (s) means these are statistically similar and those having dissimilar letter (s) differ significantly within a column G1=BPP1502 , G2=BPP1503, G3= BPP1504, G4= BPP1505

Table 8. Effect of location on hundred seed weight (g)

Location	hundred seed weight (g)
Gazipur	7.916 a
Sylhet	6.945 b
Madaripur	5.975 c

Having similar letter (s) means these are statistically similar and those having dissimilar letter (s) differ significantly within a column

Table 9. Effect of genotype on hundred seed weight(g)

Genotypes	Hundred seed weight (g)
G3	7.766 a
G4	7.333 a
G1	6.466 b
G2	6.216 b

Having similar letter (s) means these are statistically similar and those having dissimilar letter (s) differ significantly within a column
G1=BPP1502 , G2=BPP1503, G3= BPP1504, G4= BPP1505

Table 10. Effect of location on yield plant^{-1} (g)

Location	yield plant^{-1} (g)
Gazipur	41.291 a
Madaripur	29.845 b
Sylhet	18.4 c

Having similar letter (s) means these are statistically similar and those having dissimilar letter (s) differ significantly within a column

Table 11. Effect of genotype on yield plant^{-1} (g)

Genotype	Yield / plant (g)
G1	25.100 b
G2	26.766 b
G3	36.735 a
G4	30.785 a

Having similar letter (s) means these are statistically similar and those having dissimilar letter (s) differ significantly within a column G1=BPP1502 , G2=BPP1503, G3= BPP1504, G4= BPP1505

Table 12. Effect of location on carbon dioxide sequestration plant^{-1} (lbs)

Location	carbon dioxide sequestration plant^{-1} (lbs)
Gazipur	5.416a
Madaripur	3.687 b
Sylhet	1.958 c

Having similar letter (s) means these are statistically similar and those having dissimilar letter (s) differ significantly within a column

Table 13. Effect of location on carbon dioxide sequestration year^{-1} (lbs)

Location	carbon dioxide sequestration plant^{-1} (lbs)
Gazipur	10.816a
Madaripur	7.354 b
Sylhet	3.891c

Having similar letter (s) means these are statistically similar and those having dissimilar letter (s) differ significantly within a column

Table14. Effect of genotype on carbon dioxide sequestration plant^{-1} (lbs) and year^{-1}

Genotype	Carbon dioxide sequestration per plant (lbs)	Carbon dioxide sequestration per year (lbs)
G1	3.383 b	6.766 b
G2	3.083 b	6.183 b
G3	3.283 b	6.533 b
G4	5.000 a	9.933 a

Having similar letter (s) means these are statistically similar and those having dissimilar letter (s) differ significantly within a column G1=BPP1502 , G2=BPP1503, G3= BPP1504, G4= BPP1505

Appendix V: Analysis of variance tables

Table 1. Analysis of variance number of pods plant^{-1}

Source	DF	SS	MS	F	P
Treatment	3	2630	876.7	1.586	0.228
Location:Treat	6	587	97.7	0.177	0.980
Error	18	9952	552.9		

*indicates significant at 5% level of probability.
** indicates significant at 1% level of probability.

Table 2. Analysis of variance number of seeds pod^{-1}

Source	DF	SS	MS	F	P
Treatment	3	1.2600	0.4200	8.506	0.00989 **
Location:Treat	6	0.4800	0.0800	1.620	0.198808
Error	18	0.8888	0.0494		

*indicates significant at 5% level of probability.
** indicates significant at 1% level of probability.

Table 3. Analysis of variance of yield plant^{-1} (g)

Source	DF	SS	MS	F	P
Treatment	3	723.1	241.04	6.706	0.00312 **
Location:Treat	6	175.5	29.25	0.814	0.57309
Error	18	647.0	35.94		

*indicates significant at 5% level of probability.
** indicates significant at 1% level of probability.

Table 4. Analysis of variance of carbon sequestration year^{-1} (lbs)

Source	DF	SS	MS	F	P
Treatment	3	81.38	27.126	5.336	0.00831 **
Location:Treat	6	35.54	5.924	1.165	0.36721
Error	18	91.51	5.084		

*indicates significant at 5% level of probability.
** indicates significant at 1% level of probability.

Table 5. Analysis of variance number of branches plant^{-1}

Source	DF	SS	MS	F	P
Treatment	3	0.750	0.250	0.194	0.899
Location:Treat	6	7.333	1.222	0.950	0.485
Error	18	23.167	1.287		

*indicates significant at 5% level of probability.
** indicates significant at 1% level of probability.

Table 6. Analysis of variance number of plant height (cm)

Source	DF	SS	MS	F	P
Treatment	3	368.3	122.75	2.563	0.0869
Location:Treat	6	234.3	39.06	0.815	0.5719
Error	18	862.2	47.90		

*indicates significant at 5% level of probability.
** indicates significant at 1% level of probability.

Table 7. Analysis of variance number of plant breadth (cm)

Source	DF	SS	MS	F	P
Treatment	3	156.15	52.05	2.979	0.059
Location:Treat	6	27.12	4.52	0.259	0.949
Error	18	314.56	17.47		

*indicates significant at 5% level of probability.
** indicates significant at 1% level of probability.

Table 8. Analysis of variance number of stem diameter (cm)

Source	DF	SS	MS	F	P
Treatment	3	3.343	1.145	4.446	0.0166*
Location:Treat	6	0.688	0.1147	0.445	0.8391
Error	18	4.638	0.2577		

*indicates significant at 5% level of probability.
** indicates significant at 1% level of probability.

PLATES

Plate 1: Field visit with respected co-supervisor

Plate 2: Experimental field visit at BARI, Gazipur

Plate 3: Monitoring of pigeon pea plant

Plate 4: Measuring plant height

Plate 5:Harvested pigeon pea plant

Plate 6: Measuring plant breadth

Plate 7: Counting of branches per plant

Plate 8: Counting of pods per plant

Plate 9: Counting of number of seeds per pod (10 pods)

Plate 10: Pigeon pea plant showing pods

Plate 11: Packaging of harvested pods

Plate 12: Field visit at RARS, Sylhet

Plate 13: Monitoring plant height at RPRS, Sylhet

Plate 14: Monitoring pigeon pea at RPRS, Madaripur