UNIVERSITY OF EDUCATION, WINNEBA

GENOTYPE × ENVIRONMENT INTERACTION AND YIELD STABILITY ANALYSIS OF SOME COWPEA VARIETIES RELEASED IN GHANA FROM 1990 TO 2005

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GENOTYPE × ENVIRONMENT INTERACTION AND YIELD STABILITY ANALYSIS OF SOME COWPEA VARIETIES RELEASED IN GHANA FROM 1990 TO 2005

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DECLARATION

STUDENT'S DECLARATION

I, Kwabena Atakora declare that this dissertation with the exception of quotations and references contained in published works which have all been identified and acknowledged is entirely my own original work and it has not been submitted either in part or whole for another degree elsewhere.

SIGNATURE……………………………………

DATE:……………………………………...

SUPERVISORS' DECLARATION

We, hereby declare that the preparation of this work was supervised in accordance with the guidelines for supervision of thesis as laid down by the University of Education, Winneba.

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DEDICATION

This work is dedicated to my wife and children and also to my parents and siblings.

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LIST OF ABBREVIATIONS

AMMI	Additive Main Effects and Multiplicative Interaction
AEA	Avearge Environmental Axis
GEI	Genotype by Environment Interaction
G×E	Genotype by Environment
PC	Principal Component
PCA	Principal Component Analysis
PCI	Princial Component Interaction
CRI	Crops Research Institute
CSIR	Council for Scientific and Industrial Research
CV	Co-efficient of Variation
SARI	Savannah Agricultural Research Institute
LSD	Least Significant Difference
ANOVA	Analysis of Variance
DAP	Days after planting
EMS	Error Mean Squared
DFF	Days to fifty percent flowering
DFP	Days to fifty percent podding

ABSTRACT

The phenological development, growth, yield and yield stability performance of eight cowpea varieties released in Ghana between 1990 and 2015 were evaluated in field experiments carried out at Mampong-Ashanti (forest-savannah transition zone) and Fumesua (forest zone) over two cropping seasons in 2015 and 2016. The experiments were arranged in a randomized complete block design (RCBD) with three replicates. Asontem, Nhyira, Asetenapa, Hewale and Videza flowered and podded earlier (37-44 days and 49-51 days, respectively) than Soronko, Tona and Asomdwe (46-48 days and 52-55 days, respectively). Hewale, Asomdwe, Asontem and Videza by virtue of their erect and semi-erect architecture had the highest plant height in both seasons, while Tona recorded the lowest. Crop growth rate among the varieties ranged from 1.1-1.7 g/m^2/day for Asetenapa, Tona and Videzea to 2.3-3.3 g/m^2/day for Asontem, Nhyira, Soronko, Hewale and Asondwe. Pod yield ranged from 980-2540 kg/ha, with Videza and Soronko producing the lowest pod yields, while Asontem had the highest pod yield across both locations and cropping seasons. Seed yield ranged from 603-2241 kg/ha, with Asetenapa yielding the lowest (603-1407 kg/ha). Asontem produced the highest number of pods per plant and number of seeds per pod and thus the highest seed yields (1240-2241 kg/ha) over the locations and seasons. Pod harvest index ranged from 0.58-0.90. The four yield stability analysis methods used showed that Asontem and Tona were the most stable varieties and were adapted to all the environments, while Soronko and Asetenapa were the least stable and were adapted to more favourable environments.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

Cowpea (*Vigna unguiculata* (L.) Walp) is the most important food legume in Ghana and can be grown in all agro ecological zones of Ghana since it is indigenous to Africa. The yield potential of the various varieties released in Ghana range from 1.5 t/ha to 2.0 t/ha with varying dates of maturity ranging from 60-80 days (SARI, 2012).

Cowpea seeds and leaves (dry weight basis) contains more than 25% of protein, minerals and vitamins in daily human diets and is equally important as nutritious fodder for livestock (Singh *et al*., 2003b).

Due to its moderate cultivation requirements and high protein content, the crop's production in West and Central Africa in the last decades has averaged 2.6 million tons on 7.8 million hectares. This accounts for 69% of the world's production (Singh *et al*., 2003 a) while an estimated 4.5 million metric tons of cowpea is produced worldwide on 12 to 14 million hectares of land (Singh *et al*., 2002; Boukar *et al*., 2016). According to Langyintuo *et al. (*2003), world dried cowpea production as at 2010 was estimated to be 5.5 million metric tons, with Africa accounting for 94 % of the production.

The cowpea grain yield and the haulm are valuable dietary proteins for most African population and their livestock (Fatokun, 2012). According to Ravelombola *et al*. (2016), cowpea grain is highly nutritious and contains about 15.06 - 38.5 % protein, but it differs among cowpea varieties.

The cowpea plant is able to fix atmospheric nitrogen which helps maintain soil fertility. Its tolerance to drought extends its adaptation to drier areas considered marginal for most other crops (Singh *et al*., 2002) and due to the association with soil bacteria *rhizobia* it serves N source to a succeeding crop (Agyemang *et al*., 2014).

Climate change may result in strong impacts on agriculture, especially on crop growth and yield. Crops are largely influenced by climatic conditions during the growing season; thus even minor deviation from optimal conditions can seriously threaten yield. Therefore, knowledge on the effect of environmental factors on crop growth and development could reduce the possibilities of significant yield loss. There is the need to improve the selection of specific cultivars for growing in the target regions. For subsistence farmers growing crops under conditions of variable drought and other soil and biotic constraints, yield stability may be more important than high yield (Hall *et al*., 1993).

Dapaah *et al*. (2003) stated that yield stability analysis could be used to develop improved crop varieties that perform well over a range of environmental conditions and have been used by many plant breeders. This principle can also be adopted by agronomists to conduct cropping trials that produce economic yields at different environments.

1.2 Problem Statement

Cowpea grain yields are very low in West Africa. The major constraints to production have been identified as low density of cowpea, insect pests and parasitic weeds such as *Striga gesnerioides* and *Alectra vogelii,* drought stress, low soil fertility and lack of inputs, infrastructure and diseases such as viruses which results in low yield in cowpea growing areas (Karungi *et al*., 2000 ; Gioi *et al*., 2012).

Global climatic change has resulted in significant annual variation in yield performance of most agricultural species including cowpea. Consequently, genotype by environment interaction (G×E) is an important issue facing plant breeders and agronomists. Breeders therefore search for consistently high yielding and profitable cultivars for sustainable production in target areas while adapting to changing climatic conditions (Kevin *et al*., 2000; Okoye, 2010).

Different concepts and definition of stability have been described over the years and several biometric methods have been proposed for analysis of G×E interaction and stability of crops grown over a range of environments. The most widely adapted method is the regression coefficient model. For example, Finlay and Wilkinson (1963) and Eberhart and Russell (1966) proposed the linear regression coefficient and the deviations from linear regression as a stability parameter for each genotype. Other conventional models such as Shukla (1972) stability variance model considered the contribution of each genotype to G×E interaction and concluded that the variance of a genotype across environments is the stability measure.

In addition, the cultivar performance measure of Lin and Binns (1988) assumes the genotype with the lowest cultivar performance value as the most stable.

Many farmers could be interested in high yielding varieties at harvest in a particular area but to get a cultivar that could be stable in different seasons and across locations is very important. This is because only high yielding varieties in a specific area may not make the cultivar stable and therefore cannot be superior in different seasons and different locations. This means that if the climatic condition fails due to rain fed agriculture in our part of the world to specific area, then there will be total loss of crops. It is therefore necessary to test different cultivars across different environments and compare seasons across these locations in order to select the best varieties that will be stable across different locations during the cropping seasons. There is the need to select different agro ecological zones of Ghana to predict a sound and acceptable model to select right varieties for farmers to get continuous yield irrespective of season and environment.

1.3 Justification

Cowpea plants can produce over 1000kg/ha but due to environmental stresses especially severe drought and heat stress can reduce to about 360kg/ha especially when these stresses occur at the flowering stage. Informal discussions with farmers in Asante Mampong and Ejura areas revealed that, consistent low yields overtime is due to frequent environmental effects and this can be reduced by selection of better performing varieties in different growing seasons and locations.

Stability analysis has been applied to multi-environment in evaluation of crops in terms of performance and yield and there has been a general agreement amongst plant breeders that interactions between genotype and environment have influence of obtaining better varieties. However, it has become very difficult to find agreement as to what we ought to know about genotype- environment interactions due to lack of definition for stability and what we should do about them especially with the on-going climate change scenario.

It is therefore necessary to compare different yield and stability methods to make proper recommendation to both breeders and farmers to factor into their programmes in varietal release and planting on their farms respectively. In view of this, a number of advanced genotypes of cowpea coming out of the breeding programme for over two decades must be evaluated for genotype by environment (G×E) interactions to identify the high yielding stable genotypes for cultivation and for their utilization by farmers.

1.4 Objectives

The main objective of the study was to compare the average yield and yield stability of cowpea varieties by subjecting the cultivars into four statistical models for cowpea grown in different location with contrasting drought and soil fertility.

Specific Objectives: The study aims at achieving the following specific objectives:

i. To characterize cowpea genotypic responses to a set of contrasting environmental conditions for phenological development, growth and growth analysis using G×E interaction.

ii. To evaluate yield and yield components of cowpea varietal trials in a set of contrasting environments.

iii. To determine the G × E interaction effects of cowpea genotypes in different agro-ecological zones.

iv. To determine the level of association among the stability parameters derived using the appropriate models.

The above objectives were set to test the null hypothesis that:

i. Characterization of cowpea genotypic responses to a set of contrasting environmental conditions has no effect on phenological development, growth and growth analysis using G×E interaction.

ii. G×E interaction has no effect on yield and yield components of cowpea varietal trials in a set of contrasting environments.

iii. There is no effect in determining the G × E interaction effects of cowpea genotypes in different agro-ecological zones.

iv. There is no effect in determining the level of association among the stability parameters derived using the appropriate models.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin, Domestication and Distribution

The origin of cowpea has been postulated by many scientists and archeologists to different sub regions in Africa. There have also been contradictions on the origin of cowpea. Contradictory views have been shared by different authors as to the origin of cowpea with Africa, Asia and South America. However, Suliman (2000), Singh (2005) and Timko *et al*. (2007) are of the view that cowpea originated from Africa, Asia and South America. According to Timko and Singh (2008) and Doumbia (2012), genotypes from Asia are different from those in Africa implying that Asia could be an independent center of origin from African genotypes. Evidence shows cowpea existence since the Neolithic period (Singh *et al*., 2007; Akinjogula *et al.,* 2008; Agyemang *et al.,* 2015). Most studies focused mainly on the local cowpea resource, especially in Africa and Asia (Tan *et al*., 2012).

According to Agbicodo *et al*. (2009)), West Africa and the Indian Sub-continent are considered to be the origin of cowpea domestication. However, through several research, the evidence gathered do not support the theory of Asian origin as they were unable to explain the traits and distribution of wild cowpea *Vigna dekindtiana*. The intermediate-type of wild-domesticated cowpea however, found in West and Central Africa, was considered proof of the West African origin center theory (Baudoin and Marechal, 1985; Ng, 1995).

Cowpea is also believed to have originated and domesticated in Southern and Eastern Africa since large number of primitive cultivars and semi-wild forms are found (DGIC, 2001). It is believed to have originated near Ethiopia and subsequently was developed mainly in the farms of the African savannahs.

Out of more than 10,000 accessions of the worlds' cowpea collections at IITA, it was revealed that germplasms from Nigeria, Burkina Faso, Niger and Ghana showed greater diversity than those from East Africa, with the centre of diversity in Nigeria which provides further evidence that West Africa was the primary centre of domestication of cowpea. According to Daimon and Yoshioka (2001), cowpea has its origin in ancient Central and West Africa Cereal farming, 5000 – 6000 years ago.

Feleke *et al*. (2006) suggested that cowpea originated in Africa but the precise location on the African continent is the challenge now. According to D'Andrea *et al. (*2007) and Agbicodo (2009), the oldest evidence of wild cowpea was discovered in the Kintampo caves from archaeological findings in Kintampo Rock shelter in Ghana. Several parts of Africa have been suggested as being the centre of diversity of cultivated cowpea including West Africa (Otwe, 2007). Ng (1995) postulated that cowpea was first domesticated in West Africa through selection by African farmers who gathered wild cowpea haulms to feed their cattle. In following this practice, it is probable that some seeds of the earliest to mature pods which could already have dehisced before or during the harvest, were missed, leading to selection of the less shattering type while leaving behind the dehiscent wild type.

Cowpea is believed to have been transported to Europe through North Eastern Africa around 300 BC and to India about 200 BC. However, human quest for larger and best growth performance which was guided by extensive breeding work carried over several decades might have led to the diversity in cultivated and domesticated cowpeas found in Asia and Africa. In India and Southeast Asia, cowpea was further diversified producing the cultigroup *Sesquipedalis* whose long pods are used as vegetables and the cultigroup *Biflora* for its grain (Timko and Singh, 2008; IITA, 2010).

2.2 Botany/Morphology of Cowpea

Cowpea (*Vigna unguiculata)* belongs to the family Leguminosae and has diverse growth habit because genotypes and environments interact to influence both the numbers and the lengths of their branches (Onuh *et al*., 2009).

Cowpea leaves are compound and pinnate with three leaflets each (DGIC, 2001). The plant can be extremely bushy or erect type with short branches and the other prostrate, spreading or sometimes twining and climbing forms with five (5) or more orders of branching with first and second order branches up to 50 cm long. The vine length can be between 120-180 cm (Onuh *et al*., 2009). Onuh *et al.* (2009) also observed that each auxiliary inflorescence is a compound raceme of several simple racemes carried on a grooved peduncle. Each simple raceme has between 6 and 12 flower buds, but only the lower first formed pair develops while the rest degenerates to form extra – floral nectarines between the paired flowers (Onuh *et al*., 2009).

According to Abebe *et al*. (2005), the leaflets of cowpea are ovate to lanceolate, sometimes leslate, 5 – 18 cm long and 3 – 16 cm wide. In the axil of each leaf are three buds. The number of branches is the compliment of the inflorescence and can range between 2-8. The mature fruits vary widely in size, shape, colour and texture. Fruit lengths range between 10 – 20 cm and are straight with very few curved.

Cowpea taproot has many secondary roots which develop nodules in association with *Rhizobium* species to fix atmospheric nitrogen to the soil. The pods of cowpea occur in pairs, forming a V-shape and can either be cylindrical or flattened in shape. The seeds can be smooth or wrinkled with dominant colours such as red, black, brown, green buff, or white. Full coloured, spotted, marbled, speckled, eyed, or blotched colours also exist in cowpea seeds. The seed length is between 2-12 mm long. The ovary is superior with a single style and carpel (CTA, 1993).

Cowpeas must be harvested at a high moisture level, such as 18%. The grain can be stored short term at around 12% moisture or less with 8% or 9% recommended for long term storage.

2.3. Uses and Nutritional Value

In West Africa, cowpea is regarded as a major source of food for both rural and urban dwellers. The fodder is used to feed animals but fresh leaves are also used as food in most Ghanaian communities particularly the northern part of the country. Both fresh and dry seeds are used as food. Whilst the fresh pods and seeds are used as vegetables, the dry seeds are used in combination with other things for various dishes. Cowpea serves as a major source of protein in the daily diets of the rural and urban poorCowpea leaf protein content ranges from 29 to 43% (Singh, 2002).

In Africa, the mature dried seeds, immature seeds and pods and young leaves constitute food for human consumption (Asare, 2013). Cowpea utilization is important in most parts of West and Central Africa since it provides a cheaper alternative to meat and serves as a "food security crop" (Lambot, 2002) for populations that consume cowpea as traditional staple food (Langyintuo *et al*., 2003). In Ghana, the dry grains are processed into flour and a dough made out of the flour and deep fried to prepare "koose" which are served with maize or millet porridge (Hausa "kooko"). Another breath it is also boiled and served with "gari" and fried ripened plantain or with rice which is known as "waakye" (Quaye *et al*., 2009).

Singh *et al.* (1997) found that cowpea grains contain an average of 23-25% protein and 50-67% starch. Asare (2013) noted that cowpea does not only provide good source of protein, but vitamins and minerals for both humans and livestock.

A study of 100 cowpea breeding lines in the IITA collection recorded seed protein content ranged from 23 to 32% of seed weight. Similarly, protein content of 12 West African and United States cultivars ranged from 22 to 29%, with most accessions having protein content values between 22 and 24% (Hall *et al*., 2003). Based on this results, it suggests that sufficient genetic variation exists and therefore there is the need to develop new cowpea cultivars with protein content of at least 30% to help smallholder resource poor farmers. Cowpea grain is also a rich source of minerals and vitamins (Hall *et al*. 2003). According to Adeyanju *et al*. (2012), cowpea grain contains about 25 % protein and 64 % carbohydrate, hence a good panacea to malnutrition in the urban and rural folks.

Cowpea is regarded as the second most important grain legume, and currently a food security crop providing good and affordable vegetable protein and minerals for about 70 % of Ghanaians (MoFA, 2010; Doumbia, 2012).

Since most of the food consumed in many parts of Africa are mainly starchy foods (Singh *et al.,* 2002) the high protein content of cowpea (20 - 25 %) (Alayande *et al.* 2012) will compensate for the large proportion of the carbohydrate in the diet (Lambot, 2002).

2.4 Climatic and Soil Requirements of Cowpea

Cowpea is considered to be a warm-season crop well adapted to many areas of the humid conditions. According to Daimon and Yashioka (2001), cowpea is grown primarily under humid conditions and is regarded as a short – day – warm weather crop and also adapted to high temperatures of about 20 - 35°C. This clearly shows that a warm climate is essential for cowpea growth and temperatures up to 35ºC are suitable. It tolerates heat and dry conditions and therefore it is regarded as warm weather crop (SARI, 2012). It cannot tolerate cold or frost conditions and yields are reduced when high temperatures occur at flowering. Flower initiation and floral bud development are suppressed by a combination of high night temperatures and long photoperiod (Patel and Hall, 1990). At flowering, high temperatures can cause the leaves to senescense earlier which will reduce the period for pod filling and in some cultivars severe drought generally prevents the formation of seeds. Ahmed and Hall (1993) showed that continuous high night temperatures during the first four weeks after germination can cause suppression of floral buds and prevent flowering altogether. According to Uhart and Andrade (1995), phenology of crops determines the rate of leaf growth and its reproductive cycle and therefore unfavourable environment would normally impose assimilate limitation, restricts pollination and decrease pod formation and seed set of crops especially cowpea.

Cowpea can be grown under both irrigated and non-irrigated production regimes. It can respond positively to irrigation and does well also under dry land conditions. Drought tolerant is one reason that cowpea is such an important crop in many underdeveloped parts of the world.

Raemaekers (2001), reported that cowpea is well adapted to semi-arid regions with annual precipitation less than 600 mm and sub humid zones with annual precipitation between 1000 mm and 1500 mm. Cowpea is adapted to different moisture availabilities in comparison to other crops (Baidoo and Monchiah, 2014). Supplying water through irrigation is possible but leads to more vegetative growth and some delay in maturity may result. Care should be taken so that the crop is not over watered, especially in more northern latitudes, since this will suppress growth by lowering soil temperatures. The most critical moisture requiring period is just prior to and during bloom.

The morphology of cowpea plant is such that it is able to maintain high leaf water potential or high leaf relative water content during water stress (de Carvalho *et al.,* 1998) which helps it to avoid tissue dehydration. Reduction in biomass and grain yield is largely due to erratic rainfall in the beginning and towards the end of the rainy season within the semi-arid tropics since crops are often subjected to drought stress in both seedling and terminal growth stages. However, early maturing-varieties escape the terminal drought (Singh, 1994). Sato *et al*. (2003) and San Jose *et al*. (2002) believe that crop reproductive phases could be affected by fluctuation in water supply and thermal regimes. According to Baron *et al*. (2003), initiation of flowers, flowering stage, podding and seed set is greatly influenced by photoperiod and temperature. Also, crop growth and phenology which includes flowering and pod formation could be influenced by the length of moisture stress, atmospheric water demand, humidity and temperature.

Cowpea tolerates a wide variety of soils and soil conditions, but performs best on well-drained sandy loams or sandy soils. According to Valenzuela and Smith (2002), cowpea grows well in a wide range of soil texture, thus from heavy clays, if well drained to sandy with a pH range of 5.5 – 6.5. Raemaekers (2001) is of the view that a slightly acid to neutral soil is preferred by cowpea than a soil with high pH. Onwueme and Sinha (1991) in their view believe that cowpea can tolerate high soil acidity under conditions of heavy rainfall.

According to Ghalmi *et al*. (2010) and Lim (2012), cowpea grows well on well-drained sandy to sandy-loam soils with pH ranging from 5.5 – 6.5. The authors further indicated that cowpea can be cultivated in marginal areas having low soil fertility because of the crops ability to fix atmospheric nitrogen through an efficient symbiotic association with mycorrhizae. Cowpea normally thrives well on many types of soil but is less tolerant to alkaline conditions. Cowpea is adapted to a wide range of soil types including low-fertility soils, however, for optimum growth, good drainage, aeration and water supply is important for better grain yield. Cowpea forms a symbiotic relationship with a specific soil bacterium called *Rhizobium* spp. Rhizobium makes atmospheric nitrogen available to the plant by a process called nitrogen fixation. This occurs in root nodules of the plant and the bacteria utilize sugars produced by the plant.

2.5 Production Estimate

Of the crop's estimated world total area of about 10 million ha, Africa alone accounts for over 7.5 million ha, of which about 70% lies in West and Central Africa (Singh *et al*., 1996). The potential yield of cowpea grains in Africa is around 1.5-3.0t/ha but current average yield is more in the regions of 0.2-0.3t/ha (DGIC, 2001). The crop is the second most important pulse in Ghana after groundnut. Cowpea grain production estimates by Singh *et al*. (2002) are slightly higher than FAO estimates, with worldwide production of 4.5 million (Mt) on 12 to 14 million ha. About 70% of this production occurs in the drier Savanna and Sahelian zones of West and Central Africa cited in Tinko *et al*. (2007).

2.6.0 Production Constraints

2.6.1 Pests and Diseases

Several factors or constraints affect cowpea production but the major one is the destruction by insect pest while the crop is in the field. Insect pests affect both young and old plants as well. Cowpea is attacked by several insect pests and diseases.

Cowpea is susceptible at all stages of growth to pests and disease causing organisms (Ambang *et al*., 2009). According to Nkomah (2013), some common diseases of cowpea include; scab, blight, cercospora leaf spot, web blight, mosaic virus and bacterial blight. Pests that attack cowpea include aphids [*Aphis craccivora* Koch (Homoptera: Aphididae)], flower beetle [*Euphoria sepulcralis* (Fabricius) (Insecta: Coleoptera: Scarabaeidae)], pod borer [*Maruca vitrata* Fabricius (syn. *M. testulalis)* (Lepidoptera: Pyralidae)], bean fly [*Ophiomyia phaseoli* (Trybon) (Diptera: Agromizidae)], leaf hopper [*Empoasca dolichi* Paoli (Homoptera: Cicadelidae)], Thrips (Thysanoptera spp) and cowpea bruchid [*Callosobruchus* spp. (Coleoptera: Bruchidae)] (Nkomah, 2013).

Madamba *et al*. (2001) also reports that the major insect pests of cowpea include grasshoppers and foliage beetle. Some of the pests of the floral and pods stages are *Maruca testular*, *Laspeyresis ptychora* and *Heliothis spp*. According to Raemaekers (2001), cowpea aphids (*Apis craccivora)* are vectors of viruses and can destroy the entire grain.

Apart from the storage pests, most of the pest affects the plant by piercing the plant tissue and withdraw plant juices. Their feeding, especially on the fruiting stem reduces the amount of plant nutrients available for pod and seed development. Aphids (*Aphis cracivora)* is associated with this effect of cowpea and infested foliage turns yellow and dies. Aphids excrete large quantities of a sugary substance called honey dew which supports the growth of sooty mold. Sooty mold is a fungus and is dark in colour which reduces the amount of sunlight that reaches the plant.

The main diseases of cowpea include fungal diseases such as, leaf spot, some viral diseases such as yellow mosaic virus, cowpea mottle virus and bacterial blight (Omoigui *et al*.,, 2018). Anthracnose is one of the major cowpea disease which can be very severe in areas where cowpea is grown as sole crop (Youdeowei, 2002).

Parasites such as *Striga gesnerioides* and *Alectravogelii* cause considerable reduction in cowpea yield. *A.vogelii* is more prevalent in the moist savanna, whereas *Striga* is more widespread in the dry, particularly in the sahelian zone where soils are sandy and infertile (Singh and Emechebe, 1991). In West Africa, several different strains of *S. gesnerioides*have been observed and they cause different levels of parasitization in different varieties (Lane *et al*., 1995).

2.6.2 Drought and Low Soil Fertility

Cowpea is regarded as a crop which is tolerant to drought hence its cultivation in low rainfall areas. According to Martin *et al*. (1991), cowpea adapts well to environmental conditions that affect crop production thus high temperature and other biotic stresses compared with other crops. Dadson *et al*. (2005) is also of the view that growth and development of most cowpea varieties are affected by drought and high temperatures and this becomes evident during floral development. There will also be corresponding effect on vegetative growth of the plant such as plant height and number of branches as well as number of leaves. Optimum to high amount of rainfall will lead to increase in plant height and number of branches. However, drought stress could have influence on the crop by virtue of the type of variety, thus either early or late maturing.

Cowpea is one of the widely cultivated legumes in both the savannah and transitional zones of Ghana (CRI, 2006). In view of this, efforts have been made to improve cowpea production in all agro-ecological zones of Ghana by various means such as introduction of new varieties. To select appropriate genotypes for different agro-ecological zones, it is key to note the various soils and climatic factors that affect growth and development of such genotypes so that the interpretation of the observed yields under these zones would be clearly identified or showed.

To improve the performance of new varieties, appropriate agronomic practices and trials at different agro-ecological zones are very critical for breeding and production purposes (Agyemang *et al*., 2014). Again, to increase yield under such environments, there should be clearer understanding of the genotype morphological, physiological and biochemical response to the environment.

2.7.0 Plant Growth Analysis and Functions

Plant growth analysis is regarded as a physiological probe on crop development in a chronological sequence to elucidate and account for the causes of differences in yield through the events that have occurred at different stages of growth. It is considered to be the standard approach to the study of plant growth and productivity (Wilson, 1981). Growth and yield are functions involving metabolic processes and is affected by environmental and genetic factors. According to Ahad (1986), growth pattern and its understanding does not only explain how plant accumulates dry matter, but reveals the events which can make a plant more or less productive singly or in population.

The analysis of plant growth is an explanatory, holistic and integrative approach to interpreting plant forms and function. According to Evans (1996), simple primary data in the form of weights, areas, volumes and contents of plant components are used to investigate processes within and involving the whole plant.

The common growth functions are crop growth rate, leaf area index, leaf area duration, net assimilation rate, leaf area ratio and relative growth rate which are normally calculated from total shoot dry weights and leaf area indices recorded over a given period (Clawson *et al*., 1986). Several authors have used these growth analysis in calculating the growth pattern of various crops, especially cowpea. Addo-quaye *et al*. (2011) reported significant differences in crop growth rate, net assimilation rate and leaf area index using Ayiyi, UCC early and Bengpla cowpea varieties. Karikari *et al*. (2015) also recorded varied crop growth rate values for Asetenapa, Asomdwee and IT89KD-374-57 varieties.

2.7.1 Crop Growth Rate (CGR)

Crop growth rate is the measurement of the productivity of a plant in relation to the increase in dry mass per unit of plant mass over a specific period (Dictionary of Biology, 2004). It is regarded as the gain in weight of a community of plants on a unit land in a unit of time and thus used largely in growth analysis of field crops. The rate of growth is dependent on the net assimilation rate and leaf area index (Kokubun, 1988).

According to Fageria *et al*. (2006), crop growth rate are generally low during early growth stages and increases with time thus reaching maximum values during the time of flowering.

Crop growth rate analysis is used to evaluate treatment differences among cultivars within species in relation to yield. In a study to evaluate three cowpea varieties in agro-ecological zones of the central region in Ghana, Addo-Quaye *et al*. (2011) observed significant difference between two locations, Cape Coast and Twifo Hemang, and the three varieties; UCC early, Ayiyi and Bengpla at different sampling periods. It was also observed that, UCC early variety increased from 30DAP to final sampling stage in contrast with Ayiyi and Bengpla which showed fluctuations in crop growth rate from initial stage to final sampling stage.

In another study of crop growth rate, Karikari *et al*. (2015) also reported reduction in crop growth rate at the final stage of sampling of cowpea varieties. Generally, crop growth rate starts slowly and increase during vegetative growth and may continue to increase or decline due to the variety and season or location.

2.7.2 Relative Growth Rate (RGR)

Relative growth rate generally expresses the dry weight increase in a time interval relating to the initial weight. According to Fageria *et al*. (2006), relative growth rate is the increase in total dry matter per unit of a total dry matter per day. Relative growth rate is affected by a number of factors including temperature, radiation, water, nutrient supply and plant age. According to Chattjrvedi *et al*. (1980), relative growth rate declines as the plant ages and the reason being that, an increasing part of the plant is structural rather than metabolically active tissue which does not contribute to growth. Law-Ogbomo and Enharevba (2009) also attested that the decrease in relative growth rate is as a result of shading of plant parts and increase in age of lower leaves. Generally, relative growth rate crop plants begin slowly just after germination, then peaks rapidly soon afterwards and then falls off.

2.7.3 Net Assimilation Rate (NAR)

Net assimilation rate is the net gain of assimilate which is photosynthetic per unit of leaf area and time. Dictionary of botany (2003) explains that net assimilation rate is a value relating to plant productivity and size. It reflects the balance of photosynthetic rate against respiration and tissue loss rates (Quero *et al*., 2008). The measurement can be productive efficiency of leaves on a plant or crop stand. When all leaves are exposed to full sunlight, the net assimilation rate becomes high. Also, it becomes high when plants are small with few leaves since no shading occurs and later declines as the plant ages because of abscission of lower leaves (Tayo, 1982). Factors that affect net assimilation rate in crops includes temperature, solar radiation levels, carbon dioxide concentration in the surrounding air, mineral nutrition, water supply and leaf area (Fageria *et al*., 2006) and any limitation of these will affect the values.

Other factors associated are weed crop interaction and nature of canopy of plants particularly cowpea. Addo- Quaye *et al*. (2011) observed that growth habits of the three varieties of cowpea showed the extent to which weed crop brought about fluctuations in net assimilation rate values. Again, it was observed that significant difference was not observed in the net assimilation rate values in both locations. Net assimilation is influenced by solar radiation, mineral nutrition and water supply. Anarb *et al*. (2011) observed that net assimilation rate differentials was significantly affected by varietal performance.

Generally, net assimilation rate decreases with age and this is because older leaves may have lower photosynthetic efficiency.

2.7.4 Leaf Area Index

The practical means of trapping solar energy and converting it into food and other usable materials is through crop production. Strategies are designed through crop production to maximize light interception by achieving complete ground cover by manipulating plant density and spatial arrangement to promote rapid leaf expansion. Leaf area index therefore expresses of leaf surface mainly one side only to the ground area occupied by the crop. The size and orientation of the leaf determines the amount of light interception by the plant. Leaf area index differs in varieties and plant density and either fertilized or not. Addo-Quaye *et al*. (2011) reported that mean leaf area index significantly differed among cowpea varieties at the third sampling stage. They further observed that, leaf area index increase with time while for other varieties, it may either reduce or remains the same. It was further revealed that, the variations in growth stages of leaf area index was due to the genetic compositions and the number of leaves produced by the variety. Addo-Quaye *et al*. (2011) again reported that, to obtain optimum yield of cowpea, leaf area index between 1 and 2 is required after flowering.

