Agricultural Sciences, 2023, 14, 878-897
https://www.scirp.org/journal/as
ISSN Online: 2156-8561
ISSN Print: 2156-8553

Evaluation of Yield and Yield Components of Some Cowpea (*Vigna unguiculata* (L.) Walp) Genotypes in Forest and Transitional Zones of Ghana

Kwabena Atakora[1*], Margaret Esi Essilfie[2], Kofi Agyarko[2], Harrison Kwame Dapaah[2], Kwadwo Gyasi Santo[1]

[1]Department of Horticulture and Crop Production, University of Energy and Natural Resources, Dormaa Campus, Sunyani, Ghana
[2]Department of Crop and Soil Science Education, Akenten Appiah-Menka University of Skill Training and Entrepreneurial Development, Mampong, Ghana
Email: *kwabena.atakora@uenr.edu.gh, maggifremp@yahoo.co.uk, agyarkokofi@yahoo.com, hkdapaah@aamusted.edu.gh, kwadwo.santo@uenr.edu.gh

How to cite this paper: Atakora, K., Essilfie, M.E., Agyarko, K., Dapaah, H.K. and Santo, K.G. (2023) Evaluation of Yield and Yield Components of Some Cowpea (*Vigna unguiculata* (L.) Walp) Genotypes in Forest and Transitional Zones of Ghana. *Agricultural Sciences*, **14**, 878-897.
https://doi.org/10.4236/as.2023.147059

Received: May 23, 2023
Accepted: July 15, 2023
Published: July 18, 2023

Abstract

Cowpea adapts very well to environmental conditions that normally affect production of crops such as drought, temperature changes and other environmental stresses. However, apart from these attributes, the growth and development of some cowpea genotypes especially during flowering stage and yield of some cowpea are affected by drought and high temperatures. Two field trials were conducted at two different locations (Mampong and Fumesua) in the 2015 and 2016 growing seasons to evaluate yield stability of eight cowpea varieties (Asontem, Tona, Nhyira, Videza, Asomdwe, Asetenapa, Soronko and Tona) released over two decades ago by CSIR-CRI in the forest and transitional zones of Ghana. The experimental design used was a Randomized Complete Block Design with three replications. The results revealed that Asontem, Tona and Nhyira had high yields in both locations and across seasons. Asontem showed superiority amongst the genotypes across the seasons and locations with Soronko and Asetenapa having the lowest yields. The growth and development of the cowpea genotypes especially during flowering stage and yield were affected by drought and high temperatures, hence Soronko and Asetena had low yields compared to Asontem and other genotypes. It is recommended that, for farmers to get more profit due to unpredictable climatic conditions prevailing in Ghana, it will be profitable to grow early maturing cowpeas such as Asontem that can be stable across different environments in order to get stable yields with good returns.

Keywords

Drought, Yield, Location, Varieties, Rainfall

1. Introduction

Cowpea (*Vigna unguiculata* (L.) Walp) is the most important food legume in Ghana and can be grown in all agroecological zones of Ghana since it is indigenous to Africa [1]. According to Ravelombola *et al.* [2], cowpea grain is highly nutritious and contains about 15.06% - 38.5% protein, but it differs among cowpea varieties. Problems such as drought stress, low soil fertility, insect pests and diseases such as viruses which result in low yield in cowpea growing areas have been reported by [3] [4].

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 [5] [6]. Therefore, genotype by environment interaction of crops across locations is key in getting stable yield especially for cowpea. 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 [7]. Several factors such as the environment and genotypic differences determine seed yield of crops such as cowpea. According to Ayodele and Oso [8], factors which account for seed yield which have direct or indirect impacts on yield components are number of pods per plant, number of seeds per pod and 100-seed weight over a given land area. Dadson *et al.* [9] stated that seed yield of cowpea differs among varieties and is affected by drought and high temperatures, especially during floral development due to environmental interactions. 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 [10].

To get a very good seed yield, it is required that varieties with short flowering periods are planted to enable the plants to divert energy into pod and seed development. Nkaa *et al.* [11] pointed out that, the earlier the variety sets 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 [12] [13] [14]. According to Quin [15], 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 stabilize and increase seed yields of cowpea. Agyemang *et al.* [16] observed in their study that during the minor season, Nhyira, Tona and Hewale appeared to have some drought tolerance potential due to their high seed yield. 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 have been reported by [17] for mugbean grain yield [18], for cowpea yield [7] [13] and [16]. Agyemang *et al.* [7] observed that, different cowpea varieties gave different yields in short and long rainy seasons based on growth habits such as bushy, erect, or semi erect. Agele and Agbi [18] stated that during drought situations, especially in locations, cowpea plants shed their leaves to mulch the soil to reduce soil moisture evaporation. Crop performance in terms of vegetative and grain yield during the long rainy season tends to be better than the short rainy season. Agyemang *et al.* [7] recorded relatively high growth and seed yield and attributed it to the relatively high rainfall and mild temperature experienced during the production season of the major rains.