Miheretu and Sarkodie-Addo (2017), also observed significant varietal differences in leaf area index and reported that Asontem recorded higher leaf area index at 45DAP than Songotra variety but at 60DAP, Songotra recorded higher than Asontem. It has also been reported that, cowpea varieties with spreading habits or large leaf area tends to collect more light than the erect ones with leaves not wide enough (Terao *et al*., 1995). This greater light interception leads to higher rate of photosynthesis which contributes significantly towards vegetative growth of such varieties which eventually lead to higher leaf area index (Aduloju *et al*., 2009; Banerjee *et al*., 2017). Similar observation has also been made by Addo-Quaye *et al*. (2011) who recorded high leaf area index for Ayiyi and UCC-Early due to the spreading habits these varieties exhibited during the growth period.

2.8.0 Crop Improvement

2.8.1 Historical Perspective

In Africa, major achievement have been made in cowpea breeding with respect to productive and early maturing cultivars which are also resistant to pests and diseases (Singh and Ntare, 1985), with such varieties maturing in 60-70 days with grain yields of 2000gk/ha^{-1} (Ehlers and Hall, 1997).

Factors that contribute to this situation include introduction of improved varieties which requires high density sole-cropping and crop husbandry practices to achieve high yield (Ehlers and Hall, 1997). Some local farmers also prefer their local varieties with low planting densities and intercrop it with cereal crops. Lack of adequate extension services and poor quality seed used by farmers can contribute to low yields. Again, most resource-poor farmers in the marginal areas of Africa grow crops under diverse environmental conditions which are risk prone and are characterized by environmental stresses including nutrient deficiencies and inadequate moisture content due to drought situations.

Adequate soil moisture conditions makes intermediate cowpea flower over a long period and subsequently produce more seed therefore yield loss is limited. However, under deficit situation, the flowering period is cut short making the seed mature earlier. In this situation, formation of new floral nodes and flowers are delayed and can be aborted which leads to low productivity (Turk *et al*., 1980).

2.9 Harvesting

Harvesting of cowpea is normally done by manual method but combine harvesters can be used in case of large scale production. Harvesting is done according to the use of the cowpea either for the leaves, as fresh seeds as vegetables or the dry seed as food. For vegetable purposes, young leaves are mainly plucked manually. Young leaves are mostly harvested because, older leaves mostly accumulate dust and are also smeared with mud from rain drops and even leaves may discolour (Nkhoma, 2013). Fresh pods can also be harvested in the green state for various meals mostly as vegetables depending on the locality or the environment.

Harvesting of dry pods must coincide with the onset of dry season so that the pods can be fully dried. However, if dry pods are left on the field for long time especially during dry season, there will be scattering of seeds via explosive mechanism by the plant.

2.10 Yield and Yield Components

Several factors account for seed yield of crops including cowpea production either through environmental factors or genotypic differences. According to Ayodele and Oso (2014), factors which account for seed yield which have direct or indirect impact on yield components including number of pods per plant, number of seeds per pod and 100 seed weight over a given land area. Dadson *et al*. (2005) are of the view that, seed yield of cowpea differ among of varieties and are affected by drought and high temperatures, especially during floral development. The yield potential of cowpea grains in Africa is around 1.5-3.0 t/ha, but current average yield is in the regions of 0.2-0.3 t/ha (DGIC, 2001).

Cowpea varieties responds differently to the prevailing soil and climatic conditions. To get a very good seed yield, it is required that varieties with short flowering periods is planted to enable the plant to divert energy into pod and seed development. Nkaa *et al*. (2014) pointed out that, the earlier the variety set flowers, the earlier it matures. In an attempt to select varieties for different environments, it is better to select varieties that will escape drought which will also provide good seed yield in drier areas. In characterizing cowpea varieties in Ghana, similar observations were made by Cobbinah *et al*. (2011). Karikari *et al*. (2015) also made similar observations of seven varieties of cowpea planted which escaped drought due to the early maturing trait of the varieties used in the study. It was observed in their study that the highest yield of Videza amongst the seven varieties was due to continuous water supply. They further indicated that Nhyira and Videza will be more profitable than the other varieties in the minor and major seasons respectively and could serve as an alternative crop because of their desirable attributes and resistance to major biotic and abiotic constraints.

It was again observed that Videza, Hewale and Asomdwe in the study gave lower seed yield under short raining season than the seed yield of the same variety grown under long raining reason. This is because in their view, cowpea cultivars tend to have a narrow range of adaptation, as cultivars developed for one zone with distinct climatic factors usually are not very productive in other zones with different climatic factors. Similar observations have also been made by Hall *et al*. (2003).

Most varieties of cowpea normally have the potential as a drought resistant crop but failure of rainfall or lack of irrigation could be the frequent cause of shortfall in yield, especially in Ghana where cowpea production is primarily grown in dry areas. Drought is therefore considered as an important factor among several seed yield-reducing factors. According to (Quin,1997), there is a potential for further increase in seed yield by planting high-yielding genotypes, providing optimum irrigation, adding fertilizers, planting early and spraying with suitable insecticides.

Therefore, selection of cowpea genotypes that have higher tolerance to drought is needed to obtain higher and more stable seed yields. Agyemang *et al*. (2015) observed in their study that during the minor season, Nhyira, Tona and Hewale appeared to have some drought tolerance potential due to their high yield. Production of relatively more leaves and branches with erect leaf architecture in most cases reflect higher light interception and to produce more photo-assimilate to increase yield of most cowpea crops.

In the development and growth of most cowpea varieties in the Sub Saharan Africa, yield andseed development require the production of assimilates in leaves, translocation of these assimilates to the fruits, unloading of assimilates from phloem of the seed coat into cells of cotyledons and synthesis of the various seed storage compounds. Yield losses resulting from water stress are generally associated with decreases in the activity of these physiological factors and dry matter production may cause differences in grain yield. Differences in such grain yield loss has been reported by Jaiswai (1995) for mugbean grain yield difference, Agele and Agbi (2013) for cowpea yield, Karikari *et al*. (2015) and Agyemang *et al*. (2015).

Agyemang *et al*. (2014) observed that some varieties have the ability to give biological yield which in most cases relates to yield. Varieties that provided the highest biological yield under short raining season conditions were Asetenapa and Hewale, and the long raining season condition was provided also by Hewale and Tona. The growth habits of these genotypes according to them were bushy, erect or semi-erect, a characteristic which can be used as a cover crop as well as for grain. Agele and Agbi (2013) stated that during drought situations especially in locations, cowpea leaf size helps to maintain transpiration per unit area and as a result large leaf area shared soil and helps reduce soil moisture evaporation.

According to the annual report of the Basque Research (2008), plants growing under water limiting conditions tend to grow taller in an effort to scramble for below nutrients around the growth environment and do not provide good seed yield. Crop performance in terms of vegetative and grain yield during the long rainfall season tends to be better than the short rainfall season. Agyemang *et al.* (2014) recorded higher growth and seed yield and attributed to the relatively higher rainfall and milder temperature experienced during the production season of major rainfall.

Number of pods and number of seed per pod have an influence in the yield of cowpea varieties. Yield variations in cowpea due to environmental stresses are mainly due to variations in number of pods per unit area but drought that occurs during pod-filling stage reduces the number of pods per plant and poor pod-filling (Bala Subramanian and Maheswari 1992). Decrease in number of pods per plant is mainly due to the abscission of flowers and pods of cowpea under drought stress and the detrimental effect at flowering and pod-filling stage is not reversible by re-watering. Higher number of pods per plant and seeds per pod and good pod-filling is therefore a reflection of tolerant to drought (Gwathmey *et al*.,1992a).

Again, number of pods per plant depends on the genetic potential of the variety to bear or produce different pod size. In a study conducted by Miheretu and Sarkodie-Addo (2017) among cowpea varieties, they reported that Asontem produced greater pod number than Songotra variety and attributed the differences observed to the genetic potential of each of the varieties with respect to the size of pods produced.

Number of seed per pod is one of the yield components that is most sensitive to soil moisture deficit. Lower seed yield due to lower seed number in pods in seasons and locations could be due to lower assimilation efficiency to post anthesis soil and atmospheric moisture deficits which contribute to low translocation of assimilates which enhanced poor seed filling. Pressman *et al*. (2002) observed that low crop yield to extreme weather condition enhanced dehydration of pollen and poor pollination and embryo abortion which leads to low number of seed per pod. Craufural and Qi (2001) also reported that number of seeds could be reduced through promotion of embryo abortion and pod shedding due to extreme environmental events in droughted pods.

Hundred seed weight of cowpea varieties could be due to different situations such as climatic factors and genetic characteristics of individual genotypes. Abayome *et al*. (2008) observed that yield components of cowpea such as 100 seed weight depend on the genetic characteristic of genotype. Agyemang *et al*. (2015) were also of the view that 100 seed weight of cowpea genotype depends on the genetic potential of the variety. Cobbinah *et al*. (2011) also noted that, differences in 100 seed weight of cowpea varieties may be due to the rainfall as a major factor in the weather conditions experienced in the field.

2.11 Pod Yield and Pod Harvest Index of Cowpea Varieties

Cowpea pod yield most of the time depends on the variety and in particular field conditions in location and growing seasons. Most of the time major factors which improves pod yield of cowpeas include high amount of rainfall which normally leads to milder temperature with high moisture. Babaji *et al*. (2011) studied four cowpea varieties in 2005 and 2006 and observed that, pod yields of 2006 was higher than 2005 and attributed the reasons to the amount of rainfall recorded in 2006 and 2005 seasons in field conditions under rainfed which also led to milder temperature as a results of the higher rainfall experienced in 2006. In some intances pod yield sometimes may be due to the genetic make-up of cowpea genotypes.

Harvest index (HI) is a selection measure which is used to get desirable genotypes for planting. There are a number of factors that improves or help pod harvest index as a selection criteria. When crops are supplied with enough rainfall or when irrigated, it affects the growth, reproductive parts (flowering, podding) which translate into yield. During flowering and podding stage (phenological stage), continuous supply of water increases soil moisture content and therefore crops roots are able to draw enough water from soil reservoir. When there is enough rainfall, temperatures would normally reduce and for that matter extreme high temperatures and radiation may not be observed and therefore poor flower and pod development will not be observed in field conditions hence sound pods with smooth grain filling to achieve maximum yield. Dapaah *et al*. (1999) observed that continuous supply of water (irrigation) influenced high harvest index (HI) through delayed senescence which leads to the production of more assimilates to produce more seeds per pod. Also, irrigation is expected to increased harvest index of peas by increasing number of pods per plant.

2.12 Drying and Storage

Storage of cowpea depends on the moisture content. The lower the moisture content, the earlier the seeds dry and better quality. Cowpea dry seeds can be stored by both cold and sun- drying method. An exposure to -18°C in 6 to 24 hours can greatly reduce pest by 99% (Nkhoma, 2013). In Ghana, some people store the seeds in normal refrigerator while research stations also store them in cold rooms. For short term, cowpea grains can be stored at 12% moisture or less but for long term storage, it can be at 8 to 9% moisture level.

2.13 Nodules

Nodule numbers usually are lower at harvest than at earlier stages. Usually nodule numbers are especially high in lateral roots than nodules from taproots. Varietal differences most of the time accounts for nodule differences since the pattern of nodulation most often reflects the physical distribution of the root system in the soil. Ayodele and Oso (2014), also share the view that significant variation in cowpea nodulation per varieties is attributed to the genetic make up of the individual varieties. According to Hansen (1994), nodulation capacity vary between and within legume species rather than rainfall variations. Varieties that produce more nodules possess the capacity to fix nitrogen into the soil.

The establishment and maintenance of an effective symbiosis is dependent on favourable environment that allows maximum nitrogen fixation which can help to form a strong and efficient symbiotic association with mycorrhizae (Pele *et al*., 2016). Several environmental factors such as soil pH, soil fertility and extremes temperature impose limitations on the symbiotic association between the host plant and micro symbionts (Van-wyk, 2003).

The amount of nitrogen fixed is variable and depends on the host legume, cultivar, presence of saturated or near-saturated soil water for movement, soil texture and composition, bacterial species and growing conditions, especially pH and the presence of soil nitrogen. Nodule production is associated with seed yield of cowpea. Karikari *et al*. (2015), compared three varieties of cowpea; IT89KD-374-57, Asomdwee and Asetenapa, and observed that, IT89KD-374-57 was low yielding due to its production of fewer nodules and dry matter and therefore stated that low production of nodules means less nitrogen fixation by the variety.

2.14.0 Determinants of Plant performance

2.14.1 Genotype

A genotype is the entire set of genes in an organism and it can also mean an individual's collection of genes. The term can also mean a set of alleles that determines the expression of a particular characteristic or a trait known as the phenotype. According to Solomon *et al.* (2002), genotype is the genetic make up of an individual or the allele combination in an individual most often expressed in symbols.

2.14.2 Environment

According to Anon (2013), environment is generally considered as the physical and biological factors along with their chemical interactions that ultimately affect the survival of an organism. It is the surrounding of a physical system that may interact with the system by exchanging mass, energy or other properties. Environment therefore encompasses the interaction of all living species.

2.14.3 Genotype Environmental Interactions

GEI according to Dixon *et al. (*1994) is the change in a cultivar's relative performance emanating from the different responses of the genotypes to various edaphic, climatic and biotic factors.

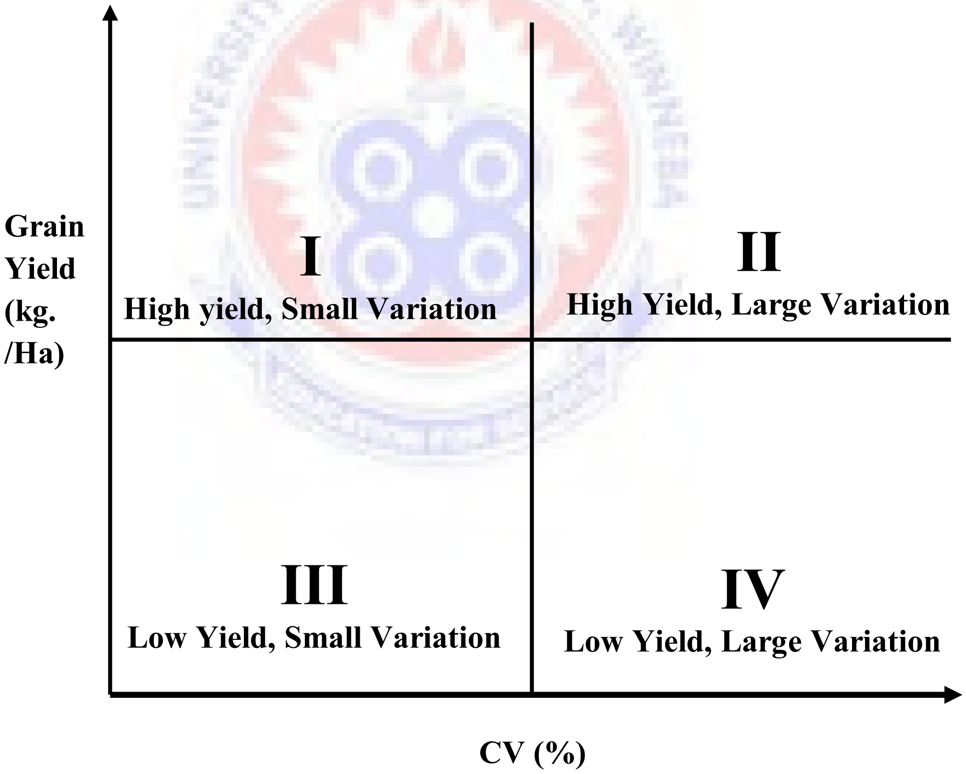
Francis and Kannenberg (1978) proposed a descriptive method for grouping genotypes by using mean yield and coefficient of variation across environments to check the consistence of performance. This Genotype grouping technique is not only to check the mean yield and co-efficient of variation but also used to expose differential fertility levels, so that varietal responses to increasing fertility for greater yield variance across different environments can be measured.The mean yield is however, plotted against coefficient of variation (CV) and the grand mean yield. The plot or the graph is divided into four groups as follows;

Group I – high yield, small variation

Group II – high yield, large variation

Group III – low yield, small variation

Group IV – low yield, large variation



Wide adaptation to particular environments and consistent performance of recommended varieties are of prime importance for successful cultivation of cowpea. Even though, many varieties are recommended for cultivation, the information on their stability may be lacking.

2.15 Concepts of Stability

Stability is the ability of a genotype to produce or perform under stressful conditions and yet be able to respond. Tollenaar and Lee (2002) are also of the view that stability is a measure of the ability of a genotype to maintain relative performance across wide environments. Genotypes that show little interaction with environments are called stable. Stability can either be static or dynamic. Static stability means the performance of the genotype remains unchanged regardless of the environmental conditions. For dynamic stability, the performance of a genotype changes in a predictable manner across a wide range of environmental conditions (Tollenaar and Lee, 2002). This clearly shows that static stability is an absolute measure, while dynamic stability is a relative measure.

Different concepts of stability have been described over the years (Lin *et al.*, 1986; Becker and Léon, 1988). Stability statistics fall into four groups depending on whether they are based on the deviations from the average genotype effect or on the genotype by environment (GE) term, and whether or not they incorporate a regression model on an environmental index (Lin *et al.*, 1986). These groups of stability statistics are related to four concepts which are, Type 1, Type 2, Type 3 and Type 4.

Type 1: A genotype is considered to be stable if its among-environment variance is small. Becker and Léon (1988) called this stability a static, or a biological concept of stability. A genotype is said to be stable if it possesses an unchanged performance regardless of any variation of the environmental conditions. Quality traits such as disease resistance and stress characters like winter hardiness is very useful for this concept of stability. Parameters used to describe this type of stability are coefficient of variability (CVi) used by Francis and Kannenburg (1978) for each genotype as a stability parameter and the genotypic variances across environments (Si^2).

The usefulness of Type1 stability depends on the range of environments under which the experiment is conducted. If the range is very large like a collection of sites from different continents then Type 1 stability may not be very meaningful. However, if the geographical range is restricted like the agro ecological zone of the same country, it could be important (Lin *et al*., 1986).

Type 2: A genotype is considered to be stable if its response to environments is parallel to the mean response of all genotypes in the trial. Becker and Léon (1988) called this stability the dynamic or agronomic concept of stability. A stable genotype has no deviations from the general response to environments and thus permits a predictable response to environments. The scopeof inference of Type 2 stability is not generalized, but specific to the test set (Lin *et al*., 1986). For a genotype to be considered stable by this definition, is only with respect to the other genotype in the test, but without any assurance that it will appear stable when assessed with another set of genotypes (Lin *et al*., 1986). A regression coefficient (bi) (Finlay and Wilkinson, 1963) and Shukla's stability variance can be used to measure Type 2 stability.

Type 3: A genotype is considered to be stable if the residual mean square (MS) from the regression model on the environmental index is small. The environmental index implicates the mean yield of all the genotypes in each location minus the grand mean of all the genotypes in all locations. Type 3 is also part of the dynamic or agronomic stability concept according to Becker and Léon (1988). Methods to describe Type 3 stability are the methods of Eberhart and Russell (1966) and Perkins and Jinks (1968).

Genotypes that combine high grain yield with at least moderate stability are said to be adapted (reliable). According to Finlay and Wilkinson (1963), the modeled genotype response is represented by: $R_{ij}=a_1+b_1M_{j}$: where R_{ij} = modeled genotype yield response in environment j. a_i = intercept value, and M_j = the environmental mean yield.

They showed that a regression coefficient (b1) approximating 1.0 indicated an average stability and in association with high yield, the entry possesses general adaptability. However, entries with low yield would be poorly adapted to the environment. Regression coefficient values increasing above 1.0 describe genotypes with increasing sensitivity to environmental change, thus below average stability. Regression coefficients decreasing below 1.0 provide a measure of greater resistance to environmental change, thus above average stability where the greatest stability is b=0.

Type 4**:** The Type 4 stability is based on the genotypes and years within a location mean square and it is part of G × L × Y. The derivation of the parameter starts with the separation of the environmental variation in to predictable (G × L) and unpredictable (G × Y) (Lin and Binns, 1991). The parameter to use in stability must be heritable or genetic and if the characteristic measured by the parameter is non-genetic, then the variation is fruitless. Type 4 looks at the year within location MS averaged over locations and measures homeostatic property only with respect to unpredictable variation excluding the predictable part (Location) that is controlled. Moreover, type 4 is not tied to a range of genotypes which are included in the test.

2.16 Statistical Methods to Measure G × E Interactions

Genotype by environment interaction studies are important since the interaction plays a significance role in the expression of the performance of different genotypes in different environments. Genotype by environment have been used on most crops under different environments (El Ameen, 2012). According to Shah *et al*. (2009), genotypes interact differently with the environments.

Crop trials at multi locations in multiple years are executed to generate experimental data to measure genotypes. Because of complexity of field trials and various definitions of yield stability (Lin *et al*., 1986), different statistical methods for measuring stability have been proposed which includes regression analysis (Yates and Cochran, 1938; Finlay and Wilkinson, 1963; Eberhart and Russell, 1966), univariate and multivariate analyses of variance (Mandel, 1971; Lin and Thompson, 1975; Ghaderi *et al.,* 1980; Crossa *et al.,* 1993) and multivariate analysis of the residuals from a main effects additive model using the additive main effect and multiplicative interaction (AMMI) approach (Gauch, 1988; Gauch and Furnas, 1991). This last method allows the modeling of GEI in more than one dimension (Vargas *et al.,* 1998). If the GEI variance is found to be significant, one or more of the various methods for measuring the stability of genotypes can be used to identify the stable genotype(s).

2.17 Conventional Analysis of Variance

In a field trial in which the yield of G genotypes is measured in E environments each with R replicates, the classic model for analyzing the total yield variation contained in G × E ×R observations is the analysis of variance. When environments and genotypes are well characterized by measuring traits associated with differences in performance, it becomes possible to use the G × E approach for studying specific adaptation (Berger *et al*., 2007). The within-environment residual mean square measures the error in estimating the genotype means because of differences in soil fertility and other factors including shading and competition from one plot to another. The GER observations are partitioned into two sources after removing the replicate effect when combining the data, thus (a) additive main effect for genotypes and environments and (b) non-additive effects due to GEI. Therefore, analysis of variance of the combined data expresses the observed (Y_{ij}) mean yield of the *i*th genotype at the *j*th environment as:

$$Y_{ij} = U + G_i + E_j + GE_{ij} + e_{ij}$$

where U is the general mean; G_i,, E_j, and GE_{ij}represent the effect of the genotype, environment, and the GEI, respectively; and $e_{ij}$is the average of the random errors associated with the *r*th plot that receives the *i*th genotype in the *j* th environment. The non-additivity interaction means that the expected value of the *i* th genotype in the *j*th environment (Y_{ij}) does not only depend on the levels of G and E separately but also on the particular combination of levels of G and E (Crossa, 1990).

The main disadvantage of the combined analysis of variance of multi-location trials is that it does not explore any underlying structure within the observed non additivity (GEI). Analysis of variance of multi-location trials is useful for estimating variance components related to different sources of variation, including genotypes and GEI. On a whole, the methodology of variance component is important in multi-location trials, since errors in measuring the yield performance of a genotype arise largely from GEI. In a breeding program, variance component methodology is used to estimate the heritability and predicted gain of a trait under selection (Crossa, 1990).

2.18 Regression Analysis

According to Crossa (1990), joint regression analysis is an important model to analyze and interpret the genotype by environment interaction (GEI) tables and it has been used to complement the traditional analysis in genetics, agronomic and plant breeding to determine yield stability of different genotypes across different environments. The joint regression analysis has been used by many scientists in different crops in different locations. Many methods have been proposed that are used in accessing yield stability.

Eberhart and Russell (1966) proposed a regression analysis which make use of mean yield, regression coefficient and mean squared deviation (Mean yield + b + S^2d) to determine yield stability which has been used for many crops in different environments. A study conducted by Ngeve and Bouwkamp (1993) on sweet potato revealed one clone genotype as the most stable among the twenty (20) genotypes using Eberhart and Russel (1966) model, though based on the S^2 d values six genotypes could have considered to be stable. Hassan *et al*. (2013) reported mean squares of environments for many traits measured which were highly significant which showed that environment had influence on the studied traits.

Francis and Kannenberg (1978) also proposed another regression stability measure using mean yield and coefficient of variation. In their study, maize genotypes were evaluated and categorized into groups based on their performance. Similar groupings have been reported by Ngeve and Bouwkamp (1993) for sweet potato. Ackura *et al*. (2006) also recorded similar observations in durum wheat. Muluken *et al*. (2014) reported a rank correlation of genotypes with environmental variance based on the regression method employed by Francis and Kannenberg (1978).

Finlay and Wilkinson (1963), proposed another regression model which makes use of mean yield and regression coefficient. Many scientists have employed the use of this model to assess yield stability of variety of genotypes across different environments. Adebisi (2010) reported significant and non-significant differences in regression coefficient using Finlay and Wilkinson (1963) stability measure (FWb). Stable and non-stable genotypes were recorded for sesame genotypes and it meant that the fourteen (14) genotypes in the study responded differently to the environments. Similar observations were made by Adebisi and Ajala (2006) for sesame seed yield in Nigeria.

2.19 Principal Component Analysis (PCA)

According to Crossa (1990) and Purchase (1997), the principal component analysis (PCA) is the most frequently used multivariate method. The main aim is to transform the data from one set of coordinate axes to another which preserves as much as possible, the original configuration of the set of points and concentrates most of the data structure in the first principal component axis. Several authors have noted various limitations for this technique (Perkins, 1972; Williams, 1976; Zobel *et al*., 1988). The view of Crossa (1990) is that the linear regression method uses only one statistic, the regression coefficient, to describe the pattern of response of a genotype across environments, and therefore most of the information is wasted in accounting for deviation.

Principal component analysis (PCA) is a generalization of linear regression that overcomes this difficulty by giving more than one statistic, the scores on the principal component axes, to describe the response of a genotype. In an experiment to estimate the AMMI analysis of genetic parameters for growth and yield components in cassava in the forest and guinea savannah ecologies of Ghana, Adjebeng-Danquah *et al.* (2017) reported very highly significant effects of genotype, environment and interaction of all traits measured, genotypic factors accounting for large proportion of the treatment sum of squares in the yield and components. Again, environment alone accounted for 77.48% for some growth parameters such as plant height. Their study also recorded a higher PCA scores (IPCA1 and IPCA2) which accounted for 85.10% of the interaction sum of squares for the first two principal components. Tedele *et al.* (2017) also recorded 10.01% which accounted for genotypes, 75.29% by environments and 14.71% by genotype × environment interaction and this was due to the large contribution of the diverse environment which resulted in the differences in the environmental means that caused variation in grain yield of linseed. Again, the AMMI analysis showed that, the first two principal components were significant ($p<0.01$) and they were cumulatively accounted for 88.58% of the total interaction between genotype and environment. Out of this IPCA1 and IPCA2 explained 63.42% and 25.16% of the interaction sum of squares indicating that the use of AMMI model is suitable to the data.

2.20 Additive Main Effects and Multiplicative Interaction (AMMI)

The additive main effect and multiplicative interaction (AMMI) method integrates analysis of variance and principal components analysis into a unified approach (Gauch, 1988). According to Gauch and Zobel (1988), Zobel *et al*. (1988) and Crossa *et al.* (1990), it can be used to analyze multilocation trials. The AMMI model according to (Gauch, 1993; Annicchiarico, 1997; Gauch and Zobel, 1989; Ariyo, 1999), has been proven to be the suitable method for depicting adaptive responses. According to Grauch and Zobel (1989), AMMI analysis has significantly improved the probability of successful selection and therefore, it has been used to analyse G×E interaction with greater precision in many crops (Bradu, 1984; Gauch 1990; Crossa *et al*., 1991; Ariyo, 1999).

Zobel *et al*. (1988) pointed out that, considering the three traditional models, analysis of variance (ANOVA) failed to detect a significant interaction component, principal component analysis (PCA) failed to identify and separate the significant genotype and environment main effects, linear regression models accounted for only a small portion of the interaction sum of squares. Instead, the AMMI model combines the conventional analysis of variance for genotype and environment main effects with principal components analysis to decompose the GEI into several interaction principal component axes (IPCA). Due to the biplot facility from the AMMI analysis, both genotypes and environments are plotted together on the same scatter plot and therefore, inferences about their interaction can be made (Horn *et al*., 2017).

In an AMMI studies conducted on cassava by Adjebeng-Danquah (2017), variations in cassava yield was recorded in relation to different environments. Fresh root yield were also significantly affected by genotype and environments with Fumesua recording the higher root yield than Nyankpala in two year period and attributed the yield variation to favourable environmental conditions prevailed in the two agro-ecological zones which made cassava responded to the Fumesua location.

2.21 GGE Bi-plot Analysis

In the past, various methods have been put forward by researchers to analyse genotype × environment interaction which includes regression co-efficient, sum of squares deviation from regression, stability variance, co-efficient of varaiability and additive main effects and multiplicative interaction. GGE bi-plots are graphical display of genotype × environment interaction pattern (GEI) of multi-environment yield trial (MEYT). Yan (1999) and Yan *et al*. (2000) proposed this method of measuring yield stability. The GGE bi-plot makes use of two concepts which are the G and the GE-Interaction and are carried out simultaneously in genotype evaluation hence GGE bi-plot.

The GGE bi-plots are constructed with the use of first two principal components (PC1 and PC2), thus the primary and secondary effects and it is achieved by subjecting environment centred yield data. Based on the graphical display, stable, unstable, and which won where or what won where genotypes as well as average environmental axis in various environments is achieved (Zerihun, 2011). Yan and Tinker (2006) reported a ranking of genotypes based on their yield performance in various environments in relation to barley plant.

According to Tedele *et al*. (2017), bi-plots determine how genotypes remain stable. Genotypes that are farther away from the centre of bi-plots determine specific adaptation. For instance, genotypes that are far away from the centre of the bi-plot indicate that they have high GE interaction and the ones that are close to the centre of bi-plot indicates high stability.

Horn *et al.* (2017) reported that IPCA scores indicates genotype stability. Therefore, the greater the IPCA scores either positive or negative, the more that genotype is adapted to a particular environment. And the closer the IPCA scores approaches zero, then the genotype is more stable or adapted across all the test environments (Egesi and Asiedu, 2002; Admassu *et al*., 2008; Horn *et al*., 2017). Similar observations have been made for crops such as wheat (Kaya *et al*., 2002) and for rice (Kayode *et al*., 2017) using the first two IPCA scores. Bi-plots of “which won where” together with IPCA scores have been used to evaluate yield stability cowpea genotypes to determine which ones that had superiority or performed better based on environments (Horn *et al*., 2017).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of Experimental Sites

The study was carried out in two locations over two seasons:-the minor season from September to December, 2015 at Mampong - Ashanti and Fumesua and the major season from April to July, 2016 at both locations.

The Mampong –Ashanti (7° and 8’ N, 1° 24’ W) experiment was conducted at the College of Agriculture Education, University of Education, Winneba, Mampong- Ashanti campus located in the forest-savannah transition agroecological zone of Ghana.The soil at Mampong belong to the Bediese series of the savannah Ochrosol. The soil is sandy loam, well drained with thin layer of organic matter with characteristic deep yellowish red colour, friable and free from stones. The pH ranges from 6.5-7.0. It is permeable, and has moderate water holding capacity (FAO, 1988; Asiamah *et al*., 2000). The site has an altitude of 457.5m above sea level.

Mampong-Ashanti has a bimodal rainfall pattern with the major rainy season occurring from March to July and minor rainy season from September to November. Between the two seasons is a short dry spell in August. Average annual rainfall is between 1094-1200mm with a temperature range of 22/23°C- 30°C (Meteorological Services Department Kumasi-Ashanti, 2005).

The Fumesua (6° 43’ N, 1° 36’ W) experiment was conducted at the research fields of the Council for Scientific and Industrial Research - Crops Research Institute CSIR-CRI), Fumesua, Kumasi, located in the forest agroecological zone. The location has an altitude of 228m above Sea level. The soil belongs to Asuansi series with thick top layer of dark grey gritty loam to gritty clay loam. It is of the Humid forest from Ferric Acrisol (FAO, 2000). The pH ranges between 6.0-7.5. Fumesua also has a bimodal rainfall pattern with the major rainfall season occurring from March to July and the minor rainfall season from September and December (Meteorological Service Department-Kumasi Ashanti, 2015). The average annual rainfall is 1650-1727mm with a temperature range of 22-31°C.