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 encourages poor pod-filling [19]. A decrease in the 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. An increase in the number of pods per plant and seeds per pod and good pod-filling could reflect tolerance to drought [20]. Again, number of pods per plant depends on the genetic potential of the variety to bear or produce different pod size. Miheretu and Sarkodie-Addo [21] reported that, Asontem produced greater pod number than Songotra variety due to the differences observed to the genetic potential of each of the varieties with respect to the size of pods produced. Number of seeds per pod is sensitive to soil moisture deficit. Lower seed yields 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, contributes to low translocation of assimilates, resulting in poor seed-filling. Pressman *et al.* [22] observed that yields due to extreme weather conditions were enhanced by dehydration of pollens and poor pollination and embryo abortion, culminating in low number of seed per pod. Craufural and Qi [23] also reported that number of seeds could be reduced through promotion of embryo abortion and pod shedding due to extreme environmental events in dried pods. Hundred seed weight of cowpea varieties depends on different situations such as climatic factors and genetic characteristics of individual genotypes. Abayome *et al.* [24] observed that 100-seed weight depend on the genetic characteristics of genotype. Agyemang *et al.* [16] observed that, 100-seed weight of cowpea genotype depends on the genetic potential of the variety. Cobbinah *et al.*

[12] 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.

Cowpea pod yield largely depends on the variety and in particular, field conditions in location and growing seasons. Babaji *et al.* [25] observed that, pod yields of 2006 was higher than those of 2005 due to high amount of rainfall recorded in 2006 and 2005 seasons in field conditions under rain-fed which also led to mild temperatures as a results of the higher rainfall experienced in 2006. Harvest index (HI) is a selection measure which is used to get desirable genotypes for planting. When there is enough rainfall, temperatures would normally reduce, and therefore, poor flower and pod development will not be observed in field conditions, hence sound pods with smooth grain filling occurs to achieve maximum yield. Dapaah *et al.* [26] observed that continuous supply of water (irrigation) influenced high harvest index (HI) through delayed senescence, which led to the production of more assimilates to produce more seeds per pod. The objective of the study was, therefore, to evaluate yield and yield components of cowpea varieties in a set of contrasting environments.

2. Materials and Methods

2.1. 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, Akenten Appiah-Menka University of Skill Training and Entrepreneurial Development, Mampong-Ashanti campus located in the forest-savannah transition agro-ecological zone of Ghana. The soil at Mampong belongs 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 [27] [28]. The site has an altitude of 457.5 m 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 - 1200 mm with a temperature range of 22/23˚C - 30˚C [29].

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 agro-ecological zone. The location has an altitude of 228 m 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 [28]. 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. The average annual rainfall is 1650 - 1727 mm with a temperature range of 22˚C - 31˚C [29].

2.2. Experimental Design and Treatments

The experimental 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.

2.3. Land Preparation and Field Layout

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

2.4. Management Practices

Planting and Agronomic Practices

Planting was done at Mampong-Ashanti and Fumesua on the 11th and 12th October, respectively for 2015 and on 27th and 28th April respectively for 2016. Three seeds per hill were planted at a distance of 50 cm × 20 cm and depth of 3 cm. 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 30 g/l and dimethoate 15 g/l). A Knapsack sprayer (15 litre capacity) was used in the spraying to control pests and diseases.

2.5. Data Collection

2.5.1. 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.

2.5.2. 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.

2.5.3. Pod Length

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

2.5.4. 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.

2.5.5. 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).

2.5.6. Seed Yield

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).

2.5.7. Pod Harvest Index

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

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

2.6. Statistical Analysis

The yield and yield components data collected were subjected to Analysis of Variance (ANOVA) using Statistical Analysis System (SAS) (SAS, 2010). Mean separation was 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 was carried out for the treatments in each location and the seasons.

3. Results

3.1. Rainfall

Monthly rainfall in 2015 and 2016 in Fumesua and Mampong and their thirty-year averages are presented in **Figure 1(a)** and **Figure 1(b)**. The total rainfall (325 mm; 63.67%) during the growing period in 2015 (September-December) was 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 1(a)** and **Figure 1(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 (180 mm) 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 (425 mm; 59.57%) was slightly higher by (135 mm; 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 by 100 mm. Generally, the rainfall amounts recorded for the 2016 season at both locations were higher than those of the 2015 growing season.