3.2 Experimental Design and Treatments

The design used for the study was a Randomised Complete Block Design with three replications.

Selected cowpea varieties released by CSIR-CRI over the period of 1990-2015 were used for the study as treatments. These were Asetenapa, Nhyira, Asomdwee, Asontem, Tona, Soronko, Hewale and Videza.

3.3: Characteristics of Cowpea Varieties Used In the Study

Variety	Year of release	Growth habit	Seed coat texture	Maturity date	Maturity Type	Seed shape
Asomdwe	2012	Semi-erect	Smooth	65-72	Early maturing	Globose
Hewale	2012	Semi-erect	Smooth-rough	64-77	Early maturing	Rhomboid
Nhyira	2005	Erect	Rough	65-68	Early maturing	Globose
Asontem	1999	Semi-erect	Smooth	65-70	Early maturing	Ovoid
Soronko	1999	Spreading/ Prostrate	Smooth	75-80	Late maturing	Ovoid
Asetenapa	1999	Erect	Smooth	63-70	Early maturing	Ovoid
Tona	2005	Erect	Smooth	71-80	Late maturing	Ovoid
Videza	2012	Semi-erect	Smooth	68-77	Late maturing	Ovoid

Source: Crops Research Institute (CRI), 2015

The land at each location was ploughed, harrowed, levelled and marked out. The experimental plots were demarcated with pegs and ropes. Each plot measured 1.5m wide × 3m long with a spacing of 0.5m between rows ×0.2m within rows. Each plot had four rows and the two middle rows were demarcated as harvestable rows.

3.4 Cultural/Management Practices

Planting was done at Mampong-Ashanti and Fumesua on the 11th and 12th October for 2015 and 27th and 28th April respectively for 2016.

Three seeds per hill were planted at a distance of 50cm×20 cm and depthof 3cm. The emerged cowpea plants were later thinned to two seedlings per hill two weeks after planting.

Weeds were controlled manually using a hoe at 21 days after planting (DAP) and hand picked at 45 days after planting.

For the two locations and the two seasons, four sprayings were carried out at 20, 30, 40 and 50 DAP using Cymetox EC (cypermethrine 30g/l and dimethoate 15 g/l). A Knapsack sprayer (15 litre capacity) was used in the spraying to control pests and diseases.

3.5.0 Data Collected

Data were collected on phenology, growth and yield and yield components

3.5.1 Growth, Phenology and Growth Functions

Plant height was measured from the base to the terminal leaf of five plants tagged within the two middle rows using a metre rule at 30, 45 and 60 days after planting (DAP).

The number of branches per plant was determined as the average number of the branches that appeared on the five tagged plants within the two middle rows in each plot at 30, 45 and 60 days after planting (DAP).

The days to 50% flowering (DDF) was taken from the planting date to the date that 50% of the plants within the two harvestable middle rows had flowered.

The days to 50% podding (DFP) was taken from the planting date to the date that 50% of the plants within the two harvestable middle rows have had pods.

Leaf area was taken at three intervals at 30, 45 and 60 days after planting (DAP). A manual method was used which was non-destructive. Leaflets from the tagged plants in each plot were taken for the measurements. The length was taken along the midrib of the leaf from the point of attachment to the petiole to the tip of the leaf while the breadth was taken by measuring the maximum width of the leaf (Wilhelm and Nelson, 2000). The leaf area (LA) was then estimated by calculating the average from the five tagged plants.

The leaf area index (LAI) was determined from the leaf area using the instantaneous approach at 30, 45 and 60 days after planting. It was carried out by calculating the leaf area of the number of plants per square meter of land and was obtained using the equation below:

$$\mathbf{LAI} = \frac{\textbf{Leaf area of number of plants}}{\textbf{1 m}^2\textbf{ of land}}$$

The crop growth rate (CGR) was calculated using the formula by Radford (1967): -

Two plants from the border rows were gently uprooted and the above ground was taken and oven dried at 70˚C and the dry taken at sampling periods or intervals at time T. The dry weight was taken from the fresh weight using the formula by Raford (1967);

$$CGR=\frac{W_2-W_1}{T_2-T_1}\quad (gm^{-2}\ day^{-1})$$

where W1 and W2 were the total above ground dry weight at sampling periods T1 and T2, respectively.

The relative growth rate was obtained based on the dry weights obtained in a method described in the crop growth rate. The relative growth rate was determined using the formula by Harper (1983):-

$$RGR=\frac{\ln W_2-\ln W}{T_2-T_1}\quad g\ g^{-1}\ day^{-1}$$

Where W1 and W2 were the total above ground dry weight at sampling periods T1 and T2, respectively.

Net assimilation rate was taken with the methods by Harper (1983) after the leaf area and leaf area index has been taken using the method by William and Nelson (2000) as described above (leaf area and leaf area index)

The net assimilation rate was calculated using the formula by Harper, (1983)

$$NAR=\frac{\ln W_2-\ln W}{T_2-T_1}\times\frac{\ln LA_2-\ln LA_1}{LA_2-LA_1}\quad (g\ m^{-2}\ day^{-1})$$

where W1 and W2 were the total dry weight (above ground) at sampling periods T1 and T2 respectively; LA 1 and LA2 were leaf areas at sampling periods T1 and T2, respectively.

3.5.2 Nodule Count

Nodule sampling was done at 30, 45 and 60 days after planting (DAP). Roots of five plants were carefully dug using a hand trowel. Soils on the roots were carefully removed and nodules attached to the roots were gently washed in water. The total number of nodules on each plant on the root hairs were removed and counted and their mean recorded.

The picked nodules were cut open with a razor blade to determine the effective nodules among them. Nodules with pinkish colour were considered active nodules, whereas those with green or grey colour were considered non-active (Gwata *et al*., 2003).

3.5.3.0 Yield and yield components

3.5.3.1 Number of pods per plant

The five plants that were randomly selected from the two middle harvestable rows tagged on each plot were harvested and the number of pods on each plant was counted and the average determined as the number of pods per plant.

3.5.3.2: Number of Seed Per Pod

Seeds of all pods on the five tagged plants were threshed and counted and their average was determined as the number of seeds per pod.

3.5.3.3 Pod Length

Using Vennier calipers, the length of the pods on each tagged plant was measured and their average was determined for pod length.

3.5.3.4 One Hundred Seed Weight

One hundred seed weight was determined as the average of five lots of 100 seeds selected from the seeds threshed from the five tagged plants.

4.5.3.5 Pod yield

The pods from the plants in the two harvestable middle rows were weighed to determine pod yield per plot and pod yield per hectare (kg/ha).

3.5.3.6 Seed Yield Per Plot

The pods of plants in the two middle harvestable rows were threshed and weighed to determine the seed yield per plot and seed yield per hectare (kg/ha).

3.5.3.7 Pod Harvest Index

Pod harvest index (PHI) was calculated using the formula:

$$\text{PHI}= \frac{\text{Seed yield}}{\text{Pod yield}}\times 100$$

3.6.0 Yield Stability Analyses

3.6.1 Stability Analyses

Data set were inputed into the model of Eberhart and Russell (1966) and the stability measure was employed. In this stability measure, the appropriate model for the ANOVA is the sum of squares due to environment and genotype by environment (linear) and deviations from the regression model. Eberhart and Russell (1966) used regression value (b) and deviation from regression (S^2d) which states that a genotype is considered stable if it has a unit regression over the environments (b=1) and the deviation from regression not significantly different from zero ($S^2d=0$). A genotype with high mean yield over the environments with a unit regression coefficient (b=1) and deviation from regression equal to zero ($S^2d=0$) is regarded as a choice as stablegenotype.

$$Y_{ij} = \mu + G_i + E_j + biE_j + d_{ij} + e_{ij}$$

where Y is the observed mean yield of the ith genotype in the jth environment ($i = 1,\ldots g$; $j = 1,\ldots e$); µ is the mean;G_i is the effect of genotype I;E_j is the effect of environment j;bi is the linear regression coefficient of the ith genotype on environmental index;d_{ij} is deviation from regression and e_{ij} is the average of the random errors associated with the ith genotype and jth environment (Eberhart and Russell, 1966).

3.6.2 Stability Analyses

Finlay and Wilkinson (1963) method uses linear regression of cultivar means on locality and the derived statistics describing the registration lines and their stability. The method makes use of the slope (bi) and the mean yield for all the genotypes. To get the significant linear regressions, the slope of the regression line was tested for conformity with non-interactive slope of one (1). Two criteria were then used in order to indicate clearly whether the genotype was stable or not stable. The linear tendency of the data for each of the genotypes was expressed by the slope of the regression line compared to the slope of 1. A slope less than 1 suggests that a genotype has lower than average sensitivity to the environmental indexes, while a slope equal to 1 means that cultivar has an average response. However, a slope greater than 1 indicates that the cultivar exhibits higher than average sensitivity to environmental indexes.

3.6.3 Stability Analysis

Mean yields of various genotypes were set for the stability analysis based on Francis and Kannenberg (1978). Genotype mean square across test environments was used to assess the stability and adaptability of genotypic mean yield. The eight genotype mean yields were imputed into the Francis and Kannenberg (1978) model. The model employed the use of coefficient of variation (CV%) for each of the eight genotype. Then the coefficient of variation was compared with the various mean yields of the various genotypes.

3.6.4 Additive Main Effects and Multiplicative Interaction (AMMI) Analysis

The data on the grain yield of 8 genotypes of cowpea in 2 year-location environments were subjected to the AMMI analysis. The AMMI model used was

$$Y_{ger} = \mu + \alpha_g + \beta_e + \Sigma\lambda_n \gamma_{gn} \eta_{gn} + \rho_{ge} + \varepsilon_{ger}$$

where Y_{ger} is the yield of genotype (g) in environment (e) for replicate (r); μ is the grand mean, α_g is genotype mean deviation (thus mean minus grand mean); β_e is the environment mean deviations; n is the number of Principal Components Analysis (PCA) axes retained in the model; λ_n is the singular value of PCA axis n; γ_{gn} is the genotype eigenvector values for PCA axis n; η_{gn} is the environment eigenvector values for PCA axis n; ρ_{ge} is the AMMI residuals and ε_{ger} is the residual error.

The AMMI model makes use of ordinary ANOVA to analyse the main effects which is the additive part and Principal Component Analysis (PCA) to analyse the non-additive residual left over by the ANOVA using the method by Gauch (1993). To get the interaction, the genotype PCA score was multiplied by that of the environment. When a cultivar and the environment have the same sign on their respective first PCA axis, their interaction becomes positive, if different then their interaction is negative.

From this, an AMMI biplot was drawn where important aspects of both genotypes and environments were plotted on the same axis in order to get the interrelationships clearly visualized and easy interpretation. In the AMMI biplot, PCA1 score is placed on the vertical axis while the yield is placed on the horizontal axis. The genotypes that appear almost on a perpendicular line had similar means and those that fall almost on the horizontal lines had similar interaction patterns.

For the interpretation of the scores; genotypes or environments with large PCA scores either positive or negative had large interactions while those (genotypes) with PCA 1 score of zero or nearly zero had smaller interaction (Crossa *et al*., 1990). The first two PCA axes were considered for this study. The biplot of the first two IPCA axes demonstrated the relative magnitude of the genotype by environment interaction (GEI) for specific genotypes and environments. If the genotype or environment is further away from the centre of the axis, then the GEI is large.

The AMMI analyses were complemented with GGE biplot analysis. The first two principal components were used to obtain GGE biplots using the Plant Breeding Tools software (PBTools, 2014). To generate a biplot for visual analysis of multi environment data, the singular values were partitioned into genotype and environment eigenvectors for the GGE biplot model (Gauch *et al.,* 2008; Yan and Kang, 2003). Collectively, AMMI and GGE biplots were used to assess the performance and interaction patterns of genotypes and environments and based on that, a genotype with absolute IPCA1 value close to zero indicated low interaction and was considered to be stable while genotypes with greater absolute IPCA1 values were considered to have high sensitivity to environmental changes.

3.7 Statistical Analysis

The data were subjected to Analysis of Variance (ANOVA) using Statistical Analysis System (SAS) (SAS, 2010). Mean separation were estimated at 5% and 1% level of significance in order to determine the ones that will be significant or highly significant. To determine the interactions among the locations, the years and treatments, a combined analysis carried out for the treatments in each location and the seasons.

Test for homogeinety was not carried out because the data were not from single population but from multiple sources with which variations between the surrounding factors would have been difficult to control. Data transformation was not done because the data points were not measured with different scalars.

CHAPTER FOUR

4.0 RESULTS

4.1.0 Weather Data for 2015 and 2016

4.1.1 Rainfall

Monthly rainfall in 2015 and 2016 in Fumesua and Mampong and their thirty-year averages are presented in Figure 1. The total rainfall (325mm; 63.67%) during the growing period in 2015 (September-December) was relatively higher in Mampong than (23.33%) in Fumesua especially during early days of the crop in September and flowering and podding stages in late October (Figure 4.1 a and b). In both locations no rainfall was recorded in December 2015. Comparing the 30-year average rainfall during the planting period, there was higher amount of rainfall (180mm) in September than what was recorded during the planting period at both locations.

During the 2016 season planting period, there were differences in total rainfall during the planting period (March-June) and the 30-year averages. The total rainfall amounts recorded in Mampong was (425mm; 59.57%) slightly higher by (135mm; 19.14%) than at Fumesua (285; 40.43%). During the critical periods of flowering and pod-filling in May, the rainfall recorded compared with the 30-year long term averages was higher by100mm. Generally, the rainfall amounts recorded for the 2016 season at both locations were higher than that of the 2015 season.

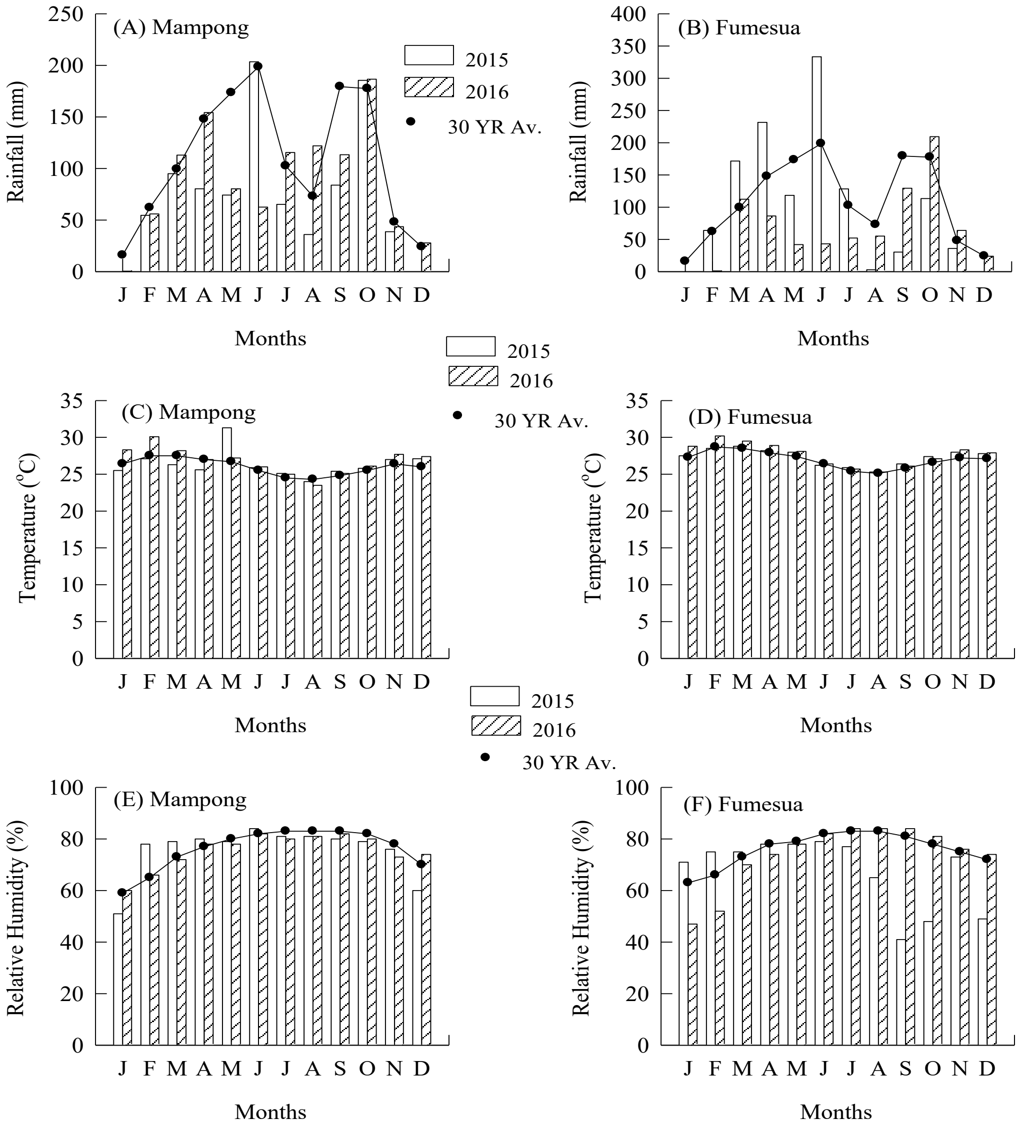


Figure 4.1: Weather Data for the 2015 and 2016 and Long-Term (30-Year) Averages at Mampong-Ashanti And Fumesua.

4.1.2 Temperature

The average monthly temperatures recorded for 2015 and 2016 are shown in Figures 4.1 c and d.

Temperature range during the year and the planting period (25-33°C) were generally slightly higher at Fumesua than at Mampong (24-27°C). The lowest temperature was recorded in August with the highest in March during both seasons and locations in the entire season. There were no differences in the temperatures between the long-term averages (30-year period) and the planting periods except in February March, May and November which, the growing period recorded slightly higher amounts of temperatures. Generally, the temperatures were slightly higher by 2.5% during the 2015 growing period than the 2016 growing period (Figures 4.1 c and d).

4.1.3 Relative Humidity

Relative humidity during the growing periods in 2015 and 2016 and their long term (30 year) averages are presented in Figures 1 e and f.

Generally, the relative humidity during the growing period was relatively similar to the long term (30 year) except was relatively close except December in the 2015 season at Mampong. At Fumesua, relative humidity differed between the 2015 and the 2016 growing seasons. There was higher relative humidity in 2016 than in 2015 season. Relative humidity during the 2015 season (September, October and December) was lower compared with the long term (30 year) average. However, in the 2016 major season relative humidity was similarbetween the growing period (March-June) and the long term (30 year) average (Figures 4.1 e and f).

4.2.0 Phenological Development and Plant Growth

4.2.1 Days to Floweringand Podding

Mean square for 50% flowering and podding is presented in Table 4.1. The combined analysis across years and locations showed a very highly significant difference among all the genotypes for days at 50% flowering (DFF). There were a very highly significant ($P<0.001$) effect of location, year, location × treatment and year × treatment. Location × year × treatment were significant at $P<0.001$ (Table 4.1).

For days to 50% podding (DFP), the combined analysis did not show significant difference for DFP. A very highly significant ($P<0.001$) difference was observed for location, treatment and location × year. Year was highly significant at $P<0.01$. However, location × treatment, year × treatment and location × year × treatment did not show any significant differences (Table 4.1).

Table 4.1: Mean Square values for days to 50% flowering and podding of eight cowpea varieties

Source of Variation	Days to 50% flowering (DFF)	Days to 50% podding (DFP)
	Mean Squares (x 10^3)	
Location (Loc)	376.0416***	260.0416***
Year	108.3750***	37.5000**
Loc × Year	35.0416***	160.1666***
Residual (A)	2.0590	1.0381
Treatments	12.3750***	6.4940***
Loc × Trt	12.4226***	1.2083^{NS}
Year × Trt	5.1845***	0.9523^{NS}
Loc×Year×Trt	3.8511**	1.0476^{NS}
Residual (B)	0.8110	1.0059

NS = Not significant; * = $p<0.05$; **= $p<0.01$; *** = $p<0.001$

The days to 50% flowering of eight cowpea varieties in 2015 and 2016 seasons are presented in Table 4.2. Days to flowering showed highly significance differences in all the location and year. The combined analysis recorded a range of 40.00 to 48.33 days in 2015 and 41.00 to 44.00 days in 2016 at Mampong. The longest days to flowering in 2015 minor season was recorded by Soronko (48.33) while the shortest days to flowering was recorded by Videza (40.00) Table 4.2.

In 2016 major season, Tona took more days to get 50% of the crops flowering (44.00). The variety which took less days to get 50% flowering was Hewale (41.00) Table 4.2.

At Fumesua during the 2015 season, days to 50% flowering ranged from 38.00 to 42.67. Tona recorded the shortest days to 50% flowering at 38.00 with Asomdwee recording the highest at 42.67 (Table 4.2). During the 2016 major season, Hewale rather recorded the shortest days to 50% flowering at 37.67 while Asomdwee recorded the highest of 42.00 days to 50% flowering (Table 4.2).

The combined analysis showed a very highly significant difference in all the sources of variation. The location, year, location × year, treatment, location × treatment and year × treatment showed a very highly significant interaction at P<0.001 level. However, location × year × treatment was significant at P<0.01 level (Table 4.1).

The days to fifty percent podding (50% DDP) of eight cowpea varieties in 2015 and 2016 seasons is presented in Table 4.2. Varying differences were observed in days to 50% podding in the varieties and the years. At Mampong during the 2015 minor season, the days to 50% podding ranged between 50.00 to 53.00 days among the varieties. The longest days to 50% podding was recorded in Soronko (53.00) while the shortest days to 50% days to podding was recorded in Asontem with a value of 50.00 days (Table 4.2). During the 2016 major season, similar observations were observed between the varieties Asontem and Soronko recording highest and lowest but other varieties together with Asontem and Soronko recorded similar values (Table 4.2). The lowest varieties were Hewale and Asontem with 49.67 days. The longest days to 50% to podding were recorded in the Videza, Asetenapa and Soronko varieties; 51.00days (Table 4.2)

At Fumesua, during the 2015 minor season, days to 50% podding ranged between 44.00 to 47.67 days. The longest days to 50% podding was recorded in Asetenapa (47.67days) while Tona recorded the shortest days of 44.00. In 2016 major season, Asomdwee, Hewale and Asontem recorded the shortest days to 50% podding (49.00days). The longest days to 50% podding was recorded by Soronko at 51.00days (Table 4.2).

A combined analysis showed that a very highly significant interactions in location, year, location × year and treatment at $P<0.001$ while location × treatment, year × treatment and location × year × treatment were not significant.

Table 4.2: Days to 50% flowering and podding of eight cowpea varieties grown at Mampong and Fumesua in 2015 and 2016

Treatments	Days to 50% flowering				Days to 50% podding			
	Mampong		Fumesua		Mampong		Fumesua	
	2015	2016	2015	2016	2015	2016	2015	2016
Asomdwee	46.00	43.00	42.67	42.00	51.00	50.00	45.00	49.00
Hewale	45.33	41.00	39.00	37.67	51.67	49.67	44.67	49.00
Nhyira	46.67	41.33	40.00	39.33	52.00	50.00	46.00	49.67
Asontem	45.00	41.67	41.00	40.33	50.00	49.67	46.00	49.00
Soronko	48.33	42.67	40.67	39.67	53.00	51.00	47.33	51.00
Asetenapa	46.00	42.67	42.00	39.00	52.33	51.00	47.67	50.00
Tona	47.33	44.00	38.00	38.33	51.67	50.67	44.00	49.67
Videza	40.00	41.67	40.00	39.67	52.00	51.00	46.00	50.00
Loc		***	0.37			***	0.41	
Yr		***	0.41			***	0.41	
Loc × Yr		***	1.65			***	0.60	
Trt		***	0.74			***	0.82	
Loc × Trt		***	1.04			NS		
Yr × Trt		***	1.04			NS		
Loc×Yr×Trt		**	1.47			NS		
CV%		2.15				2.03		

NS = Not significant; * = p<0.05; **= p<0.01; *** = p<0.001, figures after the stars the lsd values for the combined analysis

4.2.3 Plant Height

Mean square estimates for the number of branches and plant height are presented in Table 4.3. No significantdifference were observed for all the source of variation for 30 DAP for number of branches. At 45 DAP Location, ($P<0.001$) year ($P<0.01$) and location × year ($P<0.05$) were significant. The rest of the sources of variation did not show any significant difference (Table 4.3). At 60 days after planting (DAP) sampling, the combined analysis showed that only the year showed highly significant difference (Table 4.3).

Mean square values for plant height at the various sampling periods showed varied significant differences throughout the growing period. Significant differences were observed at 30 DAP (Table 4.3). During the 45 DAP sampling period, a highly significant difference at ($P<0.001$) was observed for location only. Location x year did not show significant difference. However, year, treatments, location x treatment, year x treatment and location x year x treatment were all significant at $P<0.01$. At 60 days after planting (60 DAP), all the sources of variation showed a highly significant interaction at ($P<0.001$) with the exception of location x year which was not significant (Table 4.3).

Table 4.3: Mean Squares for number of branches and plant height of eight cowpea varieties

Source of Variation	Number of branches			Plant height		
	30DAP	45DAP	60DAP	30DAP	45DAP	60DAP
	Mean Squares (x 10^3)					
Location (Loc)	0.67502^{NS}	57.73752***	2.37510^{NS}	101.7022**	4231.937***	920.948***
Year	0.81585^{NS}	10.83398**	22.91260**	77.7420**	383.560**	1288.174***
Loc × Year	0.17085^{NS}	2.81877*	3.80010	1.8122^{NS}	5.796^{NS}	30.758^{NS}
Residual (A)	0.38219	0.48316	1.11335	7.9537	11.240	9.013
Treatments	0.48466^{NS}	1.12202	0.50063	28.0441***	81.420**	156.860***
Loc × Trt	1.03264^{NS}	1.20181	0.45718	63.8420***	67.518**	87.870***
Year × Trt	0.43824^{NS}	0.50446	0.26611	4.5152^{NS}	6.674**	12.388***
Loc×Year×Trt	0.21419^{NS}	0.19734	0.28694	5.6110^{NS}	9.829**	20.317***
Residual (B)	0.31379	0.3731	0.54853	4.265	2.759	1.535

Plant height of eight cowpea varieties in 2015 and 2016 seasons are presented in Figure 4. 2. Varying differences were observed in the plant height at both locations (Mampong and Fumesua) in the 2015 growing season. Generally, plant height of various varieties was high at Mampong than at Fumesua (Figures 4. 2a and b). At Mampong during 30 DAP, Asontem recorded the greatest plant height in 2015 growing season followed by Videza and Asomdwee with Tona recording the lowest (Figure 4. 2a). At 45 DAP, Videza recorded the greatest plant height followed by Nhyira and Asomdwee with Soronko having the lowest plant height. At the final sampling stage at 60 DAP, Hewale recorded the greatest plant height followed by Videza and Asomdwee. The lowest plant height was recorded by Tona (Figure 4. 2a).

At Fumesua during the 2015 growing season, Tona recorded the highest plant height followed by Asetenapa and Asontem 30 DAP. Nhyira however, recorded the lowest plant height (Figure 2b). At 45 DAP, Asontem recorded the highest plant height followed by Asomdwe and Videza while Nhyira had the lowest plant height (Figure 4. 2b). At 60 DAP, Asontem had the highest plant height followed by Asomdwe and Videza. Tona recorded the lowest plant height at 60 DAP at Fumesua in 2015.

Plant height in the 2016 major season at both locations was higher than the plant heights obtained in 2015 (Figures 4. 2 c and d).

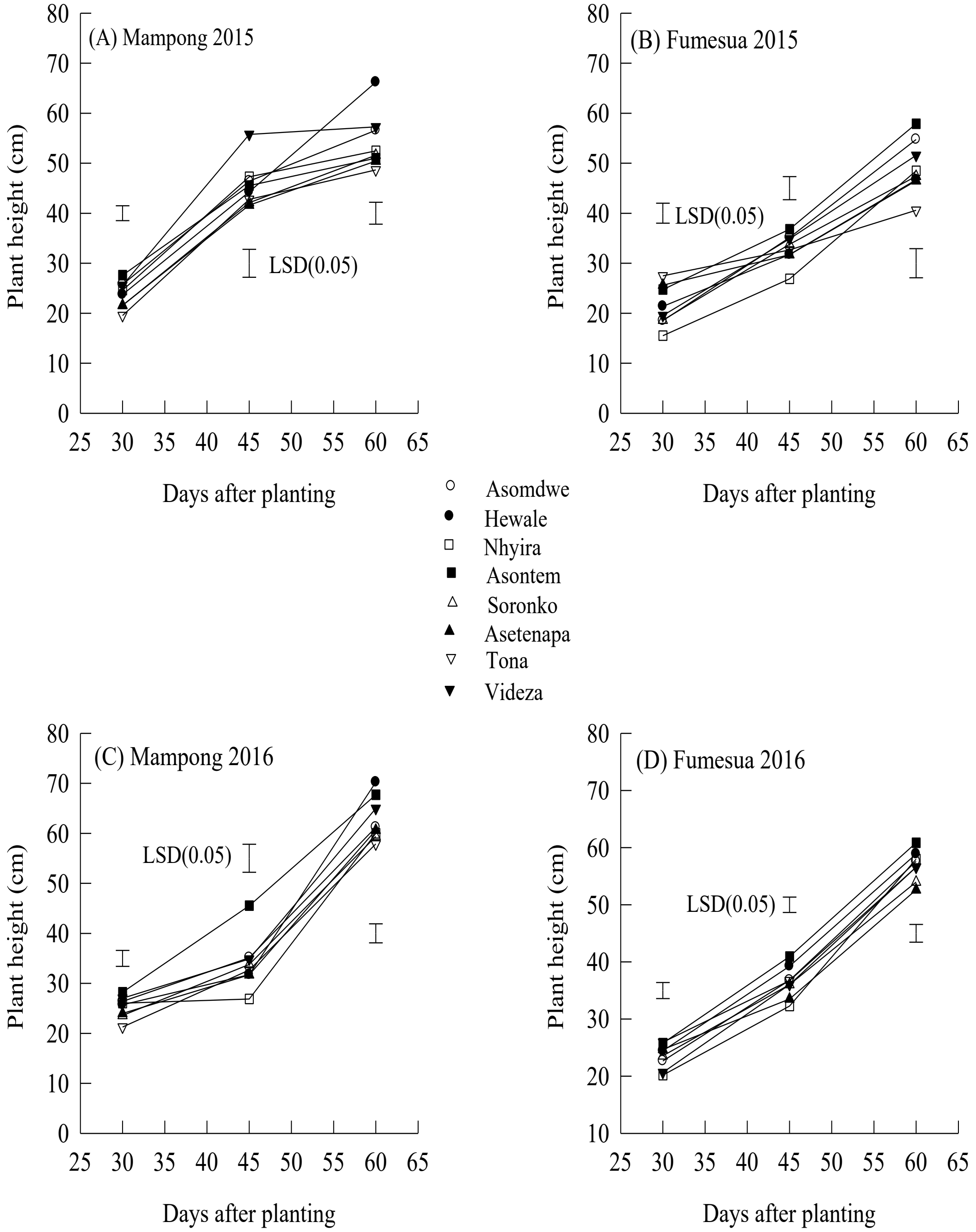


Figure 4.2: Plant height of eight cowpea varieties grown at Mampong-Ashanti and Fumesua in 2015 and 2016 growing seasons.

At Mampong during 30 DAP, Asontem recorded the highest plant height followed by Videza, Asomdwe and Nhyira, while Tona recorded the lowest plant height (Fig.4.2c). At 45 DAP, Asontem had the highest plant height among the rest of the varieties followed by Asomdwee, Hewale and Videza. Nhyira recorded the least plant height. At the last sampling stage (60 DAP), Hewale recorded the highest plant height followed by Asontem, Videza and Asomdwee. The lowest plant height was recorded by Tona (Fig. 4. 2 c). At Fumesua, during the 2016 major season, most of the varieties had heights close to each other at all the sampling periods (Fig.4.2 d). At 30 DAP, Asontem recorded the highest plant height followed by Asetenapa and Hewale with Nhyira recording the lowest plant height. At 45 DAP, similar trend continued, Asontem had the highest plant height followed by Hewale and Asomdwee. Nhyira again recorded the lowest plant height. At 60 DAP, Asontem continuously recorded the highest plant height followed by Hewale and Asomdwee, but interestingly, Asetenapa recorded the lowest plant height at the end of the sampling stage (Fig. 4.2 d).