3.2. Temperature

The average monthly temperatures recorded for 2015 and 2016 are shown in Figure 1(c) and Figure 1(d). Temperature range during the year and the planting period (25˚C - 33˚C) was generally slightly higher at Fumesua than at Mampong (24˚C - 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, in 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 (Figure 1(c) and Figure 1(d)).

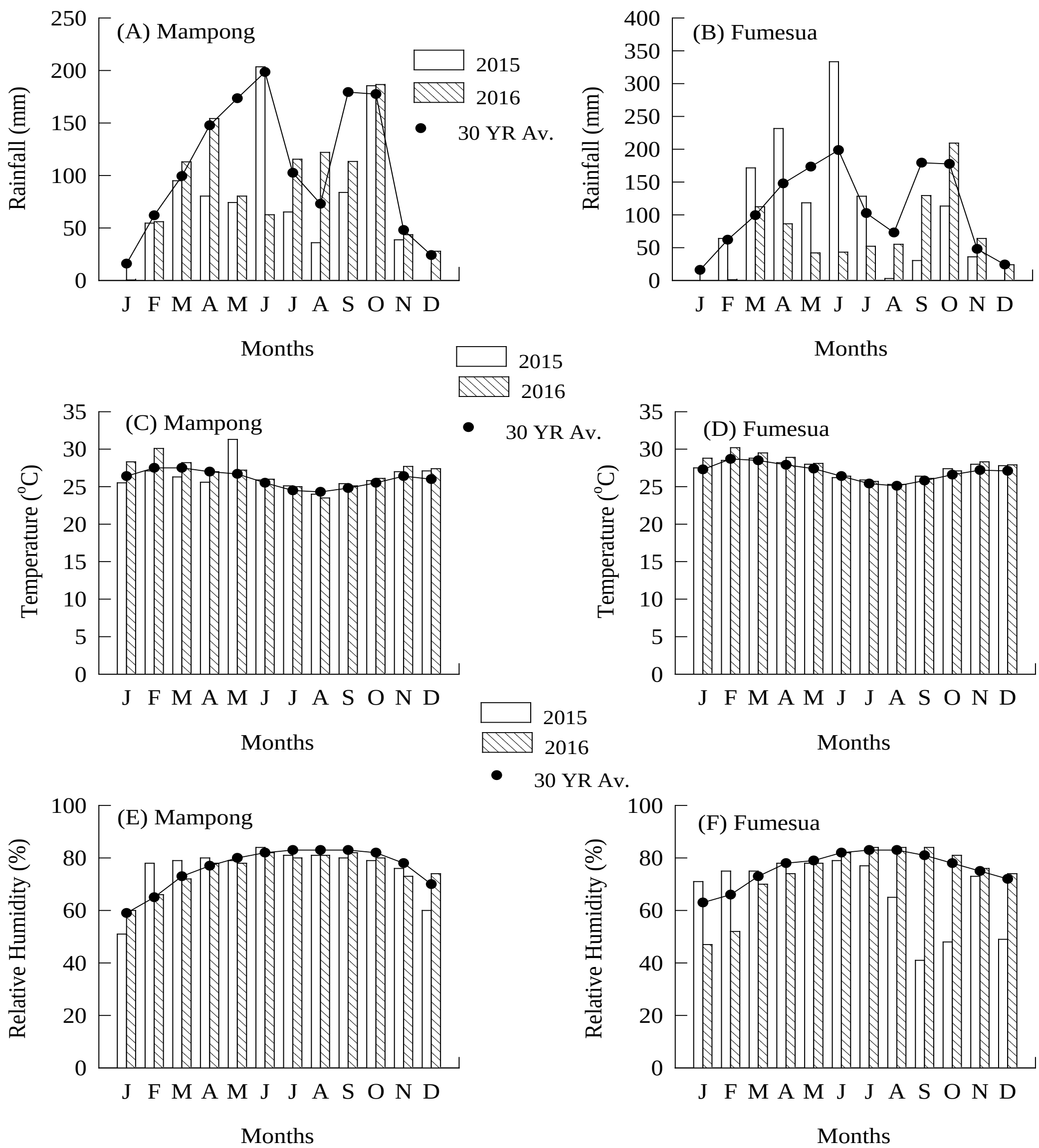

Figure 1. Weather Data for the 2015 and 2016 and Long-Term (30-Year) Averages at Mampong-Ashanti and Fumesua.

3.3. Relative Humidity

Relative humidity during the growing periods in 2015 and 2016 and their long term (30 year) averages are presented in **Figure 1(e)** and **Figure 1(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 growing season. Relative humidity during the 2015 season (September, October and December) was lower than the long term (30-year) average. However, in the 2016 major rainy season, relative humidity was similar between the growing period (March-June) and the long term (30-year) average (**Figure 1(e)** and **Figure 1(f)**).

3.4. Yield and Yield Components

3.4.1. One Hundred Seed Weight

Results of one hundred seed weight in 2015 and 2016 growing season are presented in **Table 1**. Hundred seed weight ranged from 15.33 g to 19.67 g in 2015 in the minor season at Mampong. The greatest hundred seed weight in the minor season was obtained from Asetenapa (19.67 g), followed by Asomdwee (19.33 g), Videza (17.67 g) and Tona recorded the lowest hundred seed weight of 14.67 g. In the 2016 major rainy season, a similar trend was observed. Asetenapa, Asomdwee, and Videza recorded the highest hundred seed weight of 23.00, 21.67, and 21.33 g respectively. Tona variety again recorded the lowest hundred seed weight of a value of 18.67 g. At Fumesua during the minor rainy season (2015), Asetenapa recorded the highest hundred seed weight with Asomdwee and Videza following with 18.33, 17.67 and 17.00 g respectively. The lowest hundred seed eight was recorded by Soronko and Tona (14.33 g). During 2016 major season, Videza had the highest hundred seed weight (18.33 g) and Nhyira was the second with a value of 18.33 g. Tona and Asomdwee, however, recorded the same value for hundred seed weight (18.00 g). The lowest value was recorded by Asetenapa (16.00 g). 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 $P < 0.05$.

3.4.2. 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 1**). The highest pod number in 2015 minor rainy 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 cowpea genotypes. Asontem recorded the highest pod number of 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 results, it could be observed that the lowest number of pods recorded in the 2016 major rainy season at Mampong

Table 1. Yield components of eight cowpea varieties at Mampong and Fumesua in 2015 and 2016 growing seasons.

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

was greater than the highest in the 2015 minor rainy season. A similar trend was observed at Fumesua during the minor rainy season where Asontem recorded the greatest pod number (17.33), followed by Asetenapa (16.73) with Soronko recording the lowest (7.33) (Table 1). During the 2016 major rainy season, there was a major increase in pod number compared to the 2015 minor rainy season. Asontem recorded the highest pod number (22.33), followed by Hewale 21.00 with Tona recording the lowest value 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 interactions between location × treatment. The year × treatment and location × year × treatment interactions on the other hand was significant at $P < 0.05$ level (Table 1).

3.4.3. Number of Seeds per Pod

Results from the number of seeds per pod in 2015 and 2016 growing seasons are presented in Table 1. For number of seeds/pod, varietal effects were significant. At Mampong, the highest number of seeds per pod of 14.53, which was recorded by Hewale was followed by Asontem with a value of 14.47. The least number of seeds/pod was recorded by Tona which was 10.53 in 2015. During the 2016 major rainy 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 seeds per pod in 2015 was produced by Asontem, followed by Asetenapa, Hewale and Tona while Videza recorded the lowest number of seed per pod. In 2016 major rainy season, Soronko produced the greatest effect followed by Asontem and Hewale, Videza, however, produced the least value.

3.4.4. Seed Yield

Results of seed yield of the cowpea varieties in 2015 and 2016 growing seasons are presented in **Table 2**. The average seed yield of eight genotypes varied between 1187 kg/ha and 1962 kg/ha for the 2015 minor rainy season and 1280 kg/ha to 2241 kg/ha in 2016 major season at Mampong.

Table 2. 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.

In 2015 minor rainy season at Mampong, Asontem recorded the highest seed yield of 1962 kg/ha followed by Videza 1692 kg/ha with Soronko recording the lowest seed yield of 1187 kg/ha. In 2016 major season, almost a similar trend for the 2015 minor rainy season was observed. Asontem again recorded the highest average seed yield of 2241 kg/ha followed by Videza (2064 kg/ha). The lowest seed yield was recorded by Soronko with an average seed yield of 1280k g/ha.