4.2.4 Number of Branches per Plant

Number of branches per plant among cowpea varieties ranged from 1-6 in the 2015 minor season (Fig.4. 3).

At Mampong in the minor season, Asomdwe, Asontem, Soronko and Tona recorded the greatest number of branches at 30 DAP followed by Videza, with Hewale, Nhyira and Asetenapa recording lowest number of branches. At 45 DAP, these varieties recorded the greatest number of branches namely, Videza, Asetenapa and Asontem, followed by another four varieties with the same number of branches (Asomdwee, Hewale, Soronko and Tona) with Nhyira recording the smallest number of branches per plant (Fig. 4.3a). At 60 DAP, six varieties had equal number of branches as the highest number (Hewale, Nhyira, Asontem, Asetenapa, Tona and Videza) while Asomdwee and Videza recorded the smallest number.

During the minor season at Fumesua, at 30 DAP to 60 DAP, there were slight differences as observed at Mampong (Figs.4. 3a and b). At 30 DAP, Hewale recorded the greatest number of branches followed by three varieties namely Asomdwee, Tona and Videza, and other two varieties Nhyira and Soronko. However, Asontem and Asetenapa recorded the least number of branches. At 45 DAP, significant differences were observed among the eight varieties (Fig 3b). Asontem and Soronko had the greatest number of branches followed by three varieties namely Asomdwee, Hewale and Videza followed another two, Nhyira and Tona. However, the lowest number of branches was recorded by Asetenapa. During the final sampling stage (60 DAP), Videza recorded the greatest number of branches followed by six varieties having the same number of branches with Asontem recording the lowest (Fig.4.3b).

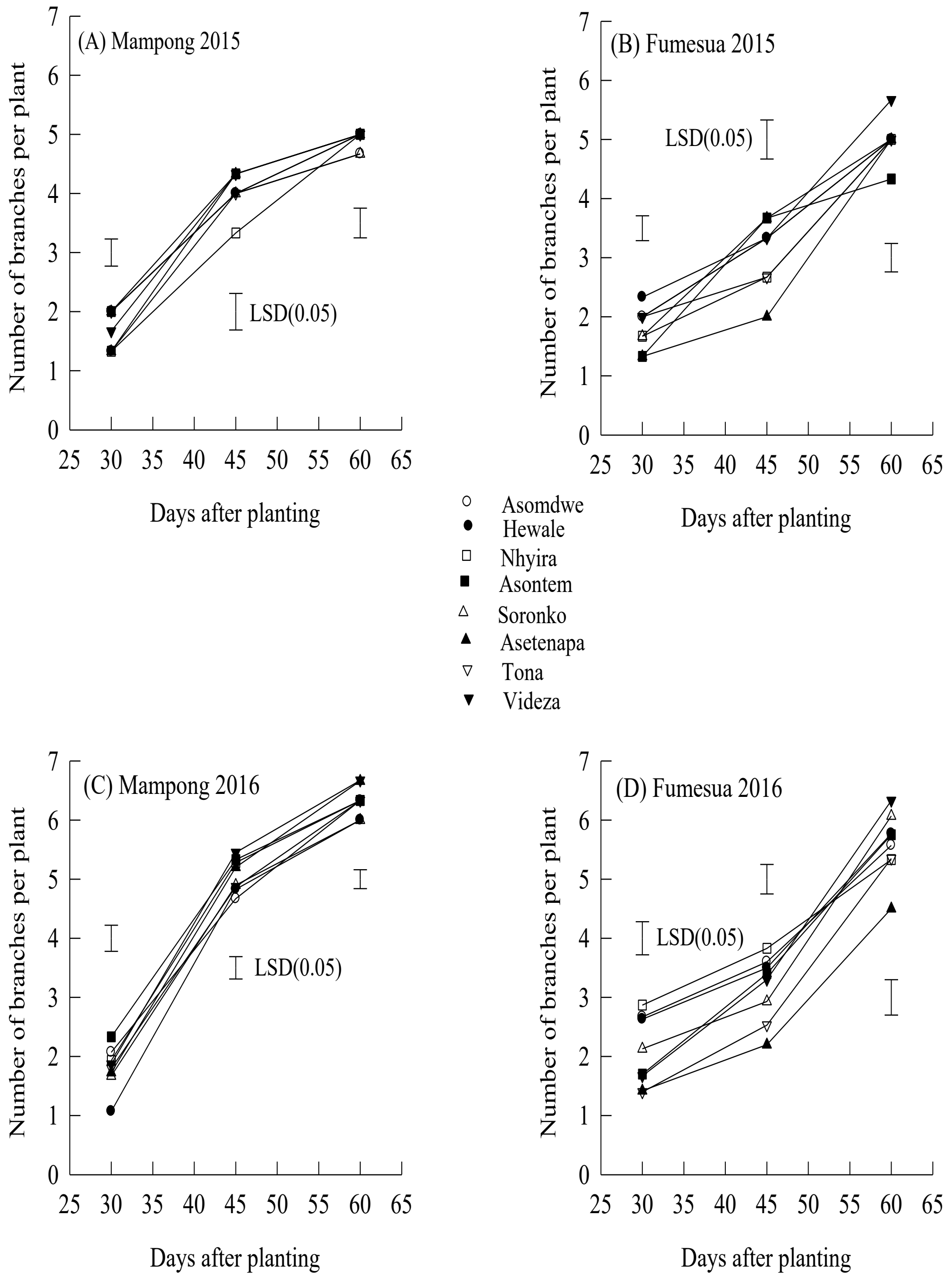


Figure 4.3: Number of Branches of Eight Cowpea Varieties Grown at Mampong and Fumesua in 2015 and 2016 growing seasons.

Generally, number of branches in the major season was higher than the minor season. Mampong recorded the greatest number of branches at the end of the last sampling stage during the growing period (Figs. 4. 3c and d).

During the 2016 major season at Mampong, Asontem recorded the greatest number of branches followed by Asomdwee and Nhyira with Hewale recording the lowest number at 30 DAP. At 45 DAP, Videza recorded the greatest number of branches followed by Asontem and Asetenapa. The lowest number of branches at 45 DAP was recorded by Asomdwee. At the final sampling stage (60 DAP), Videza had the greatest branches per plant followed by Asetenapa. Four varieties namely Asomdwe, Nhyira, Asontem and Tona had the same number of branches with Soronko and Hewale recording the lowest number of branches at the end of the sampling period (Fig. 4. 3c).

In 2016 major season, Fumesua recorded the greatest number of branches among all the varieties than Mampong (Fig.4. 3d). At 30 DAP, the trend at Mampong was not the same as at Fumesua in terms of the varieties. Nhyira had the greatest number of branches followed by Asomdwee and Hewale with Tona recording the lowest. At 45 DAP, similar trend were observed as Nhyira had the greatest number of branches followed by Asomdwee and Hewale whilst Asetenapa recorded the lowest number (Fig. 4. 3d). During the last sampling period (60 DAP), Videza recorded the greatest number of branches followed by Soronko, whilst Asetenapa rather recorded the lowest number (Fig.4.3).

There was no significant interaction at the beginning of the sampling period (30 DAP). However, year, location was highly significant with location × year, location × treatment, year × treatment, and location × year × treatment did not also show any significant difference at 45 DAP. At 60 DAP, only the year was highly significant with the rest of the sources showing no significant interaction (Table 4.3).

4.2.5 Leaf Area and Leaf Area Index

Mean square estimates for leaf area and leaf area index are represented in Table 4.4. The treatments for all the sources of variation varied across the sampling periods throughout the growing period.

Leaf area (LA) for 30 DAP showed a highly significant difference at ($P<0.001$) for location, year and treatments. Location x treatment was significant at ($P<0.05$). However, location x year, year x treatment and location x year x treatment were not significant at the first sampling stage. At 45 DAP sampling period, sources of variation which showed highly significant difference at ($P<0.001$) were location, year and treatments only. During the 60 DAP sampling stage, a highly significant difference at $P<0.001$ were observed for location, year and treatments. The other sources of variation were not significant.

Leaf area index (LAI) followed similar trend in terms of the source of variation as observed in the leaf area (LA), (Table 4.4). At the first sampling stage (30 DAP) a highly significant difference at ($P<0.001$) for location, year and treatments, all others were not significant. At 45 DAP and 60 DAP sampling periods, all interactions involving treatments were not significant. Also, location by year interaction was not significant. All other sources of variation were not significant.

Table 4.4: Mean Square values for leaf area and leaf area index of eight cowpea varieties

Source	Leaf Area (LA)			Leaf Area Index (LAI)		
of Variation	30DAP	45DAP	60DAP	30DAP	45DAP	60DAP
	Mean Squares (x 10^{3})					
Location (Loc)	660.922***	1423.95***	3395.90***	0.44417***	0.81585***	1.77670***
Year	318.390***	321.67***	635.56***	0.10600***	0.13127***	0.31740*
Loc × Year	0.047^{NS}	1.12^{NS}	2.09^{NS}	0.00650^{NS}	0.00065^{NS}	0.00041^{NS}
Residual (A)	13.071	2.65	4.23	0.00122	0.0017	0.00224
Treatments	8681.374***	3068.97***	6279.67***	0.54436***	1.49200***	3.21112***
Loc × Trt	626.429*	75.81^{NS}	71.75^{NS}	0.01880^{NS}	0.02300^{NS}	0.03459^{NS}
Year × Trt	30.889^{NS}	2.67^{NS}	7.96^{NS}	0.01376^{NS}	0.00468^{NS}	0.00506^{NS}
Loc×Year×Trt	1.625^{NS}	0.84^{NS}	10.23^{NS}	0.00936^{NS}	0.00315^{NS}	0.00504^{NS}
Residual (B)	24.60	86.82087	137.63	0.01287	0.04474	0.07063

NS = Not significant; * = $p<0.05$; **= $p<0.01$; *** = $p<0.001$

The results of leaf area of eight cowpea varieties in 2015 and 2016 growing season are presented in Figure 4. 4. Differences in leaf area were recorded among the varieties at different locations between 30 and 60 DAP.

During the 2015 minor season at Mampong, there was a sharp significant difference between Asontem and the rest of the varieties from 30 DAP to 60 DAP. Asontem recorded the lowest LA during the sampling periods. Soronko recorded the greatest leaf area followed by Tona (Figure 4.4). In the 2016 major season, similar results were obtained in Mampong, where Soronko and Tona recorded the highest leaf area with Asontem recording the lowest leaf area. Generally, the leaf area of the cowpea varieties for 2016 was higher than in 2015 at Mampong (Figure 4.4c).

Similar observations were observed at Fumesua in the two growing seasons between the sampling periods as in Mampong among the genotypes. Asontem recorded the lowest leaf area in all the sampling periods (Figure 4.4b and d). Soronko had the highest leaf area during the sampling period of 30-60 DAP. At Fumesua, the leaf area of all the varieties was generally higher.

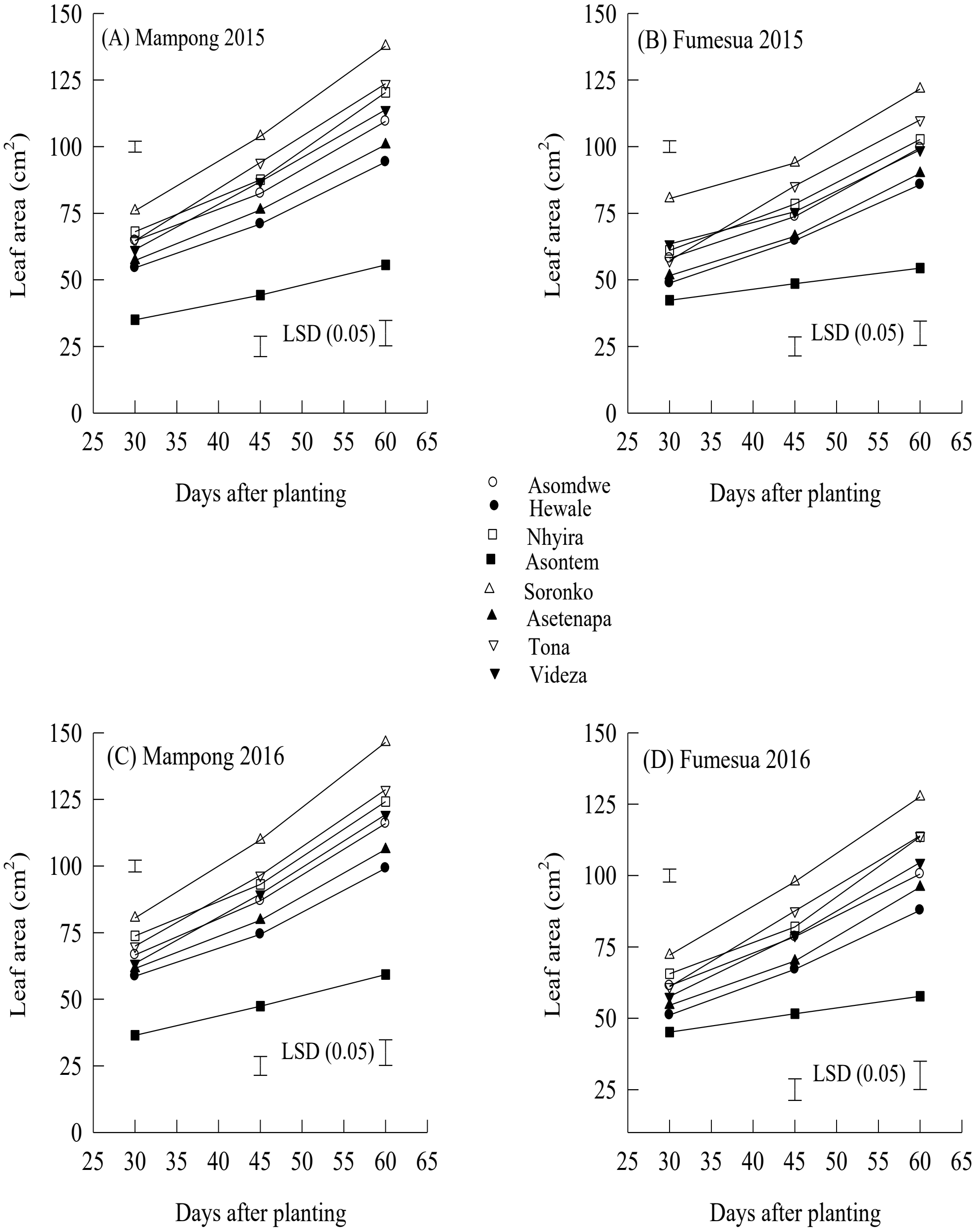


Figure 4.4: Leaf Area (cm^2) of Eight Cowpea Varieties Grown at Mampong-Ashanti and Fumesua in 2015 And 2016 Growing Seasons.

The pattern of LAI at Mampong and Fumesua is shown in Figure 4.5 over the two locations and the seasons. The trend of the leaf area index (LAI) followed the trends of leaf area in the genotypes for both locations and both seasons.

At Mampong during the 2015 minor season, Soronko recorded the highest mean leaf area index of 3.2 where as Asontem had the least LAI (1.2) (Figure 4.5a). In 2016 major season, similar trend were observed. Soronko had the highest leaf area index of 1.9, 2.5 and 3.4 from 30 to 60 days after planting, where as Asontem recorded the least LAI (0.9, 1.0 and 1.2) (Figure 4.5c).

Similar pattern were observed in Fumesua during the sampling periods, except in 2016 major season where there was a sharp deviation for Asontem and Hewale (Figure 4.5d). During the 2015 minor season, the highest mean leaf area index was recorded by Soronko from 30 DAP to 60 DAP with Asontem recording the lowest through out the sampling periods (1.8, 2.2 and 2.7; 0.9, 1.0 and 1.1 respectively). Significant differences were observed at 30 days after planting through to 60 days after planting among the varieties. In 2016 major season, Soronko showed superiority from 30 DAP to 60 DAP (Fig. 4.5d). At 45 DAP, sharp differences were observed among the varieties. There was a sharp decline in LAI for Asontem (2.1 to 1.3) and Hewale (1.4 to 1.25) from 45 DAP to 60 DAP, both varieties did not show any significance difference at 60 DAP. However, the rest of the varieties recorded significant differences throughout the sampling periods (Figure 4.5d).

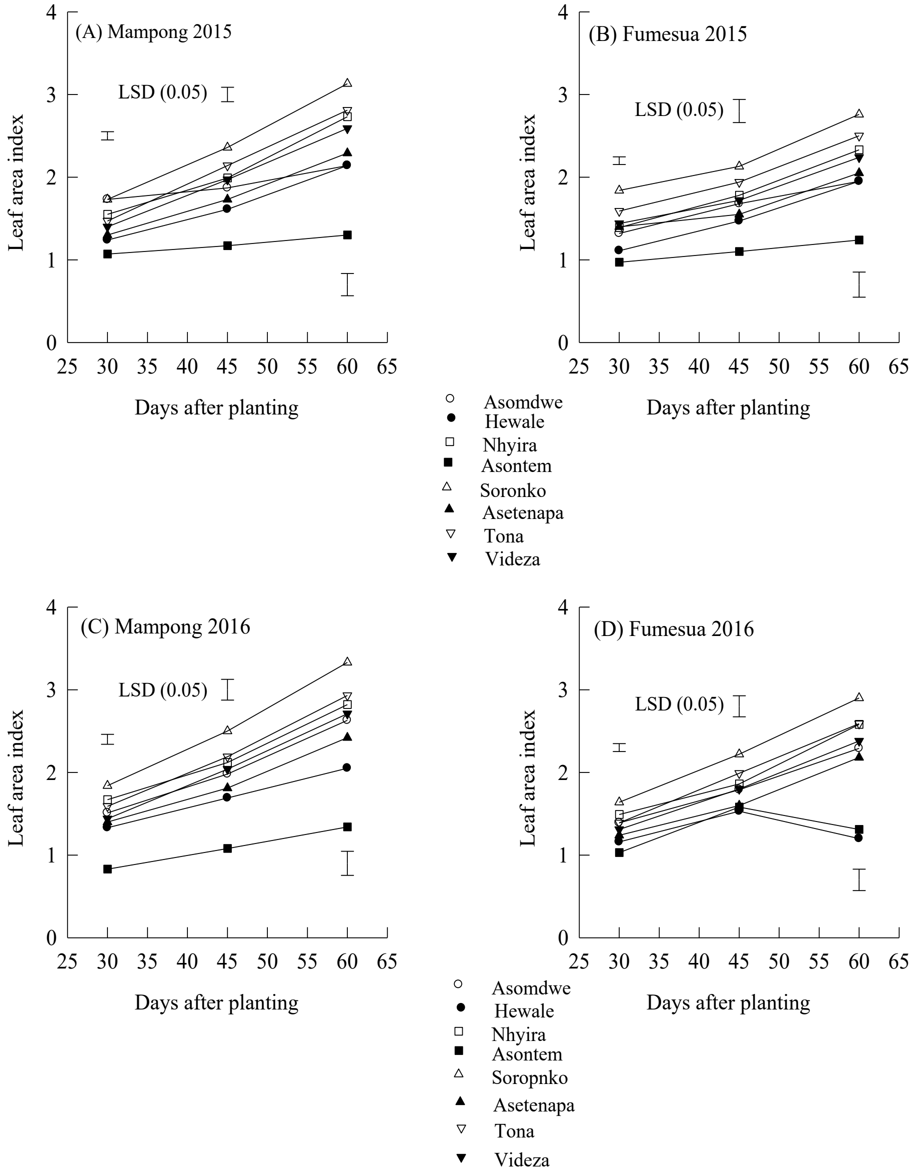


Figure 4.5: Leaf Area index of eight Cowpea Varieties Grown at Mampong- Ashanti and Fumesua in 2015 And 2016 Growing Seasons.

4.2.6 Growth Analysis

The combined analysis of mean squares for growth analysis varied among the varieties at various stages of sampling periods (Table 4.5).

Mean square for crop growth rate (CGR) recorded highly significant difference (P<0.001) for location between 30-45 DAP sampling interval, (P<0.01) for year and P<0.05 for year × treatment. Location x year, location × treatment and location x year × treatment were not significant. During the last sampling interval, changes were observed compared to the first sampling periods. A highly significant difference were observed for location, year x treatment and location x year x treatment at P<0.001. Year had highly significant difference at P<0.01, while location x year and location x treatment were significant at P<0.05. Treatment however, was not significant during the last sampling interval (45-60 DAP).

The net assimilation rate (NAR) of the combined analysis mean square had varied differences in the entire sampling period throughout the growing season (Table4.5). A highly significant difference (P<0.001) was observed for treatment at the 30 and 45 DAP sampling periods. Significant difference was observed for year at P<0.05 at 30 and 45 sampling interval. However, location, location × year, location × treatment, year x treatment and location × year x treatment did not show any significant differences at 30 and 45 DAP. During the 45-60 DAP sampling interval, location was highly significant (P<0.01). Treatment and location × treatment was highly significant at P<0.001. Year × treatment was significant at P<0.05. However, year, location × year and location x year x treatment was not significant from 45 to 60 DAP sampling intervals (Table 4.5).

The combined analysis for RGR showed that at the first two sampling periods (30-45 DAP), treatments, location × treatment, year × treatment and location × year × treatment was significant at $P<0.05$. However, location, year and location x year were not significant (Table 4.5).

At the second and the last sampling period (45-60 DAP), significant effects were observed for relative growth rate (RGR) for all the sources of variation at different levels. Location, year, location × year and location × treatment were highly significant ($P<0.001$), while treatments, year× treatment and location × year × treatment were significant at $P<0.05$ till the end of the growing period; 60 DAP (Table4.5).

Table 4.5: Mean Square values for growth analysis of eight cowpea varieties

Source of Variation	Crop Growth Rate (CGR) g m^{-2} day^{-1}		Net Assimilation Rate (NAR) g g^{-1} day^{-1}		Relative Growth Rate RGR) g m^{-2} day^{-1}	
	30-45 DAP	45-60 DAP	30-45 DAP	45-60 DAP	30-45 DAP	45-60 DAP
	Mean Squares (x 10^{3})					
Location (Loc)	8.10262***	5.33926***	0.60325^{NS}	4.28415**	0.00399^{NS}	0.00050***
Year	1.75230**	0.95600**	1.72002*	0.100010^{NS}	0.01714^{NS}	0.00287***
Loc × Year	0.30038^{NS}	0.25833*	0.16088^{NS}	0.00070^{NS}	0.00249^{NS}	0.00157***
Residual (A)	0.19146	0.03705	0.21291	0.07088	0.00329	0.00040
Treatments (Trt)	0.53349^{NS}	0.32723^{NS}	1.33307***	1.41927***	0.00415*	0.00014*
Loc × Trt	0.56531^{NS}	0.42356*	0.42749^{NS}	0.39753***	0.00582*	0.00024***
Year × Trt	0.78404*	0.76324***	0.21806^{NS}	0.13872*	0.00532*	0.00014*
Loc×Year×Trt	0.61891^{NS}	0.75550***	0.23658^{NS}	0.11485^{NS}	0.00478*	0.00014*
Residual (B)	0.29898	0.10846	0.021230	0.05769	0.00160	0.00004

NS = Not significant; * = $p<0.05$; **= $p<0.01$; *** = $p<0.001$,

4.2.7 Crop Growth Rate (CGR)

The results of the combined analysis of crop growth rate (CGR) of eight varieties of cowpea, location and season are shown in Figure 4.6. Differences in crop growth rate occurred at different sampling periods. Generally, crop growth rate showed a significant difference between Mampong and Fumesua at 45-60 days after planting in both seasons.

A highly significant interactions were observed at the 30-45 DAP in both location ($P<0.001$) and significant at $P<0.05$ for year. However, location × year, treatment, location × treatment, year × treatment and location × year × treatment interactions were not significant. During the 45-60 DAP sampling period, very highly significant interactions were observed at $P<0.001$ level for location, year × treatment and location × year × treatment. Interactions for year, treatment and location × treatment were significant at $P<0.05$ level. However, only location × year was not significant (Figure 4.6).

At Mampong during the 2015 minor season, Hewale (3.3) recorded the highest crop growth rate at 30-45 DAP followed by Asontem (3.1) and Asetenapa (3.0). The lowest among these eight varieties was recorded by Nhyira (1.6).

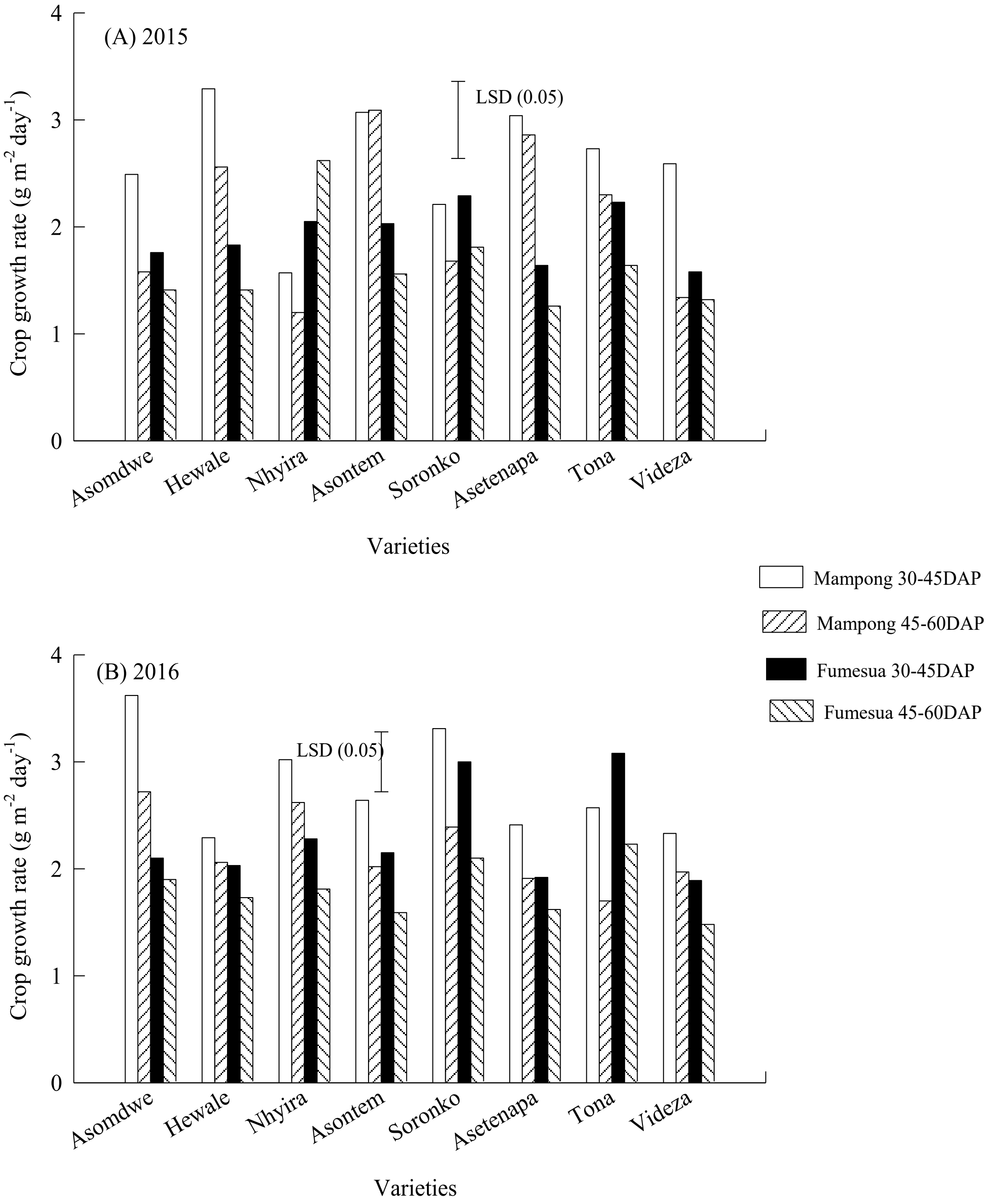


Figure 4.6: Crop Growth Rate (CGR) of Eight Cowpea Varieties Grown at Mampong-Ashanti And Fumesua in 2015 And 2016.

The pattern changed from the figures recorded in 2015 minor season compared with the 2016 major season. The varieties Asontem, Asetenapa, Hewale and Tona recorded the highest crop growth rate of 3.2, 2.8, 2.6 and 2.4 respectively in 2015. The lowest crop growth rate was recorded by Nhyira and Videza (1.20) in the 45-60 DAP sampling period. There was a decline from the initial sampling period (30-45 DAP) to the final sampling period (45-60 DAP) (Fig. 4.6 a). It was also observed that Asontem narrowly increased the crop growth rate from first sampling period to the last sampling period (3.1 to 3.2) in 2015.

During the 2016 major season at Mampong, significant increases were observed among the eight varieties. Asomdwee had the highest crop growth rate (3.6) followed by Soronko (3.3) and Nhyira (3.0) in the first sampling period. During the second sampling period (45-60 DAP), there were significant differences among the varieties. The highest crop growth rate was recorded by Asomdwee (2.7) followed by Nhyira (2.6) and Soronko (2.3) in that order. The lowest crop growth rate in the second sampling period was recorded by Tona (1.70), (Fig. 4.6 b).

At Fumesua, during the 2015 minor season, the pattern of the crop growth rate did not follow the trend of what was observed in Mampong during the sampling periods among the eight varieties. Soronko recorded the highest value of crop growth rate (2.3) followed by Tona, Nhyira and Asontem (2.2, 2.2 and 2.0) respectively in the first sampling date. During the second sampling period (45-60 DAP), all the eight varieties except Asontem had a lower crop growth rate than during the 30-45 DAP (Fig. 4.6 b). The highest crop growth rate was recorded by Nhyira (2.6) followed by Soronko (1.8), Tona (1.6) and Asontem (1.5) in the 45-60 DAP (Fig. 4.6 b). The lowest value was however recorded by Asetenapa (1.1).

During the 2016 major season at Fumesua at the 30-45 DAP sampling period, Tona had the highest crop growth rate of 3.2 followed by Soronko with a value of 3.0. Four varieties recorded appreciable values in a range of 2.03 to 2.28 (Hewale, Asomdwee, Asontem and Nyhira) during the first sampling period (Fig. 4.6 b). The lowest crop growth rate was recorded by Videza (1.7). At 45-60 DAP sampling period in the major season, there was a slower growth of the varieties by recording generally low values as compared to the 30-45 DAP sampling period. Tona had the highest CGR value of 2.23 followed by Soronko (2.2) and Asomdwee (1.90). The lowest value was recorded by Videza with a value of 1.5 growth rate (Fig. 4.6 b).

4.2.8 Relative Growth Rate (RGR)

The combined effect of varietal influence on relative growth rate is presented in Figure 4.7. Relative growth rate (RGR) differed with varieties during the sampling periods at various location and year at the sampling intervals (30-45 DAP and 45-60 DAP). Generally, there were fluctuations in the figures recorded during sampling periods from 30-45 DAP to 45-60 DAP based on varietal differences. Some varieties maintained their relative growth rate between two sampling intervals, other varieties also increased the value of RGR from 30-45 DAP to 45-60 DAP while others also showed a decrease RGR from 30-45 DAP to 45-60 DAP.

At Mampong during the 2015 minor season, fluctuations were clearly observed between the sampling periods. Varieties such as Videza, Soronko, Hewale, Asomdwe and Asontem (0.41, 0.38, 0.26, 0.25 and 0.18) had all their RGR decresed from initial sampling stage to final sampling period (0.013, 0.012, 0.022, 0.016, and 0.012). Nhyira and Asetenapa however continued to increase from first sampling periods to the final sampling stage (Fig.4.7 a). Interestingly, the interval for 30-45 DAP and 45-60 DAP saw Tona having same RGR value. In 2016 major growing season, Hewale had same value as observed by Tona (0.013) in the 2015 (Fig. 4.7 b). However, Asomdwee, Nhyira, Asontem had values increased from first sampling period to the end of the growing period (60 DAP). But Soronko, Asetenapa, Tona and Videza initially had high RGR but was reduced at the end of the growing period (Fig. 4.7 a).

In 2015, Videza and Soronko recorded the highest values (0.041, 0.038) for RGR while Tona (0.012) recorded the lowest at 30-45 DAP in Mampong.

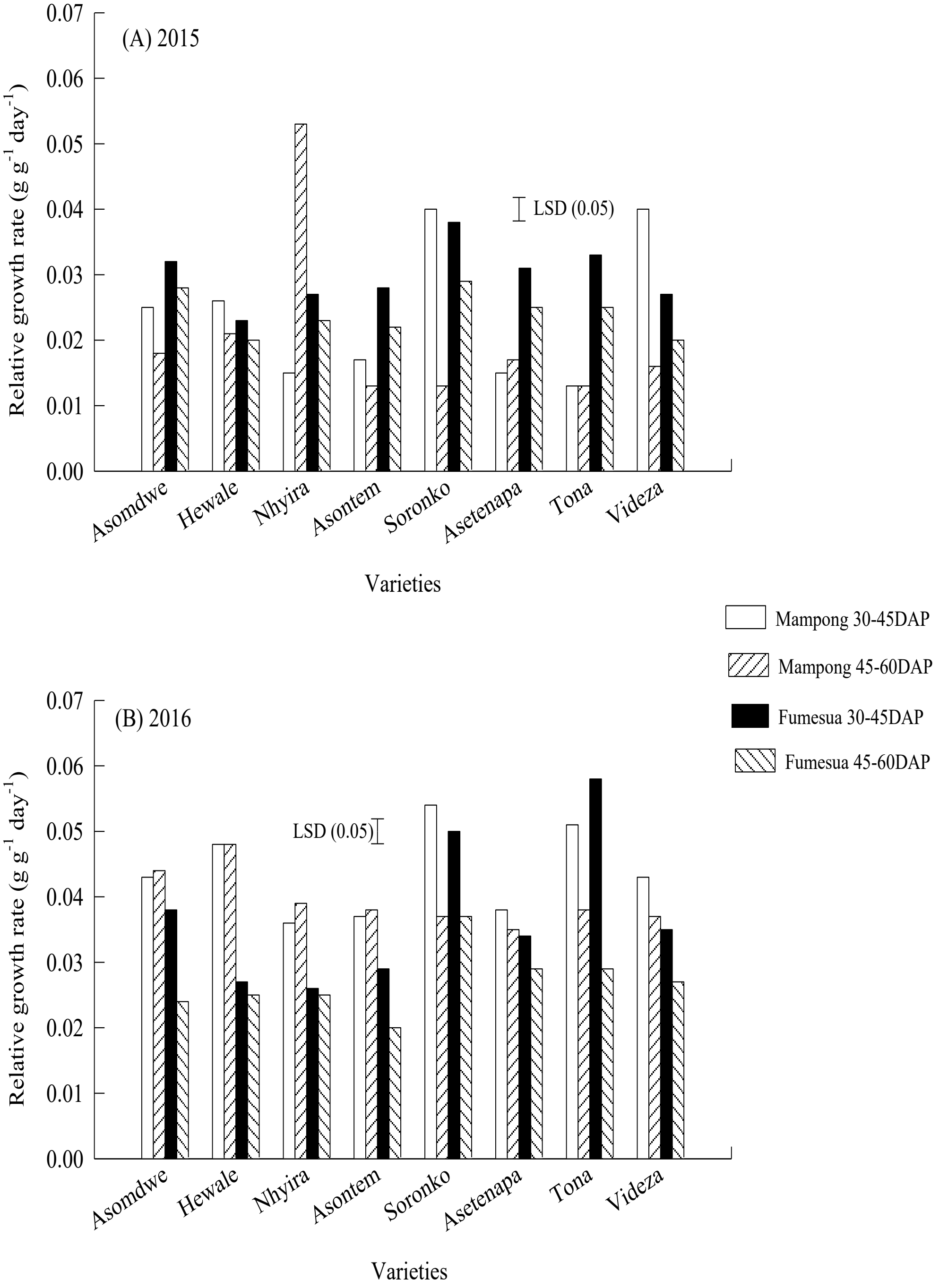


Figure 4.7: Relative Growth Rate (RGR) of Eight Cowpea Varieties Grown at Mampong-Ashanti And Fumesua in 2015 And 2016.

At 45-60 DAP, Nhyira (0.052) had the highest RGR followed by Hewale while Asontem, Soronko, and Tona recorded the lowest (Fig. 4.7 a). During 2016, Soronko (0.057) recorded the highest RGR with Asetenapa (0.032) recording the lowest among the varieties at the first sampling period (30-45 DAP). However, at the last sampling interval (45-60 DAP), Hewale had the highest RGR (0.048). Asontem and Tona had same values (0.038) while Soronnko and Videza also had the same values (0.037) of RGR (Fig. 4.7 b). The lowest value was recorded by Asetenapa (0.032).

At Fumesua in the 2015 minor season, location influencedRGR by increasing from 30-45 DAP and later declined at45-60 DAP (Fig. 4.7). A similar trend was observed during the 2016 major season though Nhyira had marginal decrease (0.026 to 0.025). In terms of high and lower values of RGR for Fumesua, Soronko (0.038) had the highest with Hewale (0.023) recording the lowest in 2015 at (30-45 DAP) sampling period. At the final sampling stage (45-60 DAP), Soronko (0.028) again recorded the highest followed by Asomdwee (0.028). Asetenapa and Tona recorded same value (0.025) with Hewale having the lowest (0.020) RGR. During the 2016 major season, at 45-60 DAP, Soronko (0.037) was high with Asontem (0.020) having the lowest (Fig. 4.7 b).

4.2.9 Net Assimilation Rate (NAR)

Mean net assimilation rate of eight cowpea varieties is presented in Figure 4. 8. Mean net assimilation rate at both locations and years varied among varieties throughout the sampling periods.

At Mampong in the 2015 minor season, some of the genotypes recorded similar values for net assimilation rate at first sampling stage (30-45 DAP).

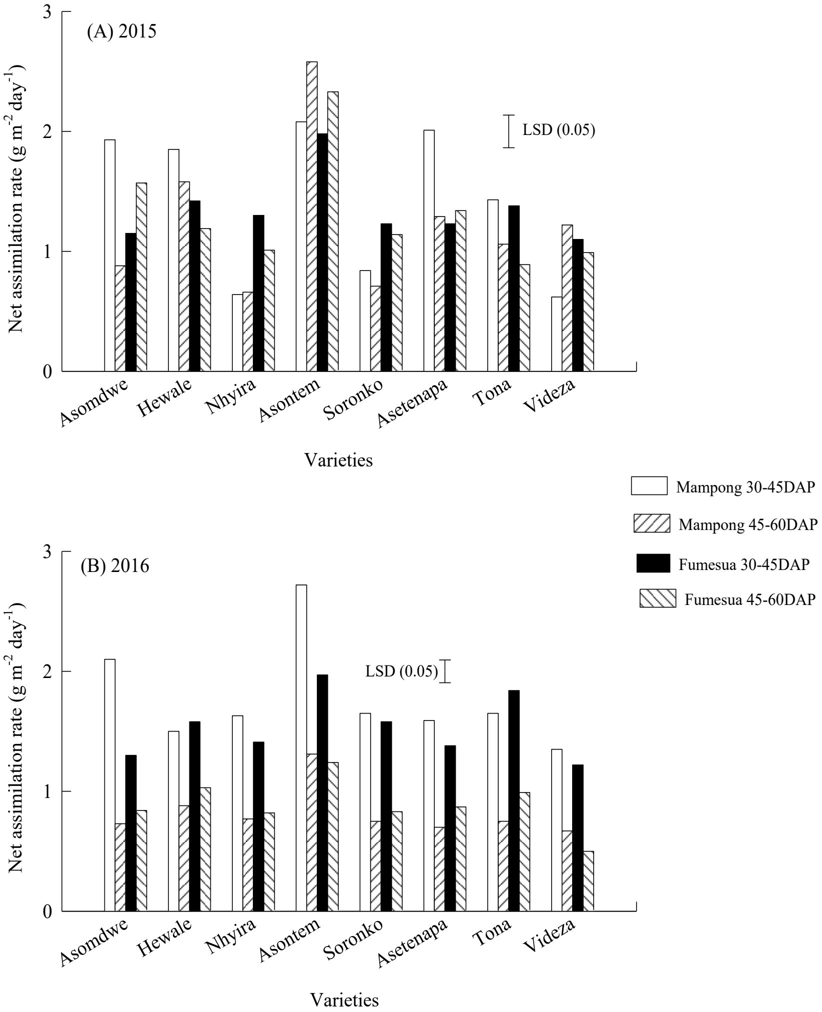


Figure 4.8: Net Assimilation Rate (NAR) af Eight Cowpea Varieties Grown at Mampong-Ashanti And Fumesua in 2015 And 2016.

Asontem (2.200) recorded the highest NAR followed by Asetenapa (2.100), Asomdwee (1.900) and Hewale (1.800) with Videza recording the lowest (0.600) NAR (Fig. 4.8 a). In 2016 major season, Asontem continued to record the highest (2.600) value by showing greater NAR among the rest of the genotypes at 30-45 DAP. Asomdwee recorded the second highest (2.100) NAR which did not follow the trend in the first sampling stage. However, the lowest NAR was recorded by Videza (0.600) (Fig. 4.8 b). The NAR across location, year, and year × location were not significant at the first sampling period. Treatment was however very highly significant at $p<0.001$ level. Location × treatment, year × treatment and location ×year × treatment interactions were not significant (Fig. 4.8 b).

At Fumesua, for the 30-45 DAP sampling interval in the 2015 minor season, some varieties were superior in Mampong. However, there were fluctuations in terms of net assimilation rate (NAR) in both locations. As observed at Mampong in the 2015 during the sampling period at 30-45 DAP, Asontem recorded the highest (2.000) NAR followed by Hewale (1.550) and Tona (1.500). Videza recorded the lowest (1.150) NAR value (Fig. 4.8 a). At the last sampling period (45-60 DAP), Asontem recorded 2.300 for highest NAR, followed by Asomdwee, (1.700), Hewale (1.650), and Asetenapa (1.400) with Tona (0.900) recording the lowest value for NAR.

During the 2016 major season, at 30-45 DAP, similar trends were observed compared to the 2015 minor season in terms of genotypes. Asontem (1.980) again recorded the highest NAR value but was followed by Asomdwee (Tona 1.800). As observed in 2015 minor season, Videza (1.400) again had the lowest value for NAR (Fig. 4.8 b).

Mean net assimilation rate at 45-60 DAP generally showed fluctuations in the last sampling period at both locations from the first sampling stage. During the 2015 minor season at the last sampling period (45-60 DAP), Asontem recorded the highest value of NAR which was followed by Hewale and Asetenapa, with Nhyira recording the lowest in Mampong. At the same sampling interval during the 2016 major season, similar trend was observed with Asontem recording the highest value. Asomdwee recorded the second highest value followed by Nhyira, Tona, Soronko and Asomdwee in that other with Videza recording the lowest value at Mampong at 45-60 DAP (Fig 4.8 b).

At Fumesua, in 2015 minor season, the highest net assimilation rate was recorded by Asontem (1.950) genotype followed by Asomdwee, Asetenapa, Hewale and Soronko. However, Tona recorded the lowest at 45-60 DAP (Fig. 4.8 a). Similarly, in 2016 major season, Asontem was high in terms of net assimilation rate among all other genotype followed by Hewale and Tona. Videza however had the lowest net assimilation rate value.

Based on the results recorded at 45-60 DAP, there were significant interactions. Significant interactions were observed based on the locations environment and genotype. Location was very highly significant ($P<0.001$), treatment, location × treatment were also very highly significant. Year × treatment was significant ($P<0.05$). However, year, location × year and location × year × treatment was not significant during the 45-60 DAP sampling interval.

Generally, there were fluctuations in the net assimilation rates during the sampling intervals. Some varieties were high in 2015 during the sampling period (30-45 DAP), but was reduced during 2015 (45-60 DAP) sampling interval. In other instance some genotypes were low during the 30-45 DAP sampling interval but were increased during the 45-60 DAP sampling interval. For instance, Asontem, Nhyira and Videza were low and increased at the last sampling period. Varieties such as Asomdwee, Hewale, Soronko, Asetenapa and Tona was high at 30-45 DAP but were low during the 45-60 DAP at Mampong (Fig 4.8).

Various genotypes also experienced such fluctuations in 2016 in Mampong major season as well. At Fumesua, such fluctuations were evident in both seasons for the genotypes under study (Fig 4.8).

4.2.10 Nodulation

Mean square of nodulation of eight cowpea varieties is presented in Table 4.6.

Nodule numbers at various stages of sampling showed highly significant differences and non-significant differences throughout the growing period for active and non-active nodules as well.

For nodule number at 30 DAP, a very highly significant (P<.001) difference was observed for treatment and location x treatment. A very high significant difference (P<0.001) was also observed for location and year. However, location × year, year × treatment and location × year × treatment did not show any significant difference among the sources of variation (Table 4.6).

At 45 DAP sampling period, all the sources of variation were very highly significant ($P<0.001$) however, during the final sampling stage (60 DAP), location and location x year were not significant (Table 4.6).

Location × year × treatment recorded high significant ($P< 0.01$) difference. The rest of the sources of variation recorded very highly significance ($P<0.001$) difference at the last sampling stage (60 DAP) (Table 4.6).

For active nodules at 30 DAP, location x year and location x year x treatment did not show any significant difference. The rest of the sources of variation recorded a very highly significant ($P<0.001$) except year x treatment which showed significant ($P<0.05$) difference. During the 45 DAP, all the sources of variation of active nodules were very highly significant ($P<0.001$) with the exception of location x year which was not significant (Table 4.6). At the end of the sampling period (60 DAP), all the sources of variation were very highly significant ($P<0.001$) (Table 4.9).

For non-active nodules, the 30 DAP stage was very highly significant ($P<0.001$) for treatment, location × treatment and year x treatment. Location and location × year × treatment were not significant. However, year and location × year did not show any significant difference. At the end of the growing period (60 DAP), year and year × treatment showed a very highly significant ($P<0.001$) difference and location x treatment was also significant ($P<0.01$). Treatments and location x year were significant ($P< 0.05$) however, location and location x year x treatment were not significant (Table 4.9).

Table 4.6: Mean Square values for nodulation of eight cowpea varieties

Source	Nodule number			Active nodules			Non-active nodules		
of	30	45	60	30	45	60	30	45	60
Varaition				Mean Squares (x 10^3)					
Location	481.5104**	1372.593***	88.1666	463.7604***	1046.760***	108.3750***	0.37500^{NS}	22.041^{NS}	2.0416^{NS}
Year	326.3437**	195.510***	748.1666***	263.3437**	311.760***	280.1666***	5.04166*	13.500^{NS}	117.0416***
Loc × Year	0.0937^{NS}	61.760***	30.3750^{NS}	5.5104^{NS}	31.510^{NS}	66.6666***	5.04166*	5.041^{NS}	4.1666*^{NS}
Residual (A)	7.2326	9.017	8.0173	4.0694	6.364	4.0694	1.76736	2.934	0.9479
Treatments	88.8437***	111.403***	49.6607***	46.1889***	782.367***	36.5178***	9.20833***	130.952***	2.0476*
Loc × Trt	33.8675***	1151.950***	23.1666***	22.4747***	419.474***	18.3273***	5.92261***	339.303***	3.0654**
Year × Trt	4.748	29.867***	27.7857***	4.5818*	32.760***	15.7380***	3.39880***	18.333***	4.4940***
Loc×Year×Trt	1.9270	40.736***	10.5654**	2.8913	43.462***	11.8571***	0.35119^{NS}	37.970***	2.3809
Residual (B)	1.578	3.50	2.571	1.784	3.98	1.851	0.4389	2.903	0.8095

NS = Not significant; * = $p<0.05$; **= $p<0.01$; *** = $p<0.001$

Mean number of nodules for combined analysis for 30 DAP is shown in Table 4.7. Nodule count at Mampong during the 30 DAP ranged from 10.00 to 19.00 in 2015 and 13 to 21.67 during the 2016 cropping season. Videza recorded the greatest nodule number (19.00) followed by Asetenapa (18.00) with Nhyira recording the lowest (10.00) in the 2015 minor season. In 2016 major season, Soronko produced the greatest nodule number followed by Videza (20. 33). Nhyira again recorded the lowest nodule number of 13.00 (Table 4.7). For active nodules, Videza recorded the highest (13.00) followed by Asetenapa (12.67) with Nhyira having the lowest (6.33) in 2015 minor season. In 2016 major season, Soronko produced the highest effective nodule number (16.67). Videza, Asetenapa and Hewale recorded equal number of effective nodule (16.33). The lowest again was recorded by Nhyira (9.33). Similar observation were observed for these varieties on the non-active nodule number (Table 4.7).

At Fumesua during the 2015 minor, similar trends were observed for number of nodules as Videza recorded the highest (17.00) with Soronko recording the lowest (7.33). During 2016 major season, Videza again had the highest nodule number of 20.00 followed by Asontem while Nhyira Soronko had the lowest nodule number of 10.00 (Table 4.7). Active nodule nodule number followed different trend for the varieties especially during the 2016 growing season (Table 4.7). In 2016, Asontem, Tona and Videza had same active number of nodules compared with 2015 where Videza only had the highest active nodule number. Varied differences were observed for the non-active nodules number. In terms of interaction, the combined analysis revealed that there were a very highly significant (P<0.001) difference between location, year, treatment and location x treatment for both nodule number and active nodule number. Location × year, year × treatment and location × year × treatment were also not significant for both nodule number and active nodule number. However, location and location × year × treatment were not significant for non-active nodule number but the rest of the sources of variation showed a highly significant ($P<0.001$) and significant ($P<0.05$) levels.

Table 4.7: Nodule number, active and non-active nodules at 30 after planting of eight cowpea varieties in 2015 and 2016

Treatments	Nodule number (30 DAP)				Active nodule number (30 DAP)				Non-active nodule number (30 DAP)			
	Mampong		Fumesua		Mampong		Fumesua		Mampong		Fumesua	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
Asomdwee	16.00	20.00	13.33	16.33	11.00	13.67	9.67	10.00	5.00	6.33	4.67	6.33
Hewale	14.00	19.00	8.00	13.00	11.00	16.33	3.33	8.67	3.00	2.67	4.67	4.33
Nhyira	10.00	13.00	7.00	10.00	6.33	9.33	4.67	7.00	3.00	3.67	2.23	3.00
Asontem	15.00	20.00	13.00	18.33	12.00	13.67	9.33	12.67	3.00	4.33	3.67	5.67
Soronko	16.00	21.67	7.33	10.00	11.67	16.67	5.33	6.67	4.33	5.00	2.00	3.67
Asetenapa	18.00	20.33	10.00	17.00	12.67	16.33	7.00	7.67	5.33	4.33	3.00	3.33
Tona	15.00	18.33	12.00	17.00	10.33	13.67	7.00	12.67	4.67	4.67	4.00	4.33
Videza	19.00	20.33	17.00	20.00	13.00	16.33	10.33	12.67	6.00	4.00	6.67	6.67
Loc		***	0.51			***	0.55			NS		
Yr		***	0.51			***	0.54			*	0.27	
Loc × Yr		NS				NS				*	0.73	
Trt		***	1.03			***	1.09			***	0.54	
Loc × Trt		***	0.73			***	1.54			***	0.77	
Yr × Trt		NS				NS				***	0.77	
Loc×Yr×Trt		NS				NS				NS		
CV%		8.37				12.49				15.36		

NS = Not significant; * = p<0.05; **= p<0.01; *** = p<0.001, figures after the stars are the corresponding lsd values for the combined analyis

Nodule number, active and non-active nodule number results for 45 DAP of the varieties are presented in Table 4.8. Sharp increase was observed from 30 DAP to 45 DAP in terms of nodule number, active and non-active nodule numbers. The nodule number ranged from 16 to 70.67 in 2015 and 20.67 to 66.33 in 2016 for Mampong. The greatest number in 2015 was recorded by Asetenapa (70.67) followed by Hewale and Asontem having the same number (50.00). However, Nhyira recorded the lowest (16.00) nodule number (Table 4.8). In 2016 major season, Asetenapa again had the greatest nodule number (66.33) while Nhyira continued to record the lowest number (20.67). Active nodule number was high for Asetenapa in both years 47.33 and 48.00 respectively while Nhyira again recorded the lowest active number 0f 13.33 and 16.33 respectively in both years. For non-active nodule number, Asetanapa was again high in 2015 and Nhyira recorded the lower number. However, in 2016 Asontem was high (21.33) and Nhyira and Asomdwee had the lowest numbers.

At Fumesa, Videza recorded the greatest number of nodules in both years 40.00 and 43.00 respectively. The lowest number of nodules in 2015 was recorded by Asontem (24.00) while Hewale had the lowest number in 2016 (Table 4.8). The highest active nodule number for both years was recorded by Videza, 37.00 and 35.67 respectively. The lowest number for 2015 was recorded by Soronko (14.33) while Hawale recorded the lowest (10.00) in 2016. For the non-active nodules, Videza and Asetenapa had the lowest (3.00) in 2015 while Soronko recorded the greatest (23.67). However, in 2016, Hawale had the lowest (Table 4.8). A very highly significant (P<0.001) interaction effects for nodules number at 45 DAP was observed for all the sources of variation (Table 4.8). Again, a highly significant difference (P<0.001) interaction were also observed for all the sources of variation for active nodules number except location x year which was not significant. For non-active nodule number, location, year and location × year were not significant. However, the rest of the sources of variation showed a highly significant (P<0.001) interaction (Table 4.8).

Table 4.8: Nodule number, active and non-active nodules at 45 days after planting of eight cowpea varieties in 2015 and 2016

Treatments	Nodule number (45 DAP)				Active nodule number (45 DAP)				Non-active nodule number (45 DAP)			
	Mampong		Fumesua		Mampong		Fumesua		Mampong		Fumesua	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
Asomdwee	20.00	22.00	34.00	36.00	15.67	17.67	13.33	24.00	4.33	4.33	20.67	12.00
Hewale	50.00	56.00	25.00	15.00	38.33	42.33	15.67	10.00	11.67	13.67	9.33	5.00
Nhyira	16.00	20.67	28.00	29.67	13.33	16.33	17.33	20.00	2.67	4.33	10.67	9.67
Asontem	50.00	54.00	24.00	28.00	30.00	32.67	16.67	18.67	20.00	21.33	7.33	9.33
Soronko	38.67	42.00	38.00	38.00	25.00	31.00	14.33	20.67	13.67	11.00	23.67	17.33
Asetenapa	70.67	66.33	37.33	42.00	47.33	48.00	34.33	31.33	23.33	18.33	3.00	10.67
Tona	23.00	30.00	37.33	42.00	19.67	24.67	23.67	31.67	3.33	5.33	13.67	10.33
Videza	43.00	56.00	40.00	43.00	26.67	41.33	37.00	35.67	16.33	14.67	3.00	7.33
Loc		***	0.77			***	0.82			NS		
Yr		***	0.77			***	0.82			NS		
Loc × Yr		***	1.08			NS				NS		
Trt		***	1.53			***	1.63			***	1.40	
Loc × Trt		***	2.16			***	2.31			***	1.97	
Yr × Trt		***	2.16			***	2.31			***	1.97	
Loc×Yr×Trt		***	3.06			***	3.27			***	2.79	
CV%		5.01				7.66				15.09		

NS = Not significant; * = p<0.05; **= p<0.01; *** = p<0.001, figures after the stars are the corresponding lsd values for the combined analysis

Nodule numbers, active and non-active nodule numbers for 60 DAP of the varieties are presented in (Table 4.9). There was a sharp decline of nodule numbers at the last sampling stage for all varieties. At Mampong, in 2015 season, Videza recorded the highest (19.33) nodule number followed by Asetenapa (18.67) with Asomdwe recording the lowest (10. 67).

During the 2016 major season, Asetanapa recorded the greatest (25.00) nodule number followed by Videza (21.33) while Asomdwe again had the lowest (Table 4.9). For active nodules, Videza again had the highest (12.33) while Asomdwee recorded the lowest (7.33) in 2015. However, in 2016 major season, Asetanapa had the highest followed by Videza. The lowest was recorded by Hewale (Table 4.9). The non-active nodules had different trend, two varieties had a value of 7.33 (Asetanapa and Tona) being the highest while Asomdwee recorded the lowest number (Table 4.9). In 2016 major season, Asontem had the highest nodule number (5.33) followed by Hewale and Nhyira (5.00) while Asomdwee recorded the lowest number (3.33) (Table 4. 9).

At Fumesa, during the 2015 season, Soronko had the greatest nodule number (18.00) among the varieties with Asontem recording the lowest number in (7.67). The highest nodule number for 2016 was recorded by Asontem (12.67) followed by Hewale and Videza (12.33) with lowest number been recorded by Tona (10.33) (Table 4. 9).

The active nodule number ranged from 5.33 to 15.00 (Table 4.9). The highest number was recorded by Soronko (15.00) while Asontem recorded the lowest number (5.33) for 2015.

In 2016 season, Videza recorded the highest number (12.33) for active nodules while Asomdwee recorded the lowest (7.00) number among the varieties.

For non-active nodules, Hewale recorded the highest (3.33) with Videza recording the lowest (1.67) number. However, in 2016, Asomdwee recorded the highest while Asetenapa, Tona and Videza had the lowest number (2.33) among the varieties (Table 4.9).

Interaction effects were observed in the parameters in the combined analysis. There was significant interaction for nodule at ($P<0.05$, $P<0.01$ and $P<0.001$) levels among the sources of variation. A very highly significant interaction ($P<0.001$) were observed for active nodule number. However, for non-active nodule, year and year × treatment showed a very highly significant ($P<0.001$) interaction while the rest of the sources of variation did not have any significant interaction (Table 4. 9).

Table4.9: Nodule number, active and non-active nodules at 60 days after planting of eight cowpea varieties in 2015 and 2016

Treatments	Nodule number (60 DAP)				Active nodule number (60 DAP)				Non-active nodule number (60 DAP)			
	Mampong		Fumesua		Mampong		Fumesua		Mampong		Fumesua	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
Asomdwee	10.67	15.00	9.00	10.67	7.33	11.33	6.33	7.00	2.67	3.33	2.67	3.33
Hewale	12.00	16.00	12.67	12.33	8.33	11.00	9.33	8.33	3.67	5.00	3.33	3.00
Nhyira	12.67	17.00	9.00	11.67	8.67	12.00	6.33	9.00	4.00	5.00	2.67	2.67
Asontem	15.00	18.67	7.67	12.67	10.67	13.33	5.33	9.67	4.33	5.33	2.33	3.00
Soronko	18.00	16.00	18.00	11.00	11.33	11.67	15.00	8.00	6.67	4.33	3.00	3.00
Asetenapa	18.67	25.0	14.00	12.00	11.33	20.33	11.00	9.67	7.33	4.67	3.00	2.33
Tona	18.00	19.67	9.00	10.33	11.67	15.67	6.67	7.33	7.33	4.00	2.33	2.33
Videza	19.33	21.33	9.33	12.33	12.33	16.67	7.67	12.33	3.33	4.67	1.67	2.33
Loc		***	0.66			***	0.56			NS		
Yr		***	0.66			***	0.56			***	0.37	
Loc × Yr		*	0.93			***	0.79			NS		
Trt		***	1.31			***	1.11			NS		
Loc × Trt		***	1.87			***	0.79			NS		
Yr × Trt		***	1.87			***	1.57			***	1.04	
Loc×Yr×Trt		**	2.62			***	2.23			NS		
CV%		11.24				13.09				23.73		

NS=Not significant;*=p<0.05;**=p<0.01;***=p<0.001, , figures after the stars are the corresponding lsd values for the combined analysis

4.3.0 Yield and Yield Components

Mean square for yield components of eight cowpea varieties is presented in Table 4.10. The combined analysis across years and locations showed very highly significant, highly significant and non-significant differences for all the yield components howed varied significant differences from the sources of variation Table 4.10.

Pod length was very highly significant at ($P<0.001$) for location and treatments. There were significant difference of pod length for year at ($P<0.05$). All other source of variation were not significant.

Number of pods per plant was significant for all the sources of variation except location × year and location × treatment. There was very highly significant difference at ($P<0.001$) for location, year and treatment while year × treatment and location × year × treatment had high significant differences at ($P<0.01$).

For number of seed per pod, there were no significant difference for location × treatment, year × treatment and location × year × treatment. High significant difference was observed for treatment at ($P<0.01$). However, very highly significant difference was observed for location, year and location x year at ($P<0.001$) (Table 4.10).

There was highly significant effect ($P<0.01$) of 100 seed weight for three sources of variation, location, year and treatments. There was highly significant difference ($P<0.01$) for location x year and significant ($P<0.05$) for location x treatment (Table 4.10). Year ×

treatment and location × year × treatment did not show any significant difference for 100 seed weight.

Pod yield exhibited a very highly significant difference (P<0.001) for location, year, location x year and treatment sources of variation (Table 4.10). There were highly significant (P<0.01) difference for year x treatment. However, location × treatment and location × year × treatment were not significant among the sources of variation (Table 4.10).

Seed yield recorded similar effect for sources of variation in terms of its significant difference. As observed in pod yield (Table 4.10), location, year, location × year and treatment were also very highly significant at (P< 0.001) for seed yield. However, location × treatment, year × treatment and location × year × treatment did not show any significant difference.

Table 4.10: Mean Square values for yield and yield components of eight cowpea varieties in 2015 and 2016

Source of Variation	Pod length	No.of pods/plant	No.of seeds/pod	100seed weight	Pod yield (kg/ha)	Seed yield (kg/ha)
	Mean Squares (x 10^3)					
Location	45.6918***	3410.550***	22.8637***	73.5000***	4974434***	5864024***
Year	11.2271*	4645.383***	81.3096***	150.0000***	4670260***	4723412***
Loc × Year	0.6386^{NS}	1234.100	13.7637***	16.6666**	899934***	1333083***
Residual (A)	1.1846	16.670	1.2920	0.7638	11378	11670
Treatments	22.8974***	105.057***	20.2019**	15.5952***	601995***	655772***
Loc × Trt	1.5586^{NS}	15.544^{NS}	3.5592^{NS}	4.0714*	35662	47697^{NS}
Year × Trt	3.1628	21.388**	3.8622^{NS}	3.6666^{NS}	103414**	73330^{NS}
Loc×Year×Trt	1.0528^{NS}	23.181**	2.9740^{NS}	2.2380^{NS}	24501	17106^{NS}
Residual (B)	1.0200	10.18	4.0109	1.9241	1443223	40826

NS = Not significant; * = $p<0.05$; **= $p<0.01$; *** = $p<0.001$

4.3.1 Pod Yield

Pod yield results of eight cowpea varieties in 2015 and 2016 growing season are presented in Table 4.11. Pod yield in 2015 minor season at Mampong ranged from 1439 kg/ha to 2261kg/ha. The highest pod yield was recorded by Asontem (2261kg/ha) followed by Hewale (1885 kg/ha) and Asomdwee (1864 kg/ha). Soronko recorded the lowest pod yield of (1439 kg/ha). During the 2016 major season, differences in pod yield was observed which did not follow the pattern in 2015 minor season except Asontem. The highest pod yield was recorded by Asontem with a value of 2540 kg/ha. Videza was next with a value of 2370 kg/ha. However, Soronko consistently recorded the lowest pod yield of 1632kg/ha (Table 4.11).

At Fumesua, during the 2015 season, varing differences of pod yield was recorded by the varieties but was lower than the values recorded in the 2015 season in Mampong. Asontem continuously produced the highest pod yield in 2015 minor season (1560kg/ha). The lowest pod yield was recorded by Videza with a value of 980.03 kg/ha (Table 4.11). During the 2016 major season, the highest pod yield was still recorded by Asontem with a pod yield value of 2088 kg/ha followed by Asomdwee 2045 kg/ha, Videza which recorded the lowest pod yield in 2015 minor season recorded third highest pod yield of 2000 kg/ha in 2016 major season. The lowest pod yield was however recorded by Soronko 1365 kg/ha as was observed at Mampong location for both seasons.

Significant interaction was observed in all the interactions except location × treatment and location × treatment × year. Location, year, location × year and treatment were very highly significant at $P<0.001$ level. However, year × treatment was significant at $P<0.05$ level.

4.3.2 Seed Yield

Seed yield results of the varieties in 2015 and 2016 seasons are presented in Table 4.11. The average seed yield of eight genotypes varied between 1187 kg/ha and 1962 kg/ha for the 2015 minor season and 1280 kg/ha to 2241 kg/ha in 2016 major season at Mampong. In 2015 minor season at Mampong, Asontem recorded the highest seed yield of 1962 kg/ha followed by Videza 1692kg/ha with Soronko recording the lowest seed yield of 1187kg/ha. In 2016 major season, almost similar trend for the 2015 minor season was observed. Asontem again recorded the highest average seed yield of 2241kg/ha followed by Videza 2064kg/ha. The lowest seed yield was recorded by Soronko with an average seed yield of 1280kg/ha.

At Fumesua, the average seed yield of the genotypes ranged between 666kg/ha to 1239.89kg/ha in the 2015 minor season. During, the 2016 major season, average seed yield ranged from 1082kg/ha to1782kg/ha (Table 4.11).

In 2015 minor season, Asontem recorded the highest average seed yield of 1240kg/ha which was followed by Tona with an average seed yield of 898.76kg/ha. However, Asetenapa recorded 603kg/ha which is the lowest among the eight genotypes. In 2016 major season, Asontem maintained its superiority by recording the highest seed yield of

1782kg/ha followed by Asomdwee which recorded 1646kg/ha. Soronko on the other hand recorded the lowest average seed yield of 1082kg/ha.

A very highly significant ($P<0.001$) interaction was observed by location, year, location × year and treatment. However, location × treatment, year × treatment and location × year × treatment interactions were not significant.

Table 4.11: Pod and seed yields and harvest index of eight cowpea varieties at Mampong and Fumesua in 2015 and 2016

Treatments	Pod yield (kg/ha)				Seed yield (kg/ha)				Pod harvest index			
	Mampong		Fumesua		Mampong		Fumesua		Mampong		Fumesua	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
Asomdwee	1864	2083	1115	2045	1594	1863	726	1645	0.85	0.89	0.65	0.80
Hewale	1885	2160	1223	1897	1542	1789	833	1637	0.81	0.82	0.68	0.86
Nhyira	1747	1943	1169	1839	1414	1647	807	1521	0.84	0.85	0.68	0.83
Asontem	2261	2540	1560	2088	1962	2241	1240	1782	0.87	0.88	0.79	0.85
Soronko	1439	1632	1067	1365	1187	1280	688	1082	0.82	0.79	0.65	0.79
Asetenapa	1729	1733	1040	1378	1407	1356	603	1089	0.81	0.78	0.58	0.79
Tona	1782	2072	1208	1828	1453	1736	899	1505	0.81	0.84	0.75	0.82
Videza	1847	2370	980	2001	1692	2054	666	1635	0.89	0.87	0.67	0.82
Loc			***	65.65			***	82.62			***	
Yr			***	65.65			***	82.62			***	
Loc × Yr			***	92.84			***	116.85			***	
Trt			***	131.29			***	165.25			***	
Loc × Trt			NS				NS				NS	
Yr × Trt			*	185.67			NS				*	
Loc×Yr×Trt			NS				NS				NS	
CV%			9.36				14.49				9.01	

NS = Not significant; * = p<0.05; **= p<0.01; *** = p<0.001, figures after the stars are the corresponding lsd values for the combined analysis

4.3.3 One Hundred Seed Weight

One hundred seed weight results in 2015 and 2016 growing season are presented in Table 4.12. Hundred seed weight ranged from 15.33g to 19.67g in 2015 in the minor season at Mampong. The greatest hundred seed weight in the minor season was obtained from Asetenapa (19.67g) followed by Asomdwee (19.33g), Videza (17.67g) and Tona recorded the lowest hundred seed weight of 14.67g. In 2016 major season, similar trend was observed. Asetenapa, Asomdwee, and Videza recorded the highest hundred seed weight of 23.00, 21.67, and 21.33 respectively. Tona variety again recorded the lowest hundred seed weight of a value of 18.67g.

At Fumesua during the minor season (2015), Asetenapa recorded the highest hundred seed weight with Asomdwee and Videza following with 18.33, 17.67 and 17.00g respectively. The lowest hundred seed eight was recorded by Soronko and Tona (14.33g). During 2016 major season, Videza had the highest hundred seed weight (18.33g) Nhyira was the second with (18.33g). Tona and Asomdwee however recorded same value for hundred seed weight (18.00g). The lowest value was recorded by Asetenapa (16.00g).

There were no interaction in location × treatment, year × treatment and location × year × treatment. Location, year and treatment were very highly significant at $P<0.001$ while location × year was significant at $P<0.05$.

4.3.4 Number of Pods per Plant

The average number of pods across genotypes ranged from 12.20 to 21.60 at Mampong during the 2015 growing season (Table 4.12). The highest pod number in 2015 minor season was recorded by Hewale (21.60) followd by Asetenapa (21.40). The lowest number of pods were recorded by Tona. In 2016 major season, there was an increase in the number of pods of the various genotypes. Asontem recorded the highest pod number 47.300 followed by Asomdwee (44.40) and Hewale (40.73) in that order. The lowest pod number was recorded by Soronko (31.37). From the result it could be observed that the lowest number of pods recorded in the 2016 major season at Mampong was greater than the highest in the 2015 minor season.

Similar trend was observed Fumesua during the minor season where Asontem recorded the greatest pod number (17.33) followed by Asetenapa (16.73) with Soronko recording the lowest (7.33) (Table 4.12). During the 2016 major season, there was a major increase in pod number than 2015 minor season. Asontem recorded the highest pod number (22.33) followed by Hewale 21.00 with Tona recording the lowest of 17.00.

The combined analysis between the location, year, location × year and treatment showed that, there were very highly significant at P<0.001 level. However, there were no significant interaction between location × treatment. The year × treatment and location × year × treatment interactions on the other hand was significant at P<0.05 level (Table 4.12).

4.3.5 Number of Seeds per Pod

Number of seeds per pod results in 2015 and 2016 season are presented in Table 4.12. For number of seed/pod, varietal effects were significant. At Mampong, the highest number of seeds per pod of14.53 which was recorded by Hewale followed by Asontem recording

14.47. The least number of seed/pod was recorded by Tona which was 10.53 in 2015. During the 2016 major season, Asontem recorded the greatest seeds number per pod (17.07) followed by Soronko (13.47) with Videza recording the lowest seed number of 12.47. Varying differences exists in both years as some of the seed number per pod was higher in 2015 than in 2016. For example, the genotypes Hewale and Asetenapa recorded higher values in 2015 than in 2016, and vice versa.

At Fumesua, the greatest number of seed per pod in 2015 was produced by Asontem, followed by Asetenapa, Hewale and Tona respectively with Videza recording the lowest number of seed per pod. In 2016 major season, Soronko produced the greatest effect followed by Asontem and Hewale, Videza produced the least.

Table 4.12: Yield components of eight cowpea varieties at Mampong and Fumesua in 2015 and 2016

Treatments	Number of pods/plant				Number of seeds/pod				100 Seed Weight (g)			
	Mampong		Fumesua		Mampong		Fumesua		Mampong		Fumesua	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
Asomdwee	18.00	44.40	11.00	19.00	12.07	12.67	9.67	12.70	19.33	21.67	17.67	18.00
Hewale	21.60	40.73	14.67	21.00	14.53	13.00	11.00	14.10	16.33	19.33	16.00	17.67
Nhyira	18.87	35.87	14.00	19.00	12.27	13.27	10.40	13.50	16.67	19.67	15.67	18.33
Asontem	16.93	47.30	17.33	22.33	14.47	17.07	12.60	15.07	16.33	19.33	15.33	17.67
Soronko	13.67	31.47	7.33	19.00	11.40	13.47	10.40	15.27	15.33	19.67	14.33	17.00
Asetenapa	21.40	38.07	16.73	20.33	13.33	12.60	11.80	12.98	19.67	23.00	18.33	16.00
Tona	12.20	33.00	9.67	17.00	10.53	13.47	10.87	13.83	14.67	18.67	14.33	18.00
Videza	19.07	39.57	13.00	20.00	10.73	12.47	8.73	8.80	17.67	21.33	17.00	19.33
Loc			***	1.30			*	0.82			***	0.57
Yr			***	1.30			***	0.82			***	0.57
Loc × Yr			***	1.85			NS				*	0.20
Trt			***	2.61			*	1.64			***	1.13
Loc × Trt			NS				NS				NS	
Yr × Trt			*	3.69			NS				NS	
Loc×Yr×Trt			*	5.22			NS				NS	
CV%			14.31				16.06				7.80	

NS = Not significant; * = $p<0.05$; **= $p<0.01$; *** = $p<0.001$, figures after the stars are corresponding lsd values for the combined analysis

4.3.6 Additive Main Effects and Multiplicative Interaction (AMMI) Analysis Results

Results of AMMI Analysis of variance of the cowpea varieties is presented in Table 4.13. From the AMMI anova, genotype (G) accounted for 24.4% of the total sum of squares (SS), environmental effects explained 63.1% while interaction GEI explained 4.6%. All of them were significant at different levels. Genotype and Environment were very highly significant at $P<0.001$ while interaction was significant at $P<0.05$ indicating that all the sources of variation is important in the analysis.

The principal component analysis (PCA) on the analysis of variance suggests that IPC1 scores was significant at $P<0.05$. However, the IPCA2 score was not significant (Table 4.13). The IPCA1 score explained 80.8% while IPCA2 explains 2.7% The IPCA1 scores was far higher than IPCA 2 (Table 4.13). The mean squares of the fixed effects by the anova in Table 4.13 which considered year in each location as an environment, showed very highly significant ($P<0.001$) differences for environment and genotype. Interaction (GEI) was highly significant at $P<0.01$.

Table 4.13: AMMI Anova table for the combined yield of eight genotypes

Source	Df	SS	SS Explained %	MS
Treatments	31	17309763		558379***
Genotypes	7	4579083	24.4	654155***
Environment	3	11866665	63.1	3955555***
Block	8	123984	0.7	15498
Interactions	21	864015	4.6	41144*
IPCA1	9	698236	80.8	77582**
IPCA 2	7	142067	2.7	20295ns
Residuals	5	23712		4742
Error	56	1358079		2442
Total	95	18791826		197809

4.3.7 AMMI Bi-plot for Mean Seed Yield

The AMMI Bi-plot of mean seed yield is shown in Figure 4.9. Results obtained from the GGE Bi-plot represent the first two principal components analysis (PC1 and PC2). The decomposition of the GGE matrix effects showed the first two principal components accounting for 97.5% of the variation which was caused by G+ GE. The PC1 accounted for 89.3% of the total variation while the PC2 was responsible for 8.2% (Fig. 4.9).

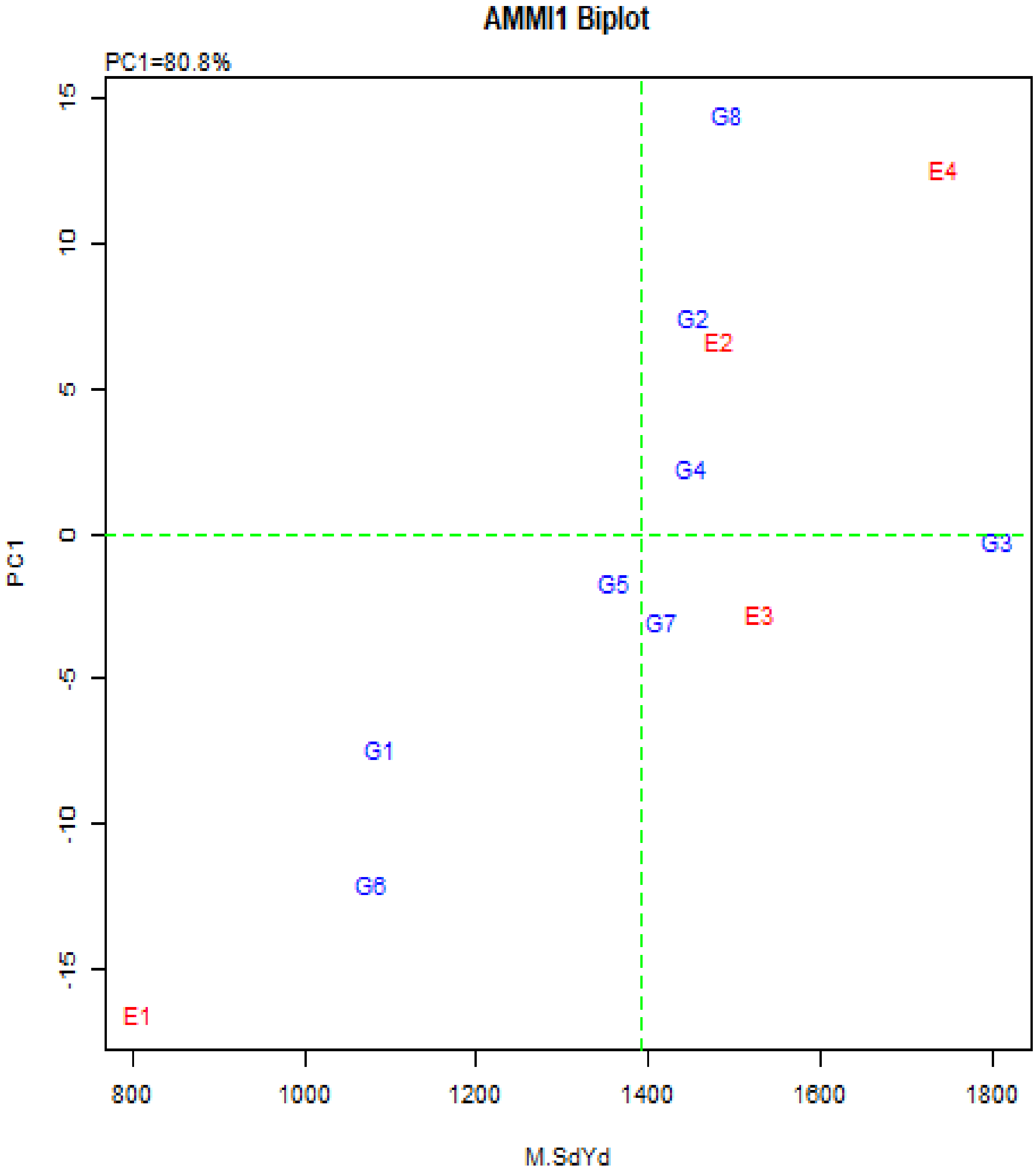


Figure 4.9: Ammi Biplot of Mean Seed Yield of Eight Cowpea Varieties in 2015 and 2016.

4.3.8 Best Four Ammi Selections Based on Best Grain Yield Genotype in Each Environment

The best four AMMI selections based on best grain yield genotype in each environment is presented in Table 4.14. The additive main effect and multiplicative interaction analysis identified four highest yielding genotypes in each of the four environments. At Fumesua 2015 which was the least environment, four genotypes namely Asontem, Tona, Hewale and Nhyira. In environment Mampong 2015, Asontem, Videza, Asomdwee and Tona were selected as the top genotypes. Fumesua 2016 top genotypes were Asontem, Hewale, Videza and Asomdwee. In the highest favourable environment (Mampong 2016), genotypes Asontem, Videza, Asomdwee and Hewale were selected.

Table 4.14: First four AMMI selection based on best grain yielding genotype in each environment

Environment	Mean grain yield (kg/ha)	Score	Rank			
			1	2	3	4
FUM2015	808	16.525	Asontem	Tona	Hewale	Nhyira
MAM2015	1531	2.692	Asontem	Videza	Asomdwee	Tona
FUM2016	1485	-6.654	Asontem	Hewale	Videza	Asomdwee
MAM2016	1746	-12.563	Asontem	Videza	Asomdwee	Hewale

4.3.9 GGE Bi-Plot Analysis of "What-Won-Where" and Environment View for Mean Seed Yield of Eight Cowpea Varieties in 2015 and 2016 Seasons

Figure 4.10 represents GGE Bi-plot environmental view for mean seed yield. From figure 7, it could be deduced that the average environment axis cuts through from the PC2 through the origin to the concentric circles. The average environment axis (AEA) relates to the ideal environment. From the bi-plot (Fig. 4.10), it indicates that E4 is located close or in the direction of the ideal environment indicating the largest PC1 scores. E2 and E3 were located around the average environment with relatively high PC1 scores. However, E1 fell outside the concentric circles and moved away from the direction of the average environmental axis indicating low PC1 score.

A "what-won-where" polygon view of the relationship between genotypes and environment is presented in Figure 8. From figure 4.11, it could be seen that the bi-plot explained a total of 97.5% for the variation observed. Out of this, 89.3% was explained by the first principal component (PC1), while the second principal component (PC2) explained 8.2%. Genotypes G3, G8, G6, and G1 (Asontem,Videza, Soronko and Asetenapa) were situated at the corners of the polygon of "what –won- where" which indicates that these genotypes are tilted in particular environments. Out of these genotypes, G3 was the highest yielding in all the test environments. Genotypes G2, G4, G5, and G7 (Asomdwe, Hewale, Nhyira and Tona) were clusted almost at the middle or centre of the "what–won-where" polygon.

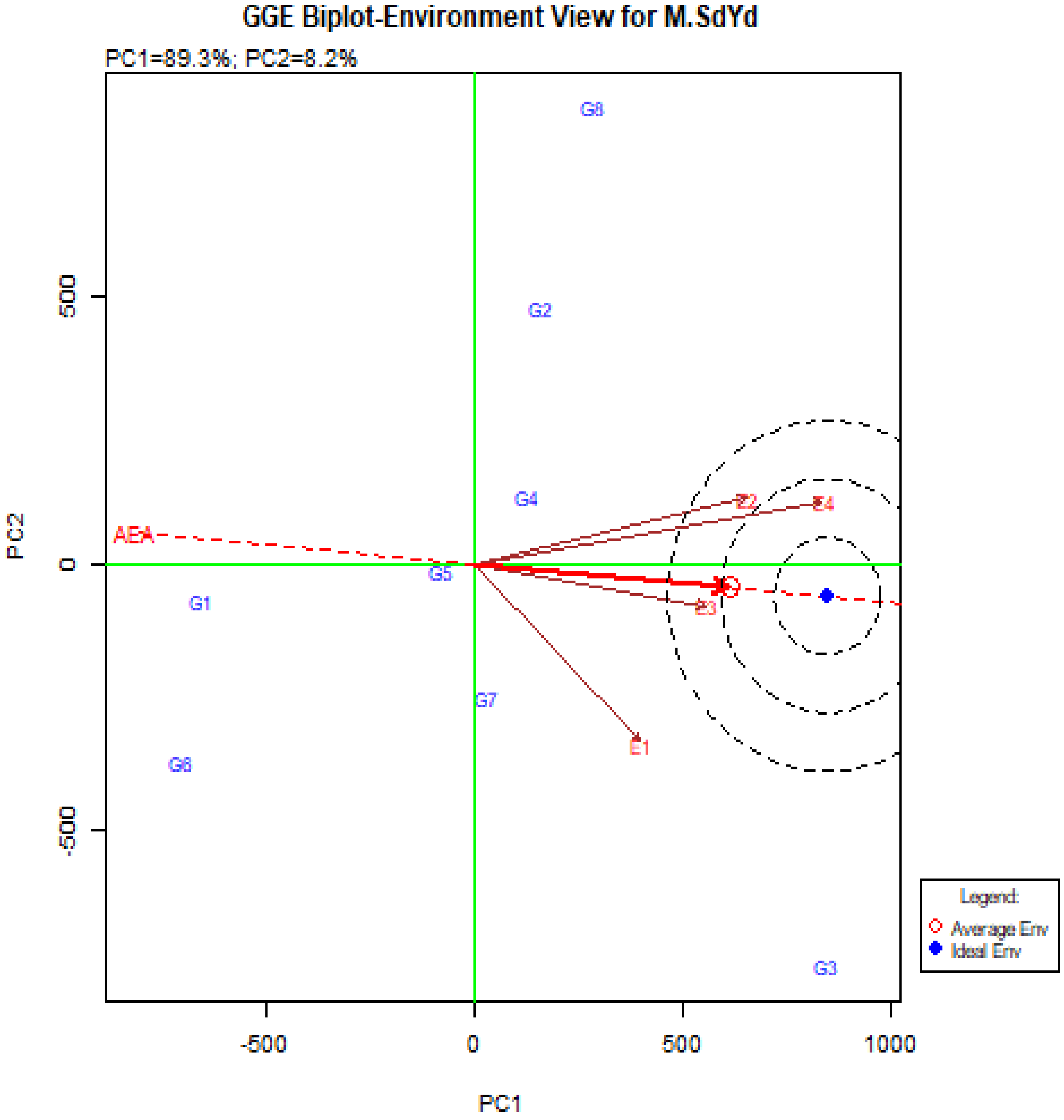


Figure 4.10: GGE Biplot of Environmental View on Mean Seed Yield of Eight Cowpea Varieties in 2015 and 2016.

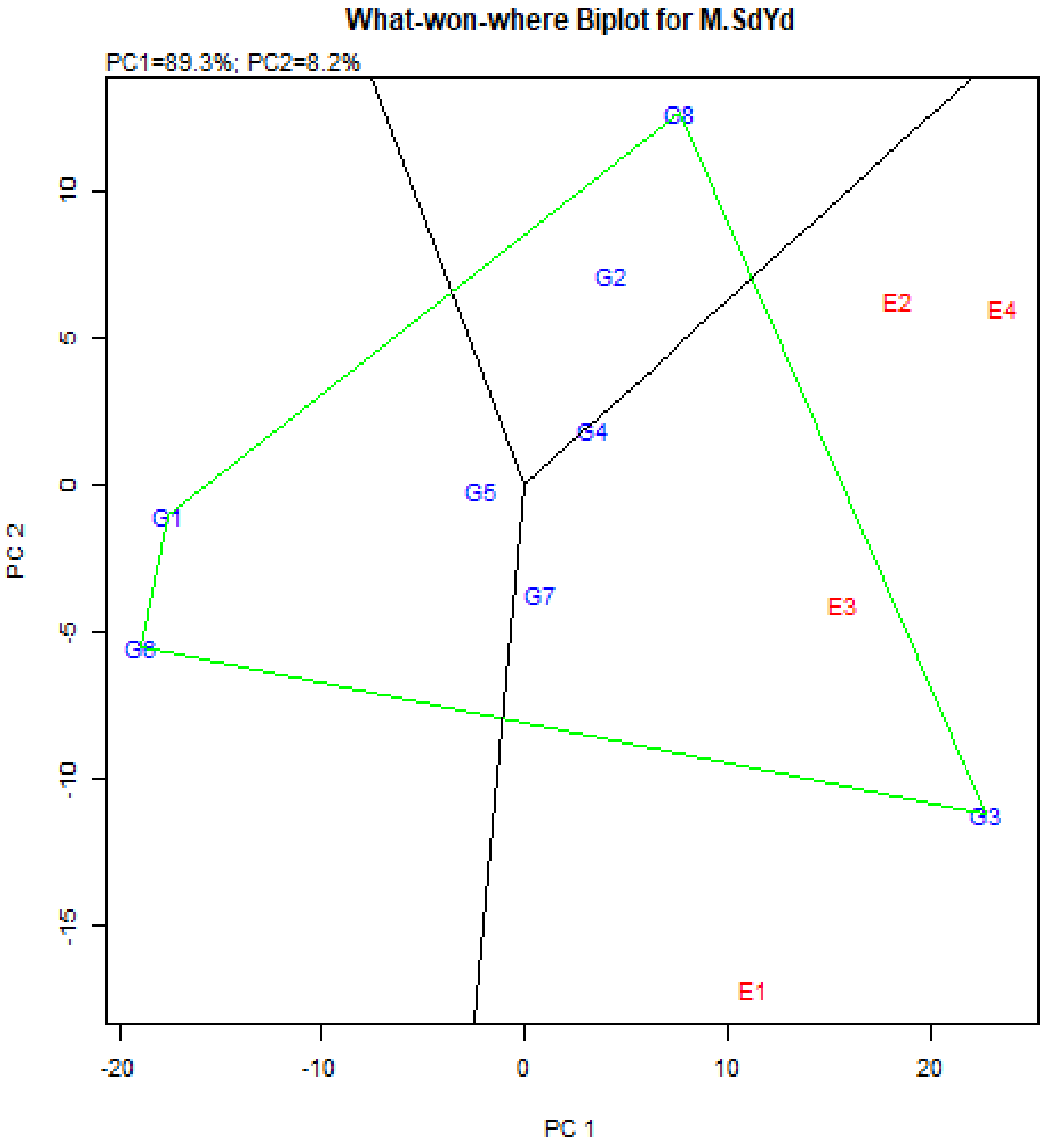


Figure 4.11: "What Won Where" View of the Relationship of Environment and Yield of Eight Cowpea Varieties in 2015 and 2016.

4.3.10 Estimates of Stability Analysis of Eight Cowpea Genotypes Evaluated in Four Environments.

Estimates of stability parameters for mean yield of cowpea varieties are shown in Table 4.14. From Table 4.15, estimates of yield stability parameter for grain yield for eight genotypes had regression coefficients close to one (1). Genotypes Hewale, Nhyira, Asontem and Tona had coefficients values close to 1 indicating that those genotypes are stable. Asomdwee and Videza are, however, higher than b value of 1 and are not considered as stable genotype. Soronko and Asetenapa also had b values of less than 1 and are therefore also considered as not stable genotypes. All the genotypes were also compared with the average mean performance of grain yield.

Again, values for mean squared deviation (S^2d) with low values for error mean squares are Tona, Asontem, Asomdwee and Nhyira. All other genotypes had high values for Error mean square (S^2d) (Table 4.14). The stability measure makes use of regression coefficient value of b=1, or close to 1, less values for Error mean square (S^2d) and the yield above the average mean yield. Therefore, these theree criteria must be satisfied by the varieties which can be classified as stable genotypes. Based on this, the varieties which falls under this criteria of this yield stability analysis method are Asontem, Nhyira and Tona. Stability measure for Eberhert and Russell (1966) was used for to determine the genotypes that were stable.

Stability estimates using Finlay and Wilkinson (1963) is presented in Table 4.14. This stability method is selected based on mean yield and regression coefficient value. This stability measure uses average mean yield with regression value b close to 1. From Table 4.14, values of b close to 1 with consistent mean yield were 1.03, 0.92, 1.04 and 0.90 for

Hewale, Nhyira, Asontem and Tona varieties respectively. These genotypes fits the yield stability estimates and are therefore considered stable. Mean yield values for Videza, Asomdwee are higher than the overall grand mean but has high regression value of b. Also, Soronko and Asetenapa has less mean yield compared with the overall grand mean and lower b values and are therefore do not fit into the stability measure as stable (Table 4.14, Fig. 4.12).

Francis and Kannenberg (1978) stability measure groups genotypes on the basis of their mean yields and their coefficients of variation relative to the grand mean and average CV. For the grain yield of cowpea, the procedure identifies two genotypes (Asontem and Tona as most desirable with higher than average yield and smaller than average CV (Table 4.14, Fig.4.13). Genotypes Videza and Hewable fell into a group with low yield with large variation. Nhyira fell into a group with low yield based on the overall grand mean with small variations which is also based on mean CV. For the last group, with low yield and large variation was recorded by Asetenapa and Soronko (Table 4.14, Fig. 4.13).