At Fumesua, the average seed yield of the genotypes ranged from 666 kg/ha to 1239.89 kg/ha in the 2015 minor rainy season. During the 2016 major rainy season, average seed yield ranged from 1082 kg/ha to 1782 kg/ha (**Table 2**). In 2015 minor season, Asontem recorded the highest average seed yield of 1240 kg/ha which was followed by Tona with an average seed yield of 898.76 kg/ha. However, Asetenapa recorded 603 kg/ha, which was the lowest among the eight genotypes. In 2016 major rainy season, Asontem maintained its superiority by recording the highest seed yield of 1782 kg/ha followed by Asomdwee which recorded 1646 kg/ha. Soronko on the other hand recorded the lowest average seed yield of 1082 kg/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.

4. Discussion

4.1. Number of Pods per Plant

Pod number produced by cowpea depends on a number of factors particularly genetic, field and climatic conditions. The greatest number of pods was produced by Asontem in all seasons and locations except, in the 2015 minor rainy season at Mampong. The greatest pod number produced by Asontem on the 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 sizes and many pods in both drought and rainfall periods than others. Asontem on the average, exhibited such characteristics more than the rest of the varieties. Similar observations were made by [21] of Asontem and Songotra genotypes. The greater number of pods produced by Asontem is also supported by [20] 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, performed 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 environmental stress, especially drought, which brought such variations in pod numbers among the genotypes. Turk *et al.* [30] and Bala Subramanina and Maheswari [19] observed that reduction in pod numbers 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 some influence on the pod numbers recorded.

As observed by Turk *et al.* [30], Bala Subramanian and Mahesweri [19], 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 effects on the genotypes under this current study as indicated by [30] and attributed the differences to environmental effects especially drought on the variation of pods produced by cowpea varieties.

A 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 rainy seasons, the number of pods produced was smaller than what was produced during the major rainy season. And in this case, Mampong had greater increase in the number of pods than Fumesua.

4.2. Number of Seeds per Pod

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 in the major rainy season at Fumesua which was not statistically different. The performance of Asontem could be due to differences that exist among the 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 sizes. The pod length and size of Asontem is long and big (diameter) and, therefore, during pod filling, more seeds were filled than it happened in most of the varieties.

Miheretu and Sarkodie-Addo [21] 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 [21]. Similar observations were also made by [24], to 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 requires the production of assimilates from the phloem before they are synthesized into the seed storage compounds. Stresses which are 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 have negative impacts during grain filling. Number of seeds per pod is one of the yield components that is most sensitive to soil moisture deficit. Lower seed number per pod in the minor rainy 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.* [22] observed that, low crop yields caused by unfavourable weather conditions enhanced dehydration of pollen and resulted in poor pollination and embryo abortion, which eventually reduced seed number per pod.

In a related development, Agyemang *et al.* [7] made similar observations when they compared seven different genotypes and attributed the reason for 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 [7]. 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 [7] 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.

4.3. One Hundred Seed Weight

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 rainy season except. The consistent values recorded could be attributed to the varietal characteristics, which are peculiar to these varieties. In a study conducted by Karikari *et al.* [13], among the three varieties considered, Asetenapa and Asomdwee had similar 100-seed weight, which was significantly different from the other varieties. The present study confirms similar values for 100-seed weight which has been reported by [13]. This assertion is also supported by [16] 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 rainy season, the rainfall figures recorded were higher than those of the minor rainy season, which influenced growth and seed development of the varieties, resulting in the differences observed. This is in line with Cobbinah *et al.* [12] who observed that differences in 100-seed weight of cowpea varieties were 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.

4.4. Seed Yield

Several factors accounts for variations in seed yield in cowpea varieties. Some-times field conditions coupled with differences in environmental situations prevailing at the growing period can cause variations in seed yield of cowpea. 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 rainy season at Mampong, Videza was the second highest in terms of seed yield, but at 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, soil conditions and genetic characteristics of individual genotypes. These observations in present study are in line with observations made by [21] [24].

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 the seed yield in 2015 especially at Fumesua. These yield differences in the location could be largely attributed to the differences in rainfall recorded in the years under consideration. In 2016, the rainfall figures experienced in the field by the crops were higher than those recorded 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 conditions 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 pronounced effects 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 a large extent, prevailed between the two years under consideration in 2015 and 2016 growing seasons. This observation has been made by [31] [32].

Water supply normally has direct effects on crop development and seed yield and to this extent when there is a variation in supply of water, which also has a bearing on soil water and thermal regimes, and as a result, 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 to rainfall in experimental periods, it was observed 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 and this situation was observed in the 2015 growing season. This clearly led to low yields obtained compared to the same varieties in the 2016 growing season. According to Agele and Agbi [18], water is regarded as the most important climatic factor in terms of rain-fed agriculture in the tropics and as such uncertainties about the onset and ending of rainfall become very crucial factors 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 (flowering to maturity) was short relatively to other periods and this might have contributed to the lower seed yield recorded in the 2015 growing season.

Cowpea seed yields 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 order 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 and they were not much affected by the stresses observed during the bad weather conditions in the minor rainy season. This observation has earlier been made by [12] [13]. In another study, Agyemang *et al.* [16] also observed that, during minor rainy 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 seed yields. 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 and locations in the growing period, though the yields were high in the major rainy season than in the minor rainy 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 yields. This characteristic ability by Asontem and other varieties has been observed in other studies [13] [16] [17] [18].

Grain yield at Mampong generally was higher than that of Fumesua for both seasons. In some cases, yield was far higher (twice), especially in the 2015 growing season. These yield differences could be attributed to the environmental differences that existed between the two locations. All the environmental conditions in Mampong were favourable during the growing period. High rainfall, available soil moisture and mild temperature figures 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. Low rainfall figures recorded in the minor rainy season particularly in Fumesua restricted the availability of soil water, which resulted in low cowpea seed yields. Seed yield variations are related to the amount of moisture available to the crop. So, in the minor rainy season, low rainfall had effects on cowpea seed yield. The high seed yields recorded in the minor rainy 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 rainy seasons. This assertion is confirmed by Agele and Agbi [18], 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.

4.5. Pod Yield

Pod yield varied among cowpea varieties, depending on the location and the 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 that of 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 figures recorded in 2016 were higher than those in the 2015. Again, in 2016 there were relatively mild temperatures coupled with high amount of moisture due to the rainfall condition experienced during the major rainy season, which enabled effective pod growth and development. This observation has been made by [25] who studied four cowpea varieties in 2005 and 2006 and observed that, pod yields of 2006 were higher than those of 2005 and attributed the reasons to the amount of rainfall recorded in 2006 and 2005 growing seasons under rain-fed field conditions, which also led to relatively mild temperatures 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 variety.

4.6. Harvest Index

Harvest index (HI) is considered an effective measure for selection of varieties since high HI values show 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 rainy season in 2016 was higher than what was recorded in 2015 minor rainy season and the varieties in Mampong were generally higher than those grown at Fumesua showing significant differences among 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 irrigation water, it affects the growth, reproductive parts (flowering, podding) which translate into yields.

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 reservoirs. 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 and that may cause the production of sound pods with smooth grain filling to achieve maximum seed yields. This situation, perhaps, accounted for the higher harvest index noticed in the 2016 growing season. However, during the 2015 growing season, there was limited supply of water coupled with high temperature, which resulted in poor flower and pod development and that might have caused the low harvest index. Dapaah *et al.* [26] observed that continuous supply of water (irrigation) increased 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 numbers per plant.

5. Conclusion

Yields of genotypes largely depend on constant water supply with adequate environmental and soil factors to have relatively stable yields in different agro-ecological zones. The study revealed that Asontem, Nhyira and Tona were the most stable cowpea varieties. The genotype by environment interaction revealed that Asontem was the most stable genotype among the genotypes tested in the study.

6. Recommendation

It is recommended that, varieties that are able to withstand harsh environmental conditions such as Asontem, Nhyira and Tona could be planted in order to break even due to instability of other cowpea varieties for rain-fed agriculture.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Fatokun, A.C. (2012) Breeding Cowpea for Resistance to Insect Pests; Attempted Crosses between Cowpea and *Vigna vexillata*. In: Fatokun, C.A.S., Tawawali, A., Singh, B.B., Kormawa, P.M. and Tamo, M., Eds., *Challenges and Opportunities for Enhancing Sustainable Cowpea Production*, International Institute for Tropical Agriculture (IITA), Ibadan, 52-61.

[2] Ravelombola, W.S., Shi, A., Weng, Y., Motes, D., Chen, P., Srivastava, V. and Wingfield, C. (2016) Evaluation of Total Seed Protein Content in Eleven Arkansas Cowpea (*Vigna unguiculata* (L.) Walp.). *Lines American Journal of Plant Sciences*, **7**, 2288-2296. https://doi.org/10.4236/ajps.2016.715201

[3] Karungi, J., Adipala, E., Ogenga-Latigo, M.W., Kyamanywa, S., Oyobo, N. and Jackai, L.E. (2000) Pest Management in Cowpea; Integrating Planting Time, Plant Density and Insecticide Application for the Control of Cowpea Field Pests in Eastern Uganda. *Crop Protection*, **19**, 237-245. https://doi.org/10.1016/S0261-2194(00)00014-4

[4] Gioi, T.D., Boora, K.S. and Chaudhary, K. (2012) Identification and Characterization of SSR. *International Journal of Plant Research*, **2**, 1-8. https://doi.org/10.5923/j.plant.20120201.01

[5] Kevin, E.T., Kathleen, M., Linda, M. and Steven, R. (2000) Effects of Changing Climate on Weather and Human Activities. University of Science Books, Sausalito, 27.