Table 4.15: Estimates of stability parameters in eight cowpea genotypes evaluated in four environments

Genotype	Overall mean yield (kg/ha)	Error mean square S^2d	Regression coefficient b	Coefficient of variation CV%
Asomdwe	1452	2516.64	1.22	3.46
Hewale	1450	5914.64	1.03	5.304
Nhyira	1360	3924.74	0.92	4.61
Asontem	1806	2145.29	1.04	2.57
Soronko	1076	5691.48	0.66	7.01
Asetenapa	1086	8602.42	0.83	8.52
Tona	1415	221.35	0.90	1.05
Videza	1491	5050.11	1.44	4.77
Overall mean yield	1392			4.66

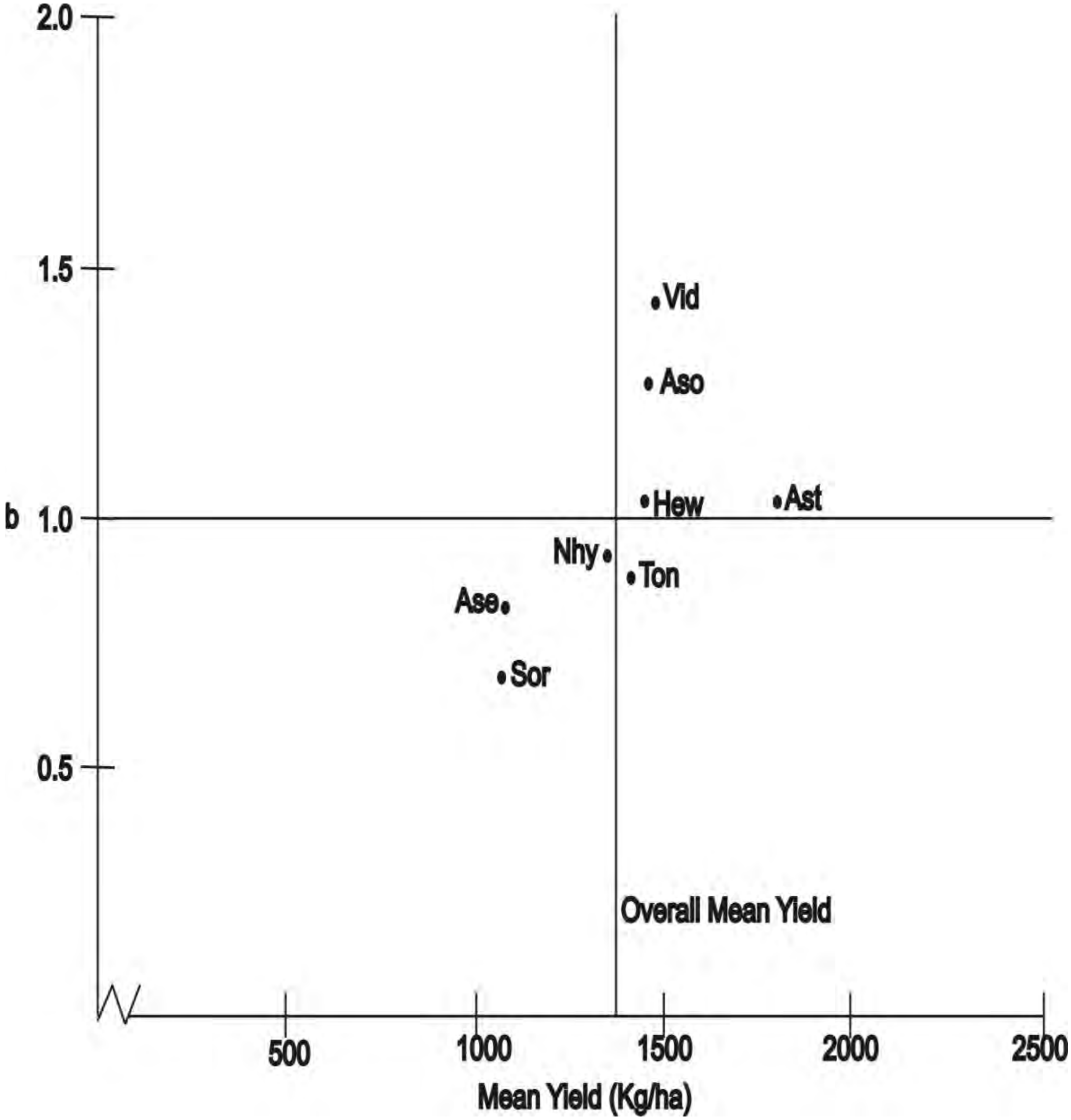


Figure 4.12: Finlay and Wilkinson (1963) Stability Analysis

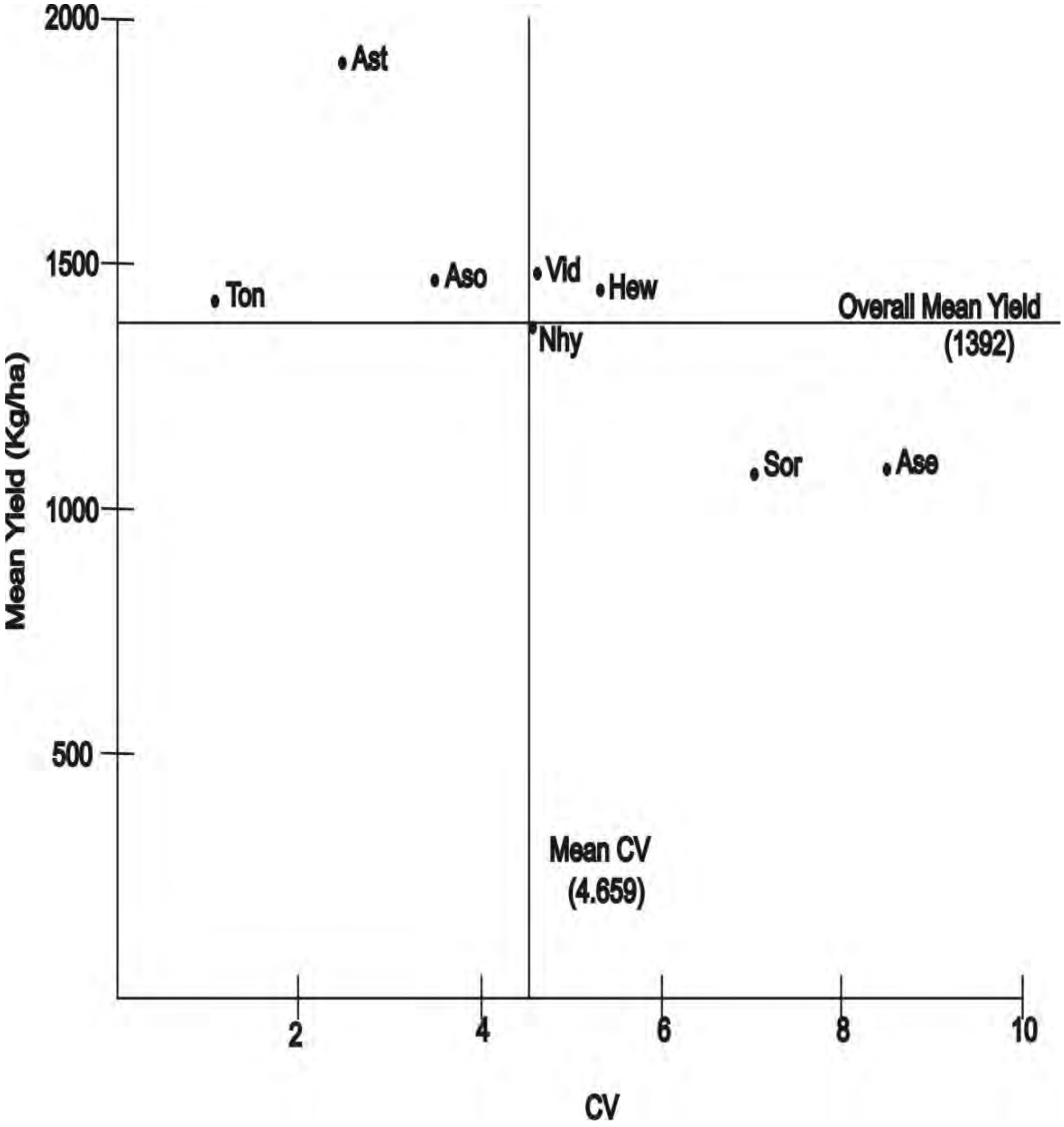


Figure 4.13: Francis and Kannenberg (1978) Stability Analysis

CHAPTER FIVE

5.0 DISCUSSION

5.1 Phenological Development and Growth

Most crops phenological stage is very critical as it predicts the yield of crops at the end of the growing period. The phenological state of cowpea remains a critical key to seed yield. Days to 50% flowering and podding at the right time with optimum climatic conditions determine good seed yield. Effective flowering and pod formation depends on how cowpea adapt itself to the change in environment. Cowpea flowers and follows with pods in a short possible time, thus as soon as cowpea flowers, pod formation follows and therefore, the earlier the crop flowers, it follows with its pod. Therefore, late maturing flowers will usually produce pods late. In this study, the early maturing varieties flowered early with early pod formation than the medium and late maturing ones. Other factors such as temperature and day length also have influence on flowering and podding.

According to Baron *et al*. (2003), initiation of flowers, flowering stage, podding and seed set is greatly influenced by photoperiod and temperature. Bell and Wright (1998) were also of the view that crop growth which includes flowering and pod formation could be influenced by the length of moisture stress, atmospheric water demand, humidity and temperature. It can be observed from the study that high significant interaction were observed for both days to 50% flowering and podding which indicates that location, year, treatments and their interactions contributed to the differences that was observed. Again, it took more days for genotypes at Mampong to flower and form pods than at Fumesua. This situation could probably be due to the higher or favourable climatic conditions prevailed in field conditions at Mampong than Fumesua. Comparing the rainfall, temperature and humidity, it could be seen that Mampong recorded higher rainfall with lower temperature and relatively high humidity. This situation might have contributed to the vegetative growth of cowpea varieties to have adequate time to produce flowers and set pods. Fumesua on the other hand had relatively low amount of rainfall compared to Mampong with high temperature coupled with low humidity. This condition probablyhave reduced water available to the roots of cowpea for ideal growth and development of flowers and pods. In this wise effective vegetative growth will be limited which most likely affected days to flowering and pod formation. Ahmed and Hall (1993) stated that continuous high night temperatures during the first four weeks after germination can cause suppression of floral buds and prevent flowering altogether. This situation might have caused the differences in the flowering and podding in the two locations.

According to Uhart and Andrade (1995), phenology of crops determines the rate of leaf growth and its reproductive cycle and therefore unfavourable environment would normally impose assimilate limitation, restricts pollination and decrease pods formation and seed set. In this wise, any subsequent environment situation which prevails after reproductive growth could change floral development and seed filling through effective pod formation. This situation could have occurred in the field conditions in both locations in this study. This observation is in line with Sato *et al*. (2003) and San Jose *et al*. (2002) that crop reproductive phases could be affected by fluctuation in water supply and thermal regimes.

Plant height was influenced by cowpea genotypes at various growth periods in both seasons in the two locations. The differences in plant height observed in the study could be due to the genetic effect of the cowpea genotypes. This difference resulted in different genotypes recording higher plant height in different seasons and locations. Plant architecture influenced the variations observed in the seasons and locations. Semi-erect varieties such as Asontem, Asomdwee, Videza and Hewale had greater plant height than the erect type such as Nhyira, Tona and Asetenapa, and this may probably be due to long vines that are possessed by the semi-erect varieties resulting in higher plant height. Similar observations were made by Karikari *et al*. (2015) for Asetenapa and Asomdwee genotypes which recorded higher plant height in the growing period. The present study confirms what Karikari *et al*. (2015) observed due to the varietal inherent characteristics.

It was again observed that the genotypes at Mampong performed better in terms of plant height than in Fumesua. These differences could be attributed to the high amount of rainfall recorded in Mampong than in Fumesua. Though cowpea can tolerate some drought but low amount of rainfall coupled with high temperature within a given period can have negative impact on cowpea growth which will result in stunted growth and may in turn affect reproductive development as well. Dadson *et al*. (2005) observed that growth and development of most cowpea varieties are affected by drought and high temperatures and drought stress could influence crop growth whether early or late maturing ones.

Differences in location, year, treatments and some interactions for mean squares were significant and apart from the locational differences or interaction, genotypes in 2016 major season had higher plant height than what was recorded in 2015 minor season. Crop performance in terms of vegetative growth during the long rainfall season tends to be better than the short rainfall season. Agyemang *et al.* (2014) recorded higher growth of cowpea genotypes and was attributed to the relatively higher rainfall and milder temperature experienced during the major rainfall season.

Number of branches of the genotypes responded differently in each of the sampling periods, seasons and location as well. The architecture of the varieties brought out the significant differences in the number of branches. Usually, cowpea varieties with spreading or semi-erect abilities tend to normally produce more branches than the erect types. Soronko which has a spreading ability produced more branches in all the seasons and locations due to that speciality in such variety. This phenominon could be ascribed to the differences in genetic composition among the cowpea genotype. However, there were some variations in the erect and semi-erect varieties and this situation could be attributed to locational effects due to environmental factors. The findings is in line with Agyemang, *et al*. (2015) that significant differences in number of branches per plant is due to genetic make up of genotypes. These observations has also been confirmed by Miheretu and Sarkodie-Addo (2017) on investigations made on some cowpea genotypes in 2017 and attributed the differences in number of branches to varietal differences between those varieties studied. Again, comparing the seasons, it could be seen that the primary branches observed in 2016 was greater than the 2015 season in both locations which ranged between 1 to 6.8 in 2016 and between 1 and 5.7 in 2015. These increases could be due to the differences in the amount of rainfall recorded in 2016 season which was higher than the values recorded in 2015 season which might have brought the differences in the number of branches. This observation is confirmed by Dadson *et al.* (2005) that growth and development of cowpea genotypes is influenced by climatic conditions. Low rainfall couple with high temperatures tends to affect growth irrespective of varieties involved. This is also evident by the genotype mean squares values for 45 days after planting for location, year and their interaction.

5.2 Growth Functions and Nodulation

Leaf area (LA) and leaf area index (LAI) of cowpea varieties are influenced by the plant archictecture thus spreading or prostrate, erect or semi-erect. The spreading varieties such as Soronko tended to have large leaf area due to more leaves as well as branches it possessed during the growth period. Again, Soronko, Tona, and Nhyira consistently performed and showed steady increase from the first sampling period to the end (30-60 DAP), while in all the locations and seasons, Asontem recorded the lowest leaf area and leaf area index. These differences may be due to the differences in leaf orientation or size of the individual genotypes in the study. Soronko, Tona and Nhyira produced broad and big leaf sizes making its length and width larger than other varieties with long length but very short width (Asontem).

In view of this, Soronko, Tona and Nhyira were believed to have greater light interception due to their leaf orientation. It is possible that, this greater light interception might have led to higher rate of photosynthesis which contributed significantly towards the vegetative growth of such varieties which eventually led to greater leaf area index. This finding is in line with Banerjee *et al*. (2012). Similar observation has also been made by Aduloju *et al*. (2009). Varietal characteristics have a bearing in the LAI of cowpea plants. Usually, erect and semi-eract varieties may tend to have higher LAI because their leaves cover a smaller ground area which is the divisor in determining the LAI. In this study, Tona, Nhyira, Videza and Asetenapa which are semi-erect types had higher LAI. However, a spreading type like Soronko recorded highest LAI which could be a deviation from the usual feature. In another situation, Addo-Quaye *et al*. (2011) reported that genetic differences in various genotypes also contributes to the differences in leaf area index in cowpea. The present study is in line with Addo-Quaye *et al*. (2011) since all the eight cowpea genotypes showed differences in LAI in seasons and also across locations as expressed in the mean squares values.

The steady increase in LAI by some varieties from the initial sampling stage till the end of the sampling period and also the initial increase and decline at end of the sampling period has been reported by Addo-Quaye *et al.* (2011) and Miheretu and Sarkodie- Addo (2017). This according to the authors might be due to the fact that genotypes behaves differently at various sampling periods especially at the first and third sampling stage and this was attributed to the genetic differences existing in the growth patterns of the varieties in field conditions. The present study also recorded such increases and decreases in some of the genotypes used in the study. This is evident in the location, year and the treatments of the sum of squares.

Generally, crop growth rate increases from initial stages and may peak during flowering and podding and mostly decline during senescence or when the plant is ageing. However, in few instances, there could be contrasting situations where some varieties may have slight increases in crop growth rate which could be ascribed to environmental conditions which might make the plant grow vegetatively. In this instance the supply of rainfall or water delays senescence since there will be adequate moisture in the crops micro environment. From this study, it could be seen that all the genotypes increased from the initial sampling period and peaking at 45 DAP in both major and minor seasons and later declined. However, Asontem and Nhyira contrasted this observation in 2015 during the minor season by increasing from the beginning of the sampling period till the end.The observation made in terms of steady increase in crop growth rate and peaking at 45 DAP and slowing down at 60 DAP for the varieties in both seasons could be attributed to the normal growth pattern of crops especially cowpea.

When vegetative growth begins, the crop growth rate begins to rise and increase especially on or before flowering and growth slows down since most vegetation cover loses water and get drier and senescence because the crop might have used the energy into productive yield. According to Fagenia *et al*. (2006), the crop growth rate generally records low values at the early stages and increase with age and reach its maximum at flowering stage but later declines as the plant aged or finally matures. This observation is in line with the present study, the crop growth increased from germination up to flowering stage and declined at maturity. Similar observation has been made by Karikari *et al*. (2015) when cowpea genotype they studied showed reduction in value of crop growth rate at the end of the growth period.

It was also observed that Asontem and Nhyira in the minor season increased from the beginning of the sampling period to the end of the sampling period (60 DAP). This contrasting observation has also been reported by Addo – Quaye *et al*. (2011) where UCC-early variety only among other varieties increased from 30 days after planting to the final sampling period at 51 DAP. In this study Asontem increased from 30-45 DAP to 60 DAP at Mampong and Nhyira at Fumesua, all in the minor season. Significant interaction was also observed during the sampling period across location and year and other factors which were more pronounced between the 45-60 DAP sampling interval. This situation could be attributed to the changes in the weather pattern in each location and season and the response of the genotypes to such conditions. These observations are corroborated by Addo-Quaye *et al*. (2011) who observed significance differences between Cape Coast and Twifo Hemeng locations in three cowpea genotype trials. This significant difference is evident in Mampong and Fumesua as it was both evident in the mean squares of growth analysis.

Relative growth rate, net assimilation rate and leaf area index has influence on the crop growth rate. Crop growth rate involves the whole crop thus leaf structure and orientation, ground cover, how the plant grows relatively in relation to the total dry weight at a time and the rate of increase in plant mass per unit leaf.As the plant grows, it intercepts light through leaf orientation which brings into the fore the leaf area and leaf area index active role in proper light interception. Appropriate light interception with onward photosynthates and translocation of assimilates will lead to the increase in plant growth at various stages which will bring out the change in size of the plant growth.

Therefore, appropriate increase in plant mass coupled with relative increase in cowpea size for effective crop growth rate is dependent on the net assimilation rate and the relative growth rate, and they play major role through juvenile, phenological and reproductive growth till the plant aged. Most of the varieties in this study had a better performance of LAI, relative growth rate and net assimilation rate which eventually enhanced the crop growth rate of the cowpea.

Relative growth rate of cowpea generally increases at the beginning of the crop and would decline as the plant ages especially after partitioning of assimilates from source to sinks (Chattjrvedi *et al*. 1980).The rate at which dry matter is accumulated in relation to the total dry weight at a time which is expressed as the crop increase in size is greatly influenced by variety, location and climatic conditions. Generally, relative growth rate of cowpea genotypes in the study increased gradually from the beginning and peaked at the second sampling stage (45 DAP).

However, during the second and last sampling stage (45-60 DAP) at Mampong, some genotypes (Nhyira, Asomdwee and Asontom) showed contrast in the normal growth rate. The relative growth rate (RGR) according to Chattjrvedi *et al*. (1980) increases at the beginning of the plant vegetation phase and later declines as plant ages. This observation has been made in the present study. Majority of the varieties and as a matter of fact, all the varieties in Fumesua followed this assertion made by Chattjrvedi *et al*. (1980). All the varieties increased the relative growth rate per day from the beginning of the sampling period (30 DAP) to the end of the sampling period (60 DAP).

The trend shows that, the increasing part of the plant was structural rather than metabolic active tissue which in effect does not contribute to the growth of the plant (Chattjrvedi *et al*., 1980). As plants aged, the rapid growth units per day slows down as the plant structure becomes structurally lignified and hard. Again, Law-Ogbomo and Enhareuba (2009) are also of the view that decreases in plant relative growth rate is due to increase in age of lower leaves of plants. It was observed in the study during the data collection that, as the plant continues to stay longer in the field, the older leaves tends to dry with some of them showing some coloration 60 DAP. Compared to the peak vegetative growth, the leaves looked so fresh and succulent which might contain a lot of moisture content, hence the decrease in relative growth rate towards the end of the plant growth. These findings support the earlier observations made by Chattiruedi *et al*. (1980) and Law-Ogbomo and Enhareuba (2009).

But there were contrasting growth rate of some of the varieties especially at Mampongfrom 45-60 DAP. Nhyira, Asontem, Asomdwee and Asetenapa from the other varieties saw increase in relative growth rate in the early stages of growth and later declined.
This observation could be due to clmatic factors and some plant factors which was peculiar in that location. According to Fagenia *et al*. (2006), a number of factors affect the relative growth rate of crop growth and these includes, temperature, radiation, water nutrient supply and plant age. From the study especially at the last sampling stage (45-60), it could be seen that most of the factors observed significant ($P<0.001$) interactions which indicates that climatic conditions such as radiation, water supply and temperature could be a factor that showed the contrasting figures observed for the rest of the varieties. In effect, these climatic

conditions especially rainfall and temperature values were optimum for Mampong than Fumesua and since nutrients travel best in solutions, perhaps the varieties had continuous water supply in the soil which might have made their leaves remained fresh which could contain more water than that was observed Fumesua.

Net assimilation rate which reflects the balance of how plants photosynthesis takes place in relation to respiration and tissue loss rates were not generally significant especially at early sampling stages except genotypic characteristics or treatments. According to Anarb *et al*. (2011) significant differences in net assimilation rate is affected by varietal performance that exists between different varieties. This observation has been made in this study. Among the eight varieties observed, Asontem showed superiority in both location and among the treatments (genotypes). This could be due to the genetic make up of the leaf or plant architecture. Asontem produced many leaves and the leaves are the spreading type and therefore it was able to produce more dry matter than the rest of the genotypes.

Again, since the plants relatively covered the soil by its canopy earlier than the other varieties, it did not suffer weed-crop competition, hence higher net assimilation rate. Some of the varieties are erect and the leaves are not large enough and therefore could not suppresses weed growth especially before the second weeding and that might have caused the fluctuating in the net assimilation rates recorded. In a study to compare three varieties of cowpea on net assimilation rate, Addo-Quaye *et al.* (2011) observed that the growth habit of the varieties exhibited or showed the extent to which weeds brought fluctuations in the values observed in the net assimilation rate. The present study corroborates that of Addo-Quaye *et al*. (2011).

It is worth noting that higher values were recorded at early stages of cowpea growth but later declined towards the end of the growing period. These observations could be due to the fact that, at initial stages of plants growth, it is exposed to full sunlight and as such the leaves are not many so shading may not exist at the juvenile stages of the crop. However, when crops aged, then there will be abscission of older or lower leaves, and most of the leaves normally may experience lower photosynthetic rate and therefore the net gain of assimilates which is photosynthetic per unit area in relation to time in effect will be low. This observation has been confirmed by Tayo (1982) and Anard *et al*. (2011).

Significant interaction was observed between location, treatments, location × treatments and year × treatment at the final stages of sampling period. This observation however, contradicts the observations made by Addo-Quaye *et al*. (2011) in Twifo Hemang and Cape Coast. This situation could be due to the differences in the weather conditions that existed between the two locations and the seasons. This observation is supported by this study. But generally, the initial sampling observation was similar to what was reported by Addo-Quaye *et al*. (2011).

Varieties of cowpea significantly influenced nodule number, active and non-active ones in both locations and seasons. The variations in the nodule numbers from the beginning (30 DAP) till harvest period (after 60 DAP) were influenced by the varietiesgenetic traits involved in the study especially the decline at maturity.These sharp decreases observed as well as the variations in nodule numbers could be attributed to the genetic make-up and also the environmental conditions observed in the locations. This is in consonants with Ayodele and Oso (2014) who made similar observation on varieties of cowpea studied. For instance, at 30 DAP, the greatest number of nodules, active and non-active nodules was recorded by Videza followed by Asetenapa with Nhyira having the lowest in 2015 Mampong.

However, during the 2016 season the trend changed with Soronko produced the greatest nodule number followed by Videza with Nhyira still recording the lowest. Again, at Fumesua, Videza recorded the greatest nodule number in both 2015 and 2016 with Nhyira and Soronko recording the lowest among the varieties. It could be observed from the study that nodules produced from Mampong were greater than the nodules at Fumesua in both years. This may be due to the differences in the environment which might have accounted for Mampong recording the highest number of nodules than Fumesua. This is because, the establishment and maintenance of effective symbiosis depends on favourable environment that normally allows maximum nitrogen to be fixed and thus from a strong and efficient symbiotic association with mycorhizae. This view is strongly argued by Pele *et al.* (2016).

Again, it could clearly be seen that results obtained in 2016 season in both locations where higher than in 2015 season in terms of nodule number, active and non-active. This might partly be due to climatic changes which was recorded in these seasons particularly rainfall and temperature. It is said that extreme temperatures and soil water movement may impose limitations on the symbiotic association between the host plant and micro symbionts (Van-

Wyk 2003). This is because in the 2016 major season both locations experience high rainfall which translated into high moisture content and lower temperatures compared to figures recorded for the 2015 season. This means that location has influenced in terms of significant interaction in cultivars as well as seasons. This is evident in the combined analysis that location, year, location × year × treatment and other sources of variation had significant influence on the number of nodules, active and non-active nodules observed. This observation affirms Van-Wyk (2003) assertion that several environmental factors had influence nodule production.

5.3 Yield and Yield Components

Pod number produced by cowpea depends on a number of factors particularly genetic, field and climatic conditions. The greatest number of pods were produced by Asontem in all seasons and locations except in the 2015 minor season at Mampong so on the average, Asontem produced the greatest number of pods. The greatest pod number produced by Asontem on average in the seasons and locations could be attributed to the genetic attributes of that genotype. Most cowpea genotypes have the potential to produce different pod size and many pods in both drought and rainfall periods than others. Asontem on the average exhibited such characteristics than the rest of the varieties. Similar observations were made by Miheretu and Sarkodie-Addo (2017) of Asontem and Songotra genotypes. The greater number of pods produced by Asontem is also supported by Gwathmey *et al.* (1992a) who observed that, greater number of pods per plant is a reflection of the variety being tolerant to drought.

Based on the locations and seasons, Asontem on the average peformed better than the rest of the varieties in terms of greater number of pods produced. On the average, the lowest number of pods was produced by Asetenapa. By the assertion explained earlier, Asetenapa could not produce much pods and the reason could be due to genetic and especially the environmental stress especially drought which brought such variation in pod numbers among the genotypes. Turk *et al*. (1980) and Bala Subramanina and Maheswari (1992) observed that reduction in pod number per plant variation is attributed to environmental conditions especially drought that occurs during pod – filling stages. Variations that occurred in the two seasons in the locations also had influenced on the pod numbers recorded.

As observed by Turk *et al*. (1980), Bala Subramanian and Mahesweri (1992), such evidence was exhibited in the interaction effects of the sources of variation. Environmental influence showed highly significant interaction in location, year, genotype and highly significant interaction for year × treatment and location × year × treatment. This means environmental conditions had effect on the genotypes under this current study as indicated by Turk *et al*. (1980) and attributed the differences to environment effect especially drought on the variation of pods produced by cowpea varieties.

Decrease in number of pods per plant could also be due to flower abortion which has effect on pod development (pod-filling) and when cowpea reaches this stage, watering or supply of water cannot reverse the situation. Due to low amount of rainfall recorded in the minor seasons, the number of pods produced were smaller than what was produced during the major season. And in this case, Mampong had greater increase in the number of pods than Fumesua.

Number of seeds per pod is influenced by the pod length and size in most situations as well as genotypic and environmental conditions. Asontem showed superiority by producing more seeds than the rest of the genotypes except the major season at Fumesua which was not statistically different. The performance of Asontem could be due to differences that exist between genotypes. It is believed that, number of seeds per pod depends on the genetic potential of the genotype and the ability to produce different pod size. The pod length and size of Asontem is long and big (diameter) and therefore during pod filling, more seeds were filled than most of the varieties.

Miheretu and Sarkodie-Addo (2017) observed that Asontem produced more pod number than Songotra and attributed the reason to the genetic potential of the genotype and its ability to produce different pod sizes. The present study is in line with observation made by Miheretu and Sarkodie-Addo (2017). Similar observation was also made by Abayomi *et al*. (2008) which the present study conforms. Pod filling is also a critical stage of many leguminous crops like cowpea. During grain filling, environmental conditions play a vital role.

Seed development require the production of assimilates from the phloem before they are synthesized into the seed storage compounds. Stresses which is due to lack of water, obviously decreases the activities of these physiological factors which may not supply the number of seeds needed by the plant. The greatest number of seeds per pod produced by Asontem and other varieties clearly shows that, there could be proper flow of assimilates from the phloem and due to the drought tolerance nature of Asontem and other genotypes, water stress could not had negative impact during grain filling. Number of seed per pod is one of the yield components that is most sensitive to soil moisture deficit. Lower seed number per pod in the minor season at both Mampong and Fumesua may be attributed to poor assimilation efficiency and post anthesis soil and atmospheric moisture deficits which contributed to low translocation of assimilates which enhanced poor seed filling. Pressman *et al*. (2002) observed that low crop yield to extreme weather condition enhanced dehydration of pollen and poor pollination and embryo abortion which eventually accounts for lower seed number per pod.

In a related development, Agyemang *et al*. (2014) made similar observations when they compared seven different genotypes and attributed the reason of high seeds produced which translated to seed yield was due to adequate supply of water which aided the translocation of assimilates into grain-filling in pods of the genotype. The present study is in line with Agyemang *et al*. (2014). However, the genotypes that produced more seeds in the present study were Asontem and Soronko with Videza producing the lowest number of seeds per pod. The lowest number of seed per pod for Videza however contradicts the study by Agyemang *et al*. (2014) who recorded highest seed number. Based on the environmental differences observed in the locations and seasons, significant interactions were observed and that led to the variations observed in the seed number.

One hundred seed weight is considered to be among one of the important yield components in cowpea. Asetenapa and Asomdwee produced the highest 100 seed weight Mampong than the rest of the varieties and also Fumesua in the minor season except. The consistent values recorded could be attributed to the varietal characteristics which is peculiar to these varieties. In a study conducted by Karikari *et al*. (2015), among the three varieties considered, Asetenapa and Asomdwee had similar 100 seed weight which was significantly different from the other variety. The present study confirms similar values for 100 seed weight which has been reported by Karikari *et al*. (2015). This assertion is also supported by Agyemang *et al*. (2015) and attributed the reasons to genetic potential of varieties.

Again, the variation in the 100 seed weight between the two seasons can be ascribed to the weather pattern particularly rainfall which was experienced by the crops in the field. In the major season, the rainfall recorded were higher than the minor season which influenced growth and seed development of the varieties resulting in the differences observed. This is in line with Cobbinah *et al*. (2011) who observed that differences in 100 seed weight of cowpea varieties was due to variations in weather pattern especially rainfall. This assertion is true since the combined analysis of the varieties had significant interactions in the year, location and location × year and treatments as well.

Several factors accounts for seed yield in cowpea varieties. Sometimes field conditions coupled with differences in environmental situations prevailing at the growing period. It was observed that seed yield of cowpea varieties varied among the varieties based on location and season. While some varieties performed better in one location in the same season, that same variety performed poorly in the other location during the same season. For instance, in 2015 minor season at Mampong, Videza was the second highest in terms of yield but Fumesua, it recorded the lowest among the varieties. Similar observations were made among some of the varieties. Asontem on the hand maintained its superiority irrespective of location and season. There are a number of factors that might have accounted for differences in seed yield. Amongst them are rainfall, humidity, environment and genetic characteristics of individual genotypes.

Taking the year or season into consideration, it could be observed from the combined analysis that seed yields of cowpea were far higher in 2016 than in 2015 in both locations and even in some instances twice or more than twice yield in 2015 especially Fumesua. This yield differences in the location could be largely attributed to the differences in rainfall recorded in the years under consideration. In 2016, the rainfall experienced in the field by the crops were higher than in 2015. Comparing the weather conditions during the growing period and a thirty-year average (30- year average), it could be seen that during the growing period in 2016, the rainfall was high compared to the 2015 season and therefore cowpea varieties responded differently to the climatic condition that prevailed during the growing period. It is believed that the influence of soil moisture especially the magnitude of moisture stress, atmospheric water demand, humidity irradiance and temperature has effect on crop growth.

Again, the period from the time of sowing to flowering initiation of cowpea, the flowering period, podding and the period of seed set until maturity greatly depends on climatic factors such as photoperiod, temperature and moisture (rainfall). Based on this assertion, it is believed that as soon as flower is initiated and there is variation in the growing period, the reproductive growth of the cowpea could change the floral development, seed filling and eventually seed yield. This situation perhaps to large extent prevailed between the two years under consideration in 2015 and 2016 growing seasons. This observation has been made by Sato *et al*. (2002) and Baron *et al.* (2003).

Water supply normally has direct effect on crop development and seed yield and to this extent when there is variation in supply of water which also has a bearing on soil water and thermal regimes, then seed yield may either increase or reduce. Crop weather relationship is of great importance in order to find a remedy to extreme weather situations and its influence of crops. Based on the climatic weather situations obtained within the 30- year period compared with rainfall in experimental period, it was observd that during the reproductive growth of the cowpea varieties, there was a deviation in the rainfall amounts recorded especially at this stage (Phenological development).

This sharp deviation might have caused some poor growth and development of cowpea which translated into poor pod formation leading to lower number of pods and seed number per pod and pod length which are yield components which was observed in the 2015. This clearly led to low yield obtained compared with same varieties in 2016. According to Agele and Agbi (2013) water is regarded as the most important climatic factor in terms of rainfed agriculture in the tropics and as such uncertainties about the on set and ending of rainfall becomes very crucial factor for growth and yield of crops. This assertion is in line with the present study as similar observations were made in 2015 and it was a major concern for farmers in Ghana in 2015. Generally, the 2015 weather figures brought some stresses on some varieties which could not meet the yield potential as compared to the yields in 2016. These adverse weather conditions might have possibly induced rapid soil water depletion and as such inability of soil profile water to meet the demands of cowpea plants. This means that the length of grain filling period thus flowering to maturity was short relatively to other periods and these might have contributed to the lower seed yield in 2015 season.

Cowpea seed yield differed among genotypes and were mostly affected by drought were observed during floral development. In this case, these varieties will respond differently to the prevailing climatic and soil conditions. This means that, in other to get a very good seed yield, it is important to select varieties with short flowering periods so that before drought sets in, the plant will be able to divert its energy into pod and seed development by escaping drought. For the current study, Asontem, Nhyira, Hewale, Asomdwe and Videza genetic abilities escaped the drought andthey were not much affected by the stresses observed during the bad weather conditions in the minor season.
This observation has earlier been made by Cobbinah *et al*. (2011) and Karikari *et al*. (2015). In another study Agyemang *et al*. (2015) also observed that during minor season, Nhyira, Tona and Hewale were observed to have had some drought tolerance potential because their yields were high. Similar observations were made by the present study where five of the varieties (Asontem, Nhyira, Hewale, Asomdwe and Videza) tolerated the harsh environmental situations to produce high yield.

Again, genetic make up of varieties had great influence on seed yield. The high seed yield of Asontem in particular and other cowpea varieties compared with Soronko and Asetenapa could be attributed to differences in the genetic make-up of the varieties under the study. Irrespective of location and year, Asontem consistently produced the highest yield in all the seasons locations in the growing period, though the yields were high in major season than minor season. Asontem and other varieties which produced high seed yield might have some inherent characteristics that are peculiar to such varieties which enabled it to produce such yield. This characteristic ability by Asontem and other varieties has been observed in other studies (Jaiswai, 1995; Agele and Agbi, 2013; Karikari *et al*., 2015 and Agyemang *et al*., 2015).

Grain yield at Mampong generally was higher than Fumesua for both seasons. In some cases yield was far higher even double especially in 2015 season. This yield differences could be attributed to the environmental differences that exist between the two locations. All the environmental conditions in Mampong were favourable during the growing period. High rainfall, available soil moisture and milder temperature experienced in the field conditions might have contributed to the greater differences in the yields obtained in the two locations. Sources of variation revealed that location, year, location × year and treatment recorded highly significant ($P < 0.001$) interaction indicating that environmental influence played a critical role in the yield difference. Due to low rainfall recorded in minor seasons and particularly Fumesua, it restricted the availability of soil water which resulted in low cowpea yields. Seed yield variations is related to the amount of moisture available to the crop so in the minor season, low rainfall had effect on cowpea seed yield. The higher yield recorded in the minor season in Mampong compared to Fumesua could be attributed to some level of rainfall recorded and this made cowpea genotypes in that location exploited substantial soil water during grain filling.

Also, the high amount of leaf and leaf number probably served as canopy to reduce high moisture loss which reduced or regulated high temperature often associated with minor seasons. This assertion is confirmed by Agele and Agbi (2013) who stated that, in drought situations, cowpea leaf size helps to maintain transpiration per unit area and as a result large leaf area shaded soil and helps reduce soil moisture evaporation.

Pod yield varied among cowpea varieties depending on the location and the growing season in each location and growing season. In most cases, favourable weather conditions caused production of more pods than unfavourable conditions. Pod yield of the main growing season were more than the minor season. The higher pod yield performance obtained in 2016 could be due to the differences in the rainfall recorded during the growing periods. Generally, the rainfall recorded in 2016 was far ahead than in 2015. Again, in 2016 there were milder temperature coupled with high amount of moisture due to the rainfall condition experienced during the major rainfall season which enabled effective pod growth and development.

This observation has been made by Babaji *et al*.,(2011) who studied four cowpea varieties in 2005 and 2006 and observed that, pod yields of 2006 was higher than 2005 and attributed the reasons to the amount of rainfall recorded in 2006 and 2005 seasons in field conditions under rainfed which also led to milder temperature as a results of the higher rainfall experienced in 2006. The differences in pods produced between the locations could also be attributed to the weather conditions prevailed in the field.

It could again be observed that Asontem consistently recorded higher pod yield than all the varieties with Soronko also recording low yields consistently but there were varying yields among the rest of the varieties and this observation could be partly due to the genetic make-up of each individual varieties.

Harvest index (HI) is considered an effective measure for selection of varieties since high HI values is an indication that such varieties would have desirable characteristics that can improve selection. Therefore, differences in pod harvest index which may aid selection could also depend on weather factors. It could be seen that generally pod harvest index in the major season in 2016 was higher than what was recorded in 2015 minor season and thevarieties in Mampong were generally higher than that of Fumesua showing significant differences between the varieties. The situation could be attributed to the climatic condition that was favourable or high in the 2016 than in 2015. When crops are supplied with enough rainfall or irrigated, it affects the growth, reproductive parts (flowering, podding) which translate into yield.

During flowering and podding stage (phenological stage), continuous supply of water increases soil moisture content and therefore crops roots are able to draw enough water from soil reservoir. When there is enough rainfall, temperatures would normally reduce and for that matter extreme high temperatures and radiation may not be observed and therefore poor flower and pod development will not be observed in field conditions hence sound pods with smooth grain filling to achieve maximum yield. This situation perhaps accounted the higher harvest index in the 2016 growing season.

However, during the 2015 season, there were limited supply of water coupled with high temperature which resulted in poor flower and pod development and that might have affected the low harvest index. Dapaah *et al*. (1999) observed that continuous supply of water (irrigation) influenced high harvest index (HI) through delayed senescence which led to the production of more assimilates which led to more seeds per pod. These results confirms the present study due to the higher amount of rainfall recorded in 2016 and also the higher amount of rainfall recorded in Mampong than Fumesua which led to the differences in the harvest index and pod number per plant.

5.4.0 AMMI stability analysis

5.4.1 AMMI Analysis of Variances for the Combined Yield of Eight Genotypes in 2015 and 2016

Genotype (G) accounted for 24.4%, environmental (E) effects accounted for 63.1% and their interactions (G x E) also explaining 4.6% of the total sum of squares (SS). These sources of variation were, however, significant which means that all the sources were very crucial in the analysis process. Based on the results, it could be seen that the most important source of variation is the environment (E) because it accounted for main effect due to its large contribution to the total sum of squares (SS) for the yield. This assertion is supported by Kaya *et al*. (2002). The variation due to the genotype (G) was however larger than the interaction (GEI) and this is an indication that differences existing among genotypes vary across environments. This is in an agreement with Gauch and Zobel (1989) and Admassu *et al*. (2008). Adjebeng-Danquah *et al*. (2017) also made similar observation and related it to environment and their interaction.

When the interaction was partitioned into principal components axis, the first IPCA 1 explained 80.8% of the interaction sum of squares (SS). The second IPCA (IPCA 2) however explained 2.7% which means that there was no need to further partition the principal component since the first two (IPCA 1 and 2) clearly explained the extent of the level of significance in the source of variations. This clearly shows that the most accurate model can be predicted using the first two IPCA's. This results is in agreement with Gauch and Zobel (1996) that in using AMMI model, it is recommended that the most accurate model can be predicted using the first two IPCA's. Kayode *et al*. (2009) however believes that genotypes × environment interaction can also be predicted by futher partitioning the IPCA's and not limiting it to the first two IPCA's. However, this observation contradicts the current study as the first two IPCA's showed accurate model for the AMMI.

5.4.2 AMMI Biplot for Mean Seed Yield of Eight Cowpea Varieties in 2015 and 2016

The graphical AMMI Biplot depicts the performance of various genotypes in relation to principal component (PC) and Mean seed yield (M.SdYd). According to Crossa *et al*. (1991) genotype or environment that have large negative or positive PC scores have high interactions but those that are close to zero on the horizontal line have little interaction across environments. Such varieties are therefore considered to be more stable than those far from the line.

It could be seen from Biplot that, Asontem is near zero thus fell almost on the horizontal line indicating that Asontem is the most stable genotype. Hewale, Nhyira and Tona are regarded as stable because they are also close to the horizontal line but are lower than Asontem in terms of stability. This indicates that Asontem, Hewale, Nhyira and Tona gave higher yields and are stable irrespective of environmental changes. However, genotypes that are further away tends to be sensitive towards particular environment and therefore Asentenapa and Soronko which consistently gave lower yields can thrive and produce better yields only at favourable environment with optimum supply of resources and rainfall thus such varieties were adapted to certain environments. This observation is in consonants with Egesi and Asiedu (2002) and Admassu *et al*. (2008).

5.4.3 Best Four AMMI Selection Based on Best Grain Yield Genotype in each Environment

From the additive main effect and multiplicative interaction (AMMI) analysis, four highest yielding genotype in each of the four environments were identified. From the Table 17, it could be observed that for high potential environment these four genotype in each of the environment would be an ideal crop to select to achieve the yield potential. That is to say that in each of the environment, best four genotypes which can withstand drought and other adverse environmental conditions or in an environment with optimum conditions will be ideal in order not to get yield losses of all eight genotypes. This means that farmers will have the benefit of selecting the best yielding genotypes for specific environment at any given period. Similar observation have been made by Adjebeng-Danquah *et al*. (2017) by selecting best four high yielding varieties in Fumesua and Nyankpala at 2012/2013 and 2013/2014 cropping seasons for cassava.

5.4.4 GGE Biplot Analysis of "What Won Where" of Eight Cowpea Varieties in 2015 And 2016.

Figure 7 displays a GGE biplot-Environment views for mean seed yield ((M.sd Yd). It could be deducted from the environment and mean seed yield view that the average environment axis (AEA) begins from the PC2 through to the concentric circles to the ideal environment. Better environment means that such environment must be close to ideal which supported the growth and high yield of genotypes. It could be seen that among the four environments, E4 is above average and close to the ideal environments. E2 and E3 are just close to the average environment while E1 is regarded as very low environment because it is outside the concentric circle which falls as a good location for growth and yield of crops. Again, it could also be observed that among the genotypes, G3-Asontem is in line with the ideal environment indicating that it performed well in all the test environments with the highest yield. Similar observations have been made by Horn *et al*. (2017) of graphical display of biplots of some genotypes performance by comparing-different environments.

The GGE biplot of "what won where" analysis provided graphical representation of the relationship existing among the various genotypes and the environment. This made clear of the genotypes performance and its stability. Asontem, Videza, Soronko and Asetenapa were found at the vertices of the polygon (Figure 8) and this is an indication that those genotypes were responsive to the environment. However, Hewale, Nhyira, Tona and Asomdwe were found close to the middle or origin and as such they were considered the least responsive to the environment and this means that those genotypes can be used for wide adaptation thus multi or different agro ecological zones.

In view of this situation, in selecting same set of genotypes for assessment or recommendation for farmers, such genotypes will be representative of the environments in order to safe yield losses and cost. In this case the biplot of "what non where" with its PC scores will show the genotypes that are stable enough and can show superiority based on environments. This observation is in consonants with Horn *et al*. (2017) superior genotypes in relation to environments.

5.4.5 Stability Measure for Eight Cowpea Varieties in 2015 And 2016 Seasons

The joint regression analysis revealed that G×E effect due to environment brought about significant differences between regression co-efficients pertaining to the regression of cowpea seed yield. For a genotype to be stable, the mean yield, regression co-efficient (b), coefficient of variation (CV%) and error mean squared (S^2d) were compared using the stability measure criteria. According to Finlay and Wilkinson (1963), a genotype considered stable should have its yield meet a criteria of high yield performance with b equal to 1 or very close to unity. Therefore, using the criteria, seed yield stability results indicated that Asontem, Hewale, Nhyira and Tona were most stable due to the regression coefficients obtained as well as the mean seed yield.

In comparing the average mean yield and the regression coefficient (b) values obtained by the cowpea varieties, it could be deduced that the statistical values that are close to 1with high yield performance as stated by Finlay and Wilkinson (1963) were Asontem, Hewale, Nhyira and Tona because they had the ability to express yield potentials. This means that these genotypes are not sensitive to environments and can be planted across various agro ecological zones. This is because they were relatively adapted to poor and better environments and as such were insensitive to environmental changes in respect to seed yield. This assertion is corroborated by Adebisi (2010) using similar methods with sesame seed germination and yield.

In a similar work, Eberhart and Russell (1966) describes a desirable genotype (stable) as one with high mean yield performance with b values equal to unity and low S^2d values. On the basis of Eberhart and Russell's (1963) stability measure, Asontem, Tona and Nhyira could be regarded as the most stable genotypes which can be planted across different environments with yield consistency. These genotypes were selected based on regression coefficient values (b) of close to 1 with low values of mean squared deviation (S^2d) with an appreciable mean yield. This suggests that environment had influence on the traits measured among the eight cowpea genotypes. Hassan *et al*. (2013) made similar observation with environment having influence on the traits measured with significant mean squares.

Francis and Kannenberg (1978) proposed a descriptive method for grouping genotypes with the use of mean yield and CV across environments in order to check consistency of their performance. It could be deduced that comparing the mean yield and CV, the genotypes that fell into this criteria were Group one (1) genotypes thus Asontem and Tona because they have low CV values compared with the other genotypes with yields above the average yield. This means that such varieties have high yield with small variation.

Nhyira was considered stable for Finlay and Wilkinson (1963) as well as Eberhart and Russell's (1966) stability measures. Therefore, by these two stability methods, Nhyira would be most stable variety. Although Hewale had high yield above the mean yield value, however, when deviation from regression (Eberhart and Russell, 1966) or the stability of Francis and Kannenberg (1978) are considered, it could be considered as a stable genotype.

Furthermore, the methods of Finlay and Wilkinson (1963), Eberhart and Russell (1966) and Francis and Kannanberg (1978) when combined would not make Nhyira and Hewale a stable genotype per the three methods put together though they gave high seed yield with respect over an array of environments in the agro-ecological zones under consideration. In this vein, Asontem and Tona could be regarded as the most stable genotypes that would fit into the three stability methods under consideration in relation to mean yield, b values, CV and S^2d. Similar varying methods have been put forward to measure yield stability genotypes across environments for effective cultivation and optimum yield of crops. Adebisi (2010) jointly used Eberhart and Russell (1966) and Choo *et al*. (1984) regression analysis for yield of sesame genotypes. This means that different methods based on the statistical values can postulate genotype stability to indicate stable genotypes as have been observed in the present study which could not exactly be a true representation of field observation.

It is an undeniable fact that such comparisons will bring out clearly the various genotypes which could not have been selected based on certain criteria measure which may not be applicable to all the set of genotypes and the environments under consideration. However, among the eight cowpea varieties under consideration, not all the varieties could meet the criteria for selection as most stable genotypes, other genotypes could do well in other environments which could be for favourable environments or low environments but statistically would not necessarily fit into most stable criteria. In this vein, proper selection of genotypes can be made which otherwise could not have been discarded as a result of one single stability measure for most stable genotypes.

Based on Finlay and Wilkinson's (1963) assertion, Videza and Asomdwe under their regression coefficient (b) values and mean yield could be regarded as highly favourable environment genotypes and as such could be cultivated under productive areas. Videza in particular was sensitive to Fumesua environment in 2015 but was able to perform better in Mampong both seasons and in 2016 season in Fumesua. This means that such variety has some desirable characteristics that could improve yield in further trials in other environments. However, using the criteria of Eberhart and Russell (1966), seed yield of genotypes Hewale, Asomdwee and Videza with regression coefficients and mean squared deviation (S^2d) values would rather be classified for favourable environments and therefore can be adapted to limited environments.

This means that these genotypes (Hewale, Asomdwe, Nhyira and Videza) can be described as somewhat stable but not to the extent of very harsh environmental conditions like Tona and Asontem genotypes. For Francis and Kannenberg (1978) who's criteria is based on grouping the genotypes in relation to high mean yield with relatively low CV's, Asomdwe, Videza, Nhyira and Hewale had high yield than the average mean yield with relatively large CVs and therefore indicating group two (2) category of this stability measure. Nhyira alone can be classified as group three (3) category due to the yield below the average mean yield compared the rest of the genotypes.

A careful look at the study reveals that two varieties, Soronko and Asetenapa consistently fitted all the stability measure as not stable variety which in effect would be for poor or low environment. These varieties were very sensitive to particular environments and therefore would not fit into the selection criteria for stable genotypes.

Using Finlay and Wilkinson (1963) criteria, Soronko and Asetenapa genotypes, were very sensitive across the environments hence low average mean yield with low regression coefficient not closer to the b value of 1. This means that they are relatively better adapted to changes in environment and can therefore be recommended for cultivation in conditions without any adverse effect on seed yield. These observations have also been made by Adebisi (2010) and Adebisi and Ajala (2006) in seed yield. Also, Eberhart and Russel (1966) also classified Soronko and Asetwnapa for low environments with the stability measure of the regression coefficient (b) vales, mean yield and mean square (S^2d). These two genotypes consistently produced yields far below the average yield with low b values coupled with values of S^2d.

Furthermore, Francis and Kannenberg (1978) grouping criteria, Soronko and Asetenapa are considered to be in the category of group four (4) which indicates that they have low yield with consistently high CV. Base on the selection of the grouping made, this technique will not only check the mean yield and the coefficient % variation but this will afford farmers and breeders or research scientists to expose differentials in the fertility status of soil but also to find out the varietal responses to increasing fertility for greater yield variance across different environments to be measured. Other scientists have employed the use of this groupings by Francis and Kannanberg (1978) for crops in various environments. Groupings of such nature has been reported by Ngeve and Bounkamp (1993) for sweet potato and Ackura *et al*. (2006) on durum wheat. Similar observation has also been made by Muluken *et al*. (2014) by ranking genotypes with environmental variance.

In the tropics and most developing countries like Ghana, it is better to engage in this type of study to select best genotypes for farmers to plant rather than try and error methods which will increase cost. This is because funds and inputs such as fertilizers are not used on regular basis to ensure maximum yield. It is therefore emperative to select such varieties (Asontem and Tona) based on the stability measure to serve many growers in the country in order to save cost and uncertainties in yields. This assertion is supported by Ngeve and Bouwkamp (1993) for potato yield and Adebisi (2010) for sesame seeds.

This means that diverse evaluation environments will exert varying selection pressures resulting in differential performance in a diverse group of test genotypes. Berger *et al*. (2007) stated that if environments and genotypes are well characterized by measuring traits associated with differential performance, it becomes possible to use the genotype × environments approach (G×E) for studying specific adaptation.

This study is in line with the observation made Berger *et al*. (2007) because sometimes, some of the genotypes under study may change overtime and this was clearly expressed by Videza genotype which did not do well in Fumesua in the 2015 minor season but thrived very well with high seed yield in the rest of the three environments in course on the study. This assertion is also supported by Nkhoma (2013) that varieties change overtime weather the method or programme under consideration has produced specific adaptation to regions or different environment.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The most important and challenging issue among breeders, agronomists and farmers that engage in crop testing is mainly genotype x environment interaction (GEI). This phenomenon (GEI) reduces the association between the phenotypic and genotypic values and bias since most varieties are sensitive to environmental fluctuations especially with the on-going climatic change. In this wise, it would be better to consider both yield and yield stability performance simultaneously in order to reduce the effect of GEI in order to select the precise and refined genotypes.

To characterize cowpea genotypes based on location and seasons, varieties that expressed certain genetic attributes which produced effective phenological development, growth and growth functionsirrespective of major and minor seasons were Nhyira, Tona, Videza, Asontem and Asomdwee.

For yield and yield components in a set of contrasting environments, varieties which had broad adaptability and less sensitive to environments were Asontem and Tona. These are the varieties that proved stable in the two growing seasons.

Cowpea varieties though is drought tolerant crop, harsh environmental conditions could lead to failure of most varieties in terms of yield. Therefore, genotype × envieonment interaction effects in agro-ecological zones could predict stable yield. It was observed generally from phenological, groth and growth analysis, and yield and yield components that there were interaction effects which influenced growth and yield of cowpea varieties. Location × year greatly influenced the interaction effects in most of the parameters measured.

A careful study of the results obtained in terms of stable genotypes by the use of different statistical models suggests that, the use o more than one statistical stability measure helped in the selection of stable genotypes since one stability measure may not fit all genotypes under consideration. Asontem and Tona were fit as stable genotypes in the association of all the stability methods. However, Nhyira, Asomdwee, Hewale and Videza in some instances were stable but some showed sensitivity in Fumesua in the minor season. Soronko and Asetenapa in all the stability measure were unstable and are considred very sensitive to environments.

6.2 Recommendations

It is suggested that due to the genotype by environment interaction effects of cowpea genotypes in different ago-ecological zones, farmers should plant varieties Asontem and Tona to get stable yield across seasons and locations.

It is suggested again that the study should include more other agro-ecological zones of Ghana specifically Sudan, Coastal and Guinea Savannah to confirm yield stability and response pattern of the genotypes studied acoss the country.

Due to the prevailing climatic change, yield potential could be achieved if proper agronomic practices such as land preparation, appropriate time of planting, weed control, regular insect management and timely haevesting will ensure growth performance and optimum grain yield. In view of this farmers could be sensitized periodically on the management practices that will ensure good yield, especially in cowpea growing areas.

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APPENDICES

APPENDIX A

Anova for regression stability analysis of eight cowpea genotypes

SUMMARY OUTPUT **ASOMDWEE**

Regression Statistics	
Multiple R	0.996622759
R Square	0.993256924
Adjusted R Square	0.989885386
Standard Error	50.16612158
Observations	4

ANOVA

	Df	*SS*	*MS*	*F*	*Significance F*
Regression	1	741403.4705	741403.5	294.600556	0.003377241
Residual	2	5033.279508	2516.64		
Total	3	746436.75			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-253.0829964	102.472914	-2.46976	0.13219993	-693.988359	187.8223666
X Variable 1	1.224655653	0.071350531	17.16393	0.00337724	0.917659095	1.53165221

SUMMARY OUTPUT **NHYIRA**

Regression Statistics	
Multiple R	0.990713345
R Square	0.981512933
Adjusted R Square	0.972269399
Standard Error	62.64774256
Observations	4

ANOVA

	Df	*SS*	*MS*	*F*	*Significance F*
Regression	1	416743.5207	416743.5	106.183737	0.009286655
Residual	2	7849.479295	3924.74		
Total	3	424593			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	80.95412276	127.9687672	0.632608	0.59166946	-469.651043	631.5592882
X Variable 1	0.918165801	0.089102956	10.30455	0.00928665	0.534786725	1.301544876

SUMMARY OUTPUT **SORONKO**

Regression Statistics	
Multiple R	0.974246347
R Square	0.949155944
Adjusted R Square	0.923733916
Standard Error	75.44192222
Observations	4

ANOVA

	Df	*SS*	*MS*	*F*	*Significance F*
Regression	1	212497	212497.033	37.33596486	0.025753653
Residual	2	11382.97	5691.48363		
Total	3	223880			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	163.0261823	154.1031	1.0579035	0.400999424	-500.0258347	826.0781993
X Variable 1	0.655636494	0.1073	6.11031627	0.025753653	0.193962167	1.117310821

SUMMARY OUTPUT TONA

Regression Statistics	
Multiple R	0.99943
R Square	0.99886
Adjusted R Square	0.99829
Standard Error	14.87797
Observations	4

ANOVA

	Df	*SS*	*MS*	*F*	*Significance F*
Regression	1	387979.292	387979.2921	1752.755328	0.000570042
Residual	2	442.707874	221.3539369		
Total	3	388422			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	181.3665	30.3908037	5.967807984	0.026948437	50.60540643	312.1275552
X Variable 1	0.885913	0.02116071	41.86592084	0.000570042	0.794865558	0.976959963

SUMMARY OUTPUT **HEWALE**

Regression Statistics	
Multiple R	0.988966
R Square	0.978054
Adjusted R Square	0.967081
Standard Error	76.90815
Observations	4

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	527213	527213	89.13359	0.011034
Residual	2	11829.73	5914.864		
Total	3	539042.8			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	12.1968	157.0981	0.077638	0.945184	-663.742	688.1354
X Variable 1	1.032713	0.109385	9.441058	0.011034	0.562066	1.50336

SUMMARY OUTPUT ASONTEM

Regression Statistics	
Multiple R	0.995998
R Square	0.992012
Adjusted R Square	0.988018
Standard Error	46.31723
Observations	4

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	532852.2	532852.2	248.3828	0.004002
Residual	2	4290.572	2145.286		
Total	3	537142.8			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	385.5264	94.6109	4.074863	0.055278	-21.5514	792.6043
X Variable 1	1.038222	0.065876	15.76017	0.004002	0.754779	1.321664

SUMMARY OUTPUT **ASETENAPA**

Regression Statistics	
Multiple R	0.975468
R Square	0.951537
Adjusted R Square	0.927305
Standard Error	92.74921
Observations	4

ANOVA

	Df	*SS*	*MS*	*F*	*Significance F*
Regression	1	337803.9	337803.9	39.2685	0.024532
Residual	2	17204.83	8602.415		
Total	3	355008.8			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-62.3531	189.4562	-0.32912	0.773337	-877.517	752.811
X Variable 1	0.826645	0.131916	6.266458	0.024532	0.259057	1.394233

SUMMARY OUTPUT **VIDEZA**

Regression Statistics	
Multiple R	0.995095
R Square	0.990213
Adjusted R Square	0.98532
Standard Error	71.06416
Observations	4

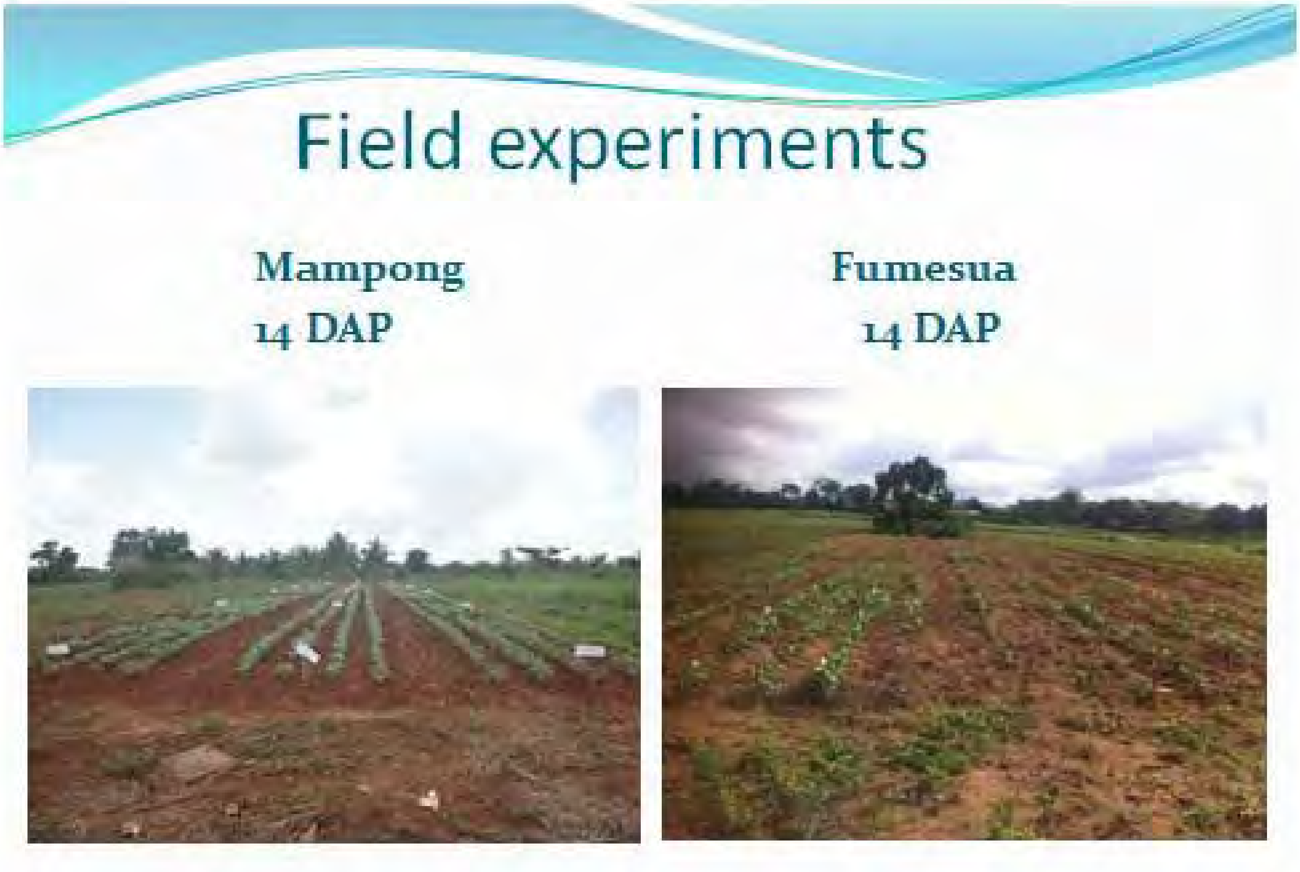
ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1021919	1021919	202.3555	0.004905
Residual	2	10100.23	5050.114		
Total	3	1032019			

Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
-511.37	145.1607	-3.52278	0.071987	-1135.95	113.2066
1.437788	0.101073	14.22517	0.004905	1.002904	1.872672

APPENDIX B

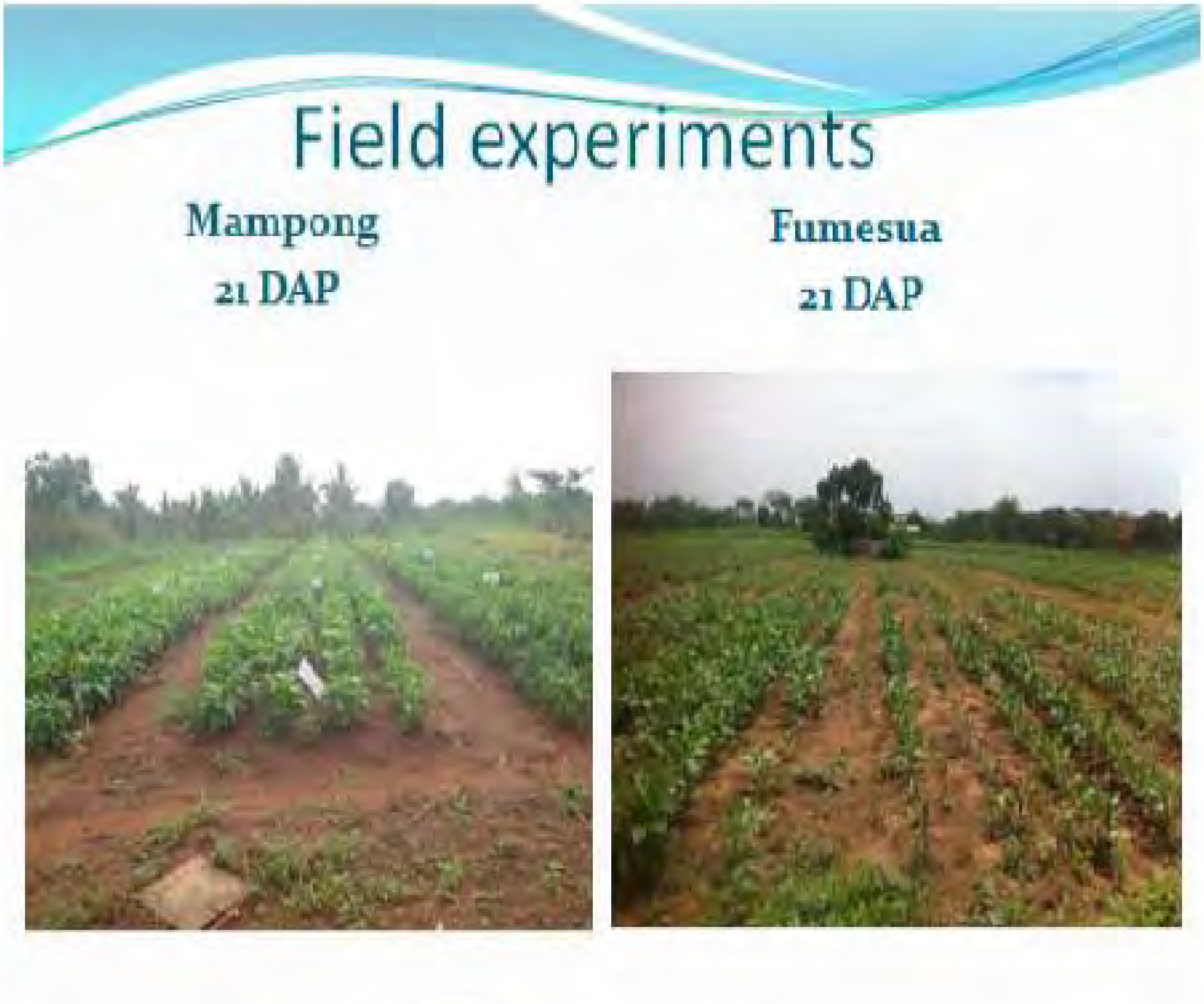
Field experiments of cowpea varieties in the two locations



Field experiments

Mampong
14 DAP

Fumesua
14 DAP



Field experiments

Mampong
21 DAP

Fumesua
21 DAP

Field experiments

Mampong

35 DAP

Fumesua

35DAP

Field experiments

Mampong
50 DAP

Fumesua
50DAP

Field experiments

Mampong
60DAP

Fumesua
60DAP