[6] Okoye, M.N. (2010) Stability and Genetic Variability of Oil Palm Bunch Yield Components. NIFOR Second Cycle Oil Palm Hybrids. LAP Lambert Academic Publishing, Dudweiler, 84.

[7] Agyemang, K., Berchie, J.N., Bonsu, O., Tetteh, I., Nartey, E. and Fordjour, J.K. (2014) Growth and Yield Performance of Improved Cowpea (*Vigna unguiculata* L.) Varieties in Ghana. *The Journal of Agricultural Science*, **2**, 44-55. https://doi.org/10.12735/as.v2i4p44

[8] Ayodele, O.J. and Oso, A.A. (2014) Cowpea Responses to Phosphorus Fertilizer Application at Ado-Ekiti, South-West Nigeria. *Journal of Applied Science and Agriculture*, **9**, 485-489.

[9] Dadson, R.B., Hashem, F.M., Javaid, L., Joshi, J., Allen, A.L. and Devine, T.E. (2005) Effect of Water Stress on the Yield of Cowpea (*Vigna unguiculata* L. Walp) Genotypes in the Delmarva Region of the United States. *Journal of Agronomy and Crop Science*, **191**, 210-217. https://doi.org/10.1111/j.1439-037X.2005.00155.x

[10] Raemaekers, R.H. (2001) Directorate General for International Co-Operation (DGIC), Crop Production in Tropical Africa. DGIC, Brussels, 335-338.

[11] Nkaa, F.K., Nwokeocha, O.W. and Ihuoma, O. (2014) Effect of Phosphorus Fertiliz-

er on Growth and Yield of Cowpea (*Vigna unguiculata* L.). *IOSR Journal of Pharmacy and Biological Sciences*, **9**, 74-82. https://doi.org/10.9790/3008-09547482

[12] Cobbinah, F.A., Addo-Quaye, A.A. and Asante, I.K. (2011) Characterization, Evaluation and Selection of Cowpea (*Vigna unguiculata* (L.) Walp) Accessions with Desirable Traits from Eight Regions of Ghana. *ARPN Journal of Agricultural and Biological Science*, **6**, 21-32.

[13] Karikari, B., Arkorful, E. and Addy, S. (2015) Growth, Nodulation and Yield Response of Cowpea to Phosphorus Fertilizer Application in Ghana. *Journal of Agronomy*, **14**, 234-240. https://doi.org/10.3923/ja.2015.234.240

[14] Hall, A.E., Cisse, N., Thiaw, S., Elawad, H.O.A., Ehlers, J.D., Ismail, A.M. and McWatters, K.H. (2003) Development of Cowpea Cultivars and Germplasm by the Bean/Cowpea CRSP. *Field Crops Research*, **82**, 103-134. https://doi.org/10.1016/S0378-4290(03)00033-9

[15] Quin, F.M. (1997) Importance of Cowpea. In: Singh, B.B., Dashiell, K.E., Mohan Raj, D.R. and Jackai, L.E.N., Eds., *Advances in Cowpea Research*, Colcorcraft, Hong Kong, 10-13.

[16] Agyeman, K., Berchie, J.N., Osei-Bonsu, I. and Fordjour, J.K. (2015) Seed Yield and Agronomic Performance of Seven Improved Cowpeas (*Vigna unguiculata* L.) Varieties in Ghana. *African Journal of Agricultural Research*, **10**, 215-221. https://doi.org/10.5897/AJAR2014.8835

[17] Jaiswai, V.P. (1995) Performance of Green Gram (*Phaseolus radiate*) and Black Gram (*P. mango*) Genotypes to Date of Planting during Summer. *Indian Journal of Agronomy*, **40**, 516-525.

[18] Agele, S.O. and Agbi, O.M. (2013) Growth and Yield Responses of Selected Cowpea (*Vigna unguiculata* L. Walp) Cultivars to Weather and Soil Factors of the Sowing Seasons. *Research & Reviews in Bio Sciences RRBS*, **7**, 265-276.

[19] Bala-Subramanian, V. and Maheswari, M. (1992) Compensatory Growth Responses during Reproductive Phase of Cowpea after Relief of Water Stress. *Journal of Agronomy and Crop Science*, **168**, 85-90. https://doi.org/10.1111/j.1439-037X.1992.tb00982.x

[20] Gwathmey, C.O., Hall, A.E. and Madore, M.A. (1992) Adaptation to Midseason Drought of Cowpea Genotypes with Contrasting Senescence Traits. *Crop Science*, **32**, 773-778. https://doi.org/10.2135/cropsci1992.0011183X003200030039x

[21] Miheretu, A. and Sarkodie-Addo, J. (2017) Response of Cowpea (*Vigna unguiculata* (L.) Walp) Varieties Following Application of Nitrogen Fertilizers and Inoculation. *IOSR Journal of Agriculture and Veterinary Science*, **10**, 32-38. https://doi.org/10.9790/2380-1004013238

[22] Pressman, E., Peet, M.M. and Pharr, D.M. (2002) The Effect of Heat Stress on Tomato Pollen Characteristics Associated with Changes in Carbohydrate Concentration in the Developing Anthers. *Annals of Botany*, **90**, 631-636. https://doi.org/10.1093/aob/mcf240

[23] Craufurd, P.Q. and Qi, A. (2001) Phototation Adaptation of Sorghum (*Sorghum bicolor*) in Nigeria. *Agriculture and Forest Meteorology*, **108**, 199-211. https://doi.org/10.1016/S0168-1923(01)00241-6

[24] Abayome, Y., Ajibade, T., Samuel, O. and Saaduden, B. (2008) Growth and Yield Response of Cowpea (*Vigna unguiculata* L. Walp) Genotypes to Nitrogen Fertilizer (NPK) Application and in the Southern Guinea Savanna Zone of Nigeria. *Asian Journal of Plant Science*, **7**, 170-176. https://doi.org/10.3923/ajps.2008.170.176

[25] Babaji, B.A., Yahaya, R.A. and Mahadi, M.A. (2011) Growth Attributes and Pod Yield of Four Cowpea (*Vigna unguiculata* (L.) Walp.) Varieties as Influenced by Residual Effect of Different Application Rates of Farm Yard Manure. *Journal of Agricultural Science*, **3**, 165-171. https://doi.org/10.5539/jas.v3n2p165

[26] Dapaah, H.K., McKenzie, B.A. and Hill, G.D. (1999) Effects of Irrigation and Sowing Date on Phenology and Yield of Pinto Beans (*Phaseolus vulgaris* L.) in Canterbury, New Zealand. *New Zealand Journal of Crop and Horticultural Science*, **27**, 297-305. https://doi.org/10.1080/01140671.1999.9514109

[27] FAO/UNESCO Soil Map of the World Revised Legend, with Corrections. World Soil Resources Report 60. Rome. (Reprinted as Technical Paper 20, ISRIC, Wageningen, 1994).

[28] Asiamah, R.D., Adjei-Gyapong, T., Yeboah, E., Fening, J.O., Ampontuah, E.O. and Gaisie, E. (2000) Soil Characterization and Evaluation of Four Primary Cassava Multiplication Sites (Mampong, Wenchi, Asuansi and Kpeve) in Ghana. SRI Technical Report No. 200, Kumasi.

[29] (2015) Meteorological Services Department of Ghana Ashanti Region, Kumasi, Weather Data Report No. 25, 21-28.

[30] Turk. K.J., Hall, A.E. and Asbel, C.W. (1980) Drought Adaptation of Cowpea. I. Influence of Drought on Seed Yield. *Agronomy Journal*, **72**, 413-420. https://doi.org/10.2134/agronj1980.00021962007200030004x

[31] Sato, S., Peet, M.M. and Thomas, J.F. (2002) Determining Critical Pre- and Post-Anthesis Periods and Physiological Processes in *Lycopersicon esculentum* Mill. Exposed to Moderately Elevated Temperatures. *Journal of Experimental Botany*, **53**, 1187-1195. https://doi.org/10.1093/jexbot/53.371.1187

[32] Barron, J., Rockstrom, J., Gichuki, F.N. and Hatibu, N. (2003) Dry Spell Analysis and Maize Yields for Two Semi-Arid Locations in East Africa. *Journal of Agriculture & Forest Meteorology*, **117**, 23-37. https://doi.org/10.1016/S0168-1923(03)00037-